THE DEVELOPMENT OF A BUILDING ENERGY PERFORMANCE EVALUATION PROGRAM (EnAd) FOR ARCHITECTURAL DESIGN PROCESS

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FATMA ZEHRA ÇAKICI

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submitted by **FATMA ZEHRA ÇAKICI** in partial fulfillment of the requirements for the degree of **Doctor of Philosophy in Department of Architecture, Middle East Technical University** by,

Prof. Dr. Canan Özgen
Dean, Graduate School of **Natural and Applied Sciences** ___________________

Prof. Dr. Güven Arif Sargın
Head of Department, **Dept. of Architecture, METU** ___________________

Assoc. Prof. Dr. Arzu Gönenç Sorguç
Supervisor, **Dept. of Architecture, METU** ___________________

Examining Committee Members:

Prof. Dr. Celal Abdi Güzer
Dept. of Architecture, METU ___________________

Assoc. Prof. Dr. Arzu Gönenç Sorguç
Dept. of Architecture, METU ___________________

Assoc. Prof. Dr. Mehmet Halis Günel
Dept. of Architecture, METU ___________________

Assoc. Prof. Dr. Ali Murat Tanyer
Dept. of Architecture, METU ___________________

Asst. Prof. Dr. İlhan Koç
Dept. of Architecture, Selçuk University ___________________

Date: *31.01.2013*

I hereby declare that all information in this thesis document has been obtained and presented in accordance with academic rules and ethical conduct. I also declare that, as required by these rules and conduct, I have fully cited and referenced all material and results that are not original to this work.

Name, Last name : Fatma Zehra Çakıcı
Signature :

ABSTRACT

THE DEVELOPMENT OF A BUILDING ENERGY PERFORMANCE EVALUATION PROGRAM (EnAd) FOR ARCHITECTURAL DESIGN PROCESS

Çakıcı, Fatma Zehra
Ph.D., Department of Architecture
Supervisor: Assoc. Prof. Dr. Arzu Gönenç Sorguç

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Energy performance in buildings has become one of the most broadly debated subjects in contemporary architecture; and current legislation has emphasized its importance by requiring buildings to possess an energy performance certificate. Due to the technological advances in computational tools, it is possible to analyze the energy performance of buildings before construction starts; however most energy performance evaluation tools, requiring complex solid models and high technical knowledge in the field, can be used only during the post design phases. Since any design decision has an important effect on the energy performance of a building, evaluation tools should be used from the very beginning of the design process. In this dissertation, a building energy performance evaluation program, entitled the Energy performance Advisor (EnAd), was developed for evaluating the energy performance of buildings considering not only the legal framework of Turkey, but also the building design process. The program does not need advanced expertise, and was developed to be usable in any phase of the design process. The program, using the monthly calculation method of TS EN ISO 13790, was developed based on the European Union Directive on Energy Performance in Buildings (EPBD) and the current Turkish legislation on the subject. EnAd integrates the legal framework with the energy performance criterion into the building design process, while providing rapid feedback on energy performance and related legislation, and guiding the designer to improve design decisions. This dissertation has also shown the effects of building size, exposed surfaces, ventilation and infiltration, window-wall ratio, U-values, set-point temperatures and temperature differences between the outside and inside spaces on energy performance of buildings through generic case studies while searching the reasons for discrepancies between the results derived from the four evaluation tools, three of which is highly acknowledged energy performance evaluation tools. The validity, reliability, precision and usability of EnAd as a design-support tool has been proved through the usability and convergence tests conducted. Finally, the thesis has pointed out the importance of the use of energy performance evaluation tools from early stages of architectural design process to achieve higher performances as well as the roles of decision makers in this process.

Keywords: Energy Performance, Energy Performance in Buildings, EPBD, Performance Evaluation Program, Monthly Calculation Method, TS EN ISO 13790.

ÖZ

MİMARİ TASARIM SÜRECİ İÇİN BİNA ENERJİ PERFORMANSI DEĞERLENDİRME PROGRAMI (EnAd) GELİŞTİRİLMESİ

Çakıcı, Fatma Zehra
Doktora, Mimarlık Bölümü
Tez Yöneticisi: Doç. Dr. Arzu Gönenç Sorguç

Ocak 2013, 241 sayfa

Binalarda enerji performansı çağdaş mimarlığın en kritik konulardan biri haline gelmiştir. Mevcut yasaların yapılmış ve yapılacak olan binaların enerji performansı sertifikası almasını istemiş olması konunun önemini vurgulamaktadır. Hesaplamalı araçlardaki teknolojik gelişmeler sayesinde, inşaat başlamadan önce binaların enerji performanslarının analizi mümkündür. Ancak, karmaşık katı modeller ve yazılım üzerine uzmanlaşma gerektiren enerji performans değerlendirme araçlarının çoğu tasarım sonrası süreçte kullanılabilmektedir. Tasarım kararlarının binaların enerji performansı üzerinde önemli etkileri olduğundan, değerlendirme araçları tasarım başından itibaren kullanılmalıdır. Bu tez kapsamında, yasalar ve bina tasarım süreci göz önüne alınarak, binaların enerji performansını değerlendirmek amacıyla EnAd isimli bir bilgisayar programı geliştirilmiştir. İleri uzmanlık gerektirmeyen bu program, tasarım sürecinin herhangi bir aşamasında kullanılmak üzere tasarlanmıştır. TS EN ISO 13790 tarafından belirlenen aylık hesaplama yöntemini kullanan program, Avrupa Birliğinin Binalarda Enerji Performansı Direktifi ve konuya ilişkin mevcut Türk mevzuatına dayanılarak geliştirilmiştir. Yasalarla enerji performans ölçütlerini bütünleştiren program, hem enerji performansı hem de ilgili mevzuat hakkında geri bildirimler sunarak tasarım kararlarını iyileştirmede tasarımcıya yardımcı olmayı amaçlamıştır. Bu tez çalışmasında, bina boyutları, ısı kaybeden yüzeyler, havalandırma ve sızdırma, U-değerleri, pencere-duvar oranı, ayar sıcaklıkları ve iç ve dış ortam sıcaklık farklarının binaların enerji performansı üzerindeki etkileri irdelenmiş ve kullanılan dört değerlendirme programı aracılığıyla sonuç farklılıkların nedenleri de araştırılmıştır. Geliştirilen tasarım-destek aracının kullanılabilirliği, geçerliliği, güvenirliği ve hassasiyeti kullanılabilirlik ve yakınsama testleri ile kanıtlanmıştır. Sonuç olarak, daha iyi performans düzeylerine ulaşmak için karar vericilerin süreçteki rollerinin yanı sıra mimari tasarım sürecinin ilk aşamalarından itibaren enerji performans değerlendirme araçlarının kullanımının önemine işaret edilmiştir.

Anahtar Kelimeler: Enerji Performansı, Binalarda Enerji Performansı, EPBD, Performans Değerlendirme Programı, Aylık Hesaplama Yöntemi, TS EN ISO 13790.

To My Family

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NOMENCLATURE

Symbols and units

Symbol	Quantity	Unit
A	Area	m^2
A_C	Conditioned area	m^2
A_E	Thermal envelope area	m^2
A_g	Ground/Basement floor area contacting with earth	m^2
A_n	Net conditioned area	m^2
A_r	Roof area	m^2
A_s	projected area of the opaque part	m^2
A_W	External wall area	m^2
A_w	Window area	m^2
b	Adjustment factor for heat transfer coefficient	-
B	Correction factor for an unconditioned adjacent space	-
c	compactness ratio	-
d	Layer thickness	m
dt	Overall layer thickness	m
E	Energy	kJ, MJ, kWh
EP	Energy performance indicator	MJ/m^2a, kWh/m^2a kg_{CO2}/m^2a, €/m^2a
f	building shape factor	m^{-1}
F	Factor	-
F_c	Curtain factor	-
F_f	Frame area fraction	-
F_s, F_{sh}	Shading correction factor	-
g	Total solar energy transmittance	-
$g_{\perp}$	Effective total solar energy transmittance (normal incidence)	-
h	depth of basement floor above ground level	m
H	Heat transfer coefficient	W/K
H_A	Transmission heat transfer coefficient to adjacent buildings	W/K
H_D	Direct heat transfer coefficient between the heated or cooled space and the exterior through the building envelope	W/K
H_g	Transmission heat transfer coefficient to ground	W/K
H_T	Transmission heat transfer coefficient	W/K
H_U	Transmission heat transfer coefficient to unconditioned spaces	W/K

H_V	Ventilation heat transfer coefficient	W/K
I_{sol}, I_i	solar irradiance on surface *i* during the calculation step(s)	W/m^2
$p_a c_p$	Heat capacity of air per volume	$J/(m^3/K)$,$Wh/(m^3/K)$
P	Perimeter	m
Q	Quantity of heat	KJ, MJ, kWh
Q_C	Energy need for cooling	kWh/m^2
Q_H	Energy need for heating	kWh/m^2
Q_L	Energy need for lighting and appliances	kWh/m^2
Q_m	Monthly Energy Need for Heating	kWh/m^2
Q_W	Energy need for domestic hot water supply	kWh/m^2
R	Thermal resistance	m^2K/W
R_e	external thermal resistance of the wall; between the air layer and the external environment	m^2K/W
R_i	internal thermal resistance of the wall; between the air layer and the internal environment	m^2K/W
R_{se}	external thermal surface resistance	m^2K/W
R_{si}	internal thermal surface resistance	m^2K/W
R	Reference	-
R_r	"Energy Performance Regulation" reference	-
R_s	"Building Stock" reference	-
t	Time, period of time	Ms^a
U	Thermal transmittance	$W/(m^2/K)$
U_g	Thermal transmittance of ground or basement contacting with earth	$W/(m^2/K)$
U_r	Thermal transmittance of roof	$W/(m^2/K)$
U_U	Thermal transmittance to unconditioned spaces or adjacent buildings	$W/(m^2/K)$
U_W	Thermal transmittance of external wall	$W/(m^2/K)$
U_w, U_s	Thermal transmittance of window or opaque surface	$W/(m^2/K)$
$V^{\cdot}$	Airflow rate through the heated or cooled space	m^3/h
V	Volume	m^3
V_C	Conditioned volume	m^3
$V_{W,day}$	Volume of domestic hot water delivered per day at specified temperatures	m^3/day
W	Water temperature	°C
$W_{,0}$	Cold water supply temperature	°C
$W_{,del}$	Specified domestic hot water delivery temperature	°C
z	Depth of basement floor below ground level	m
γ	Gain use factor	-
η	efficiency, utilization factor	

θ	Centigrade temperature	°C
θ_a	Temperature of the adjacent building	°C
θ_e	Temperature of the external environment	°C
θ_i	Internal temperature of the building under consideration	°C
λ	Thermal conductivity	W/(m.K)
τ	Time constant	h
φ	Heat gaining	W
φ_i	Interior heat gaining	W
φ_s	Solar gaining	W
α	absorption coefficient	-
α_j	Average solar absorption factor of absorbing surface j in the sunspace	-
$\alpha_{S,c}$	Dimensionless absorption coefficient for solar radiation of the opaque part	-

Abbreviations

AAC	Autoclaved Aerated Concrete *(Gazbeton)*
BEP	Building Energy Performance
CDDR	Cooling degree-day region
EPBD	Energy Performance in Buildings Directive
HDDR	Heating degree-day region
PVC	Polyvinylchloride
RC	Reinforced concrete
Rr *(RG)*	Referance value *(Refrans Göstergesi)*

CHAPTER 1

INTRODUCTION

This first chapter explains the general structure and the objectives of the thesis. The contents and scope of each chapter are presented under the disposition.

1.1 Introduction

It is known that buildings are responsible for about 40% of all energy consumption around the world, and this rate has been showing an increasing trend as buildings become more complex in response to the various comfort needs of the "users". Recent researches have shown that buildings in Turkey account for 36% of the country's total energy consumption and 32% of its CO_2 emissions (United Nations Development Program; Turkey, 2012); yet Turkey is an energy dependent country, importing more than 70% of its energy requirements from abroad, and this figure is expected double by 2025 (Yılmaz, 2009). It has already been acknowledged that high energy consumption is one of the main reasons behind the rapid depletion of natural resources and the major environmental problems that we encounter today. The 1970s oil crisis showed nations just how fragile they are in the absence of energy and highlighted the need to control its use.

Today, civil and governmental authorities at both national and global scales are taking action to reduce energy consumptions, and to control and minimize the adverse impacts on the environment. One of the first responses came from the United Nations (UN), which has organized many international summits to develop global strategies that have led to the implementation of international policies and agreements to control and reduce energy consumption. Among these, the Brundtland Report, proposing the very first formal definition of a sustainability concept; Agenda 21, pointing out the necessity of local action programs; and the Kyoto Protocol, addressing the control of greenhouse gas emissions can be considered as turning points in environmental control. The European Union (EU) has also published directives regarding energy consumption, the efficient use of energy and energy performance in buildings. One of the most important directives issued by EU is the Energy Performance in Buildings Directive (EPBD), which requires all member states to adopt their national calculation methods for the evaluation of energy performances of buildings. Accordingly, each and every government has re-organized its policies, laws, standards and regulations to define their methods. Furthermore, the governments have developed their own national assessment tools as a control mechanism.

It is known that every design decision has a significant effect on the energy performance of a building; and the performance-based design approach is a compromise among the different systems, such as structure, acoustics, energy, etc. During the design process, the designer is required to verify and validate the design according to performance goals, meaning that the performance-based design approach requires an integrated solution that is formulated with the help of different disciplines (Spekkink, 2007). For those practicing architecture in the 2000s, performance-based design has become much more popular with the advances in computational tools and technologies, which allow designers to embed any performance criteria into the design process. It has already been acknowledged that energy performance is one of the most critical elements in building design, and the success of the design can be evaluated on the basis of performance indicators. To this end, many evaluation tools and certification systems have been introduced for the assessment of the energy performance of buildings.

The main difficulty encountered in the use of energy performance evaluation tools is the requirement of technical expertise in the field. Since these tools have been developed primarily for use by engineers, they require very high level of technical knowledge on the subject. Another drawback of such evaluation tools is related with their structures and the database they use, in that each is developed by different countries for different regions and climatic conditions. Accordingly, each uses different building standards and calculation methods, and each makes different assumptions and defaults in the evaluations, limiting their validity. Furthermore, these tools require complex solid models; however a 3D model of a building can only be developed in the late phases of the design process. The main focus of these tools is on performance evaluation rather than guiding the designer in the design phase to support design decisions, but there is a need for them to be a part of the architectural design process so as to improve the design and to achieve the desired performance goals. In this regard, energy performance assessment tools should be re-designed to integrate a performance evaluation concept that can be applied throughout the entire architectural design process.

1.2 Objectives

In this thesis, a computer program is proposed that can be used as a tool for the evaluation of the energy performance of buildings, and depending on the results, to make an assessment of the overall energy performance class of buildings. The development of a tool, entitled the Energy performance Advisor (EnAd), featuring a flexible user-friendly interface that does not require advanced expertise and is usable in any phase of the design process is targeted. In the development of EnAd, directives, standards, laws and regulations are considered as the objectives or constraints so as to support design decisions. EnAd is developed based on the requirements of the Directive of Energy Performance in Buildings (EPBD), TS EN ISO 13790[1], the Turkish Regulation on Energy Performance in Buildings (BEP) and other related legislations. The monthly evaluation method proposed by TS EN ISO 13790 is employed in the analysis. The objectives of this study are outlined below:

i. To develop a soft tool that can integrate legislations and energy performance criteria into the building design process.
ii. To provide a soft tool for integration into all phases of the design process so as to support design decisions.
iii. To provide a user-friendly soft tool with high flexibility
iv. To improve the convergence of energy performance with performance goals from the very early phases of the design

1.3 Disposition

Chapter 2 presents a literature survey focusing on the relationship between sustainability, energy and performance evaluation tools in architecture. This chapter also aims to examine the different legislations related with the energy performance of buildings and their effects on architectural design since the 1970s. The currently available building evaluation tools are also studied in this chapter. Finally, the hypothesis of the study is set out in Chapter 2.

Chapter 3 presents the theoretical background of EnAd, and provides information on the legislation, definitions, tables and formulations required for the calculations. The program structure of the tool is then presented, after which the database is compiled and the assumptions and formulas required for the dataflow of EnAd are put forward. The chapter also points out the deficiencies and problems encountered in use of legislations for the evaluation of energy performance in buildings.

Chapter 4 describes the materials used and the methodology followed in the course of this study.

[1] TS EN ISO 13790: Thermal performance of buildings – Calculation of energy use for space heating and cooling

Chapter 5 explains the need for energy performance evaluation tools, while presenting the objectives and the development process of EnAd. It also presents details of the background studies, including the determination of energy-related design decisions, the selection of legislations in relation with design decisions, and the extraction of performance goals and constraints from the legislations. The chapter continues with an introduction to the scope and structure of EnAd, in which the Inputs and outputs of the program are illustrated with figures showing the program interface. Finally, the results of the usability tests conducted to test the flexibility and ease of use of the tool is presented at the end of the chapter.

In Chapter 6, the validity, precision, reliability and use of EnAd are presented; and three currently available evaluation programs that are internationally recognized for their precision and reliability are introduced for comparison. This chapter also presents several cases, including a control case, generic cases and real cases to be used in convergence tests, which are applied to test the precision and reliability of EnAd. The results of the comparisons are discussed at the end of the chapter.

Chapter 7 presents the conclusions of the study and describes its findings and contribution to literature while concluding with future remarks and its feedback to different fields.

The appendices provide a list of legislation related with the subject matter.

CHAPTER 2

LITERATURE REVIEW

This chapter explores the sustainability concept in relation to the use of energy and the related legislations and policies, as well as the performance assessment tools currently in use in architectural design. The legal framework is investigated and the role of legislation in implementing the sustainability concept and controlling the use of energy in architecture is discussed.

2.1 Sustainability, Energy and Performance in Architecture

It is known that buildings are responsible for the consumption of large amounts of energy and environmental resources during their life cycle, starting from the initial design and culminating in their demolition. Statistics have shown that buildings account for about 40% of primary energy consumption (IEA, 2012), and 50% of the raw materials extracted (Altun, 2009) in the world. They consume 39% of the energy and 72% of the electricity, and emit 38% of CO_2 in the United States (USGBC, 2009), whereas construction and demolition result in 30% of solid waste generation in Australia, 30% in England and 50% in Hong Kong (Ekanayake and Ofori, 2004). Similar consumption figures can be observed in the European Union (EU Energy Efficiency, 2012), OECD countries and in Turkey (Kibert, 2002).

The adverse impact of construction works on the environment has forced many authorities around the world to take serious measures. Although the first international studies attempting to resolve these environmental problems on a global scale date back to the 1960s, the first systematic study was realized by the United Nations (UN) in the Brundtland report (1987). This report defined the sustainability concept in a broader framework for the first time as:

> *"Humanity has the ability to make development sustainable to ensure that it meets the needs of the present without compromising the ability of future generations to meet their own needs."* *(Brundtland report, 1987)*

The sustainability concept, which was first put forward as a means of protecting the environment three decades ago, has since been transformed from a conceptual notion into a community action plan. It covers wide range of issues, as cited by the United Nations (2008), from biodiversity, consumption and production patterns, human settlement, waste and water to global warming and energy efficiency. Buildings and the built environment have a close relationship with sustainable development in terms of the environment, natural resources, waste management and energy efficiency, as well as the well-being of the human race. Within the context of environmental sustainability, the improvement of the energy performance of buildings is vital in the reduction of energy use and its adverse impacts on the environment.

Policies and legislations are accepted as other efficient ways of controlling energy use in buildings. In general, legislation forces architects and other actors involved in the design process to consider buildings in terms of their effect of the environment, the economy and human comfort systematically; and yet no strict rules for the selection of sustainable, green, ecological, etc. design approaches. Above all, sustainable architecture can be seen as 'good practice', as suggested by Guy and Farmer (2001), with the level of 'goodness' of a building measurable from its performance. As Mezzi et al. (2004) suggest, sustainability can be considered as 'performances of a building', and so it can be said that performance criteria make sustainability measureable. Performance-based design requires the integration of performance requirements into the building throughout the design process, as discussed in the following sections.

2.2 The role of Legislation in Implementing Sustainability and Energy Performance in Architecture

The realization of sustainable built environments begins with effective and consistent policies; and the implementation of such policies into practice can be achieved through both voluntary and mandatory measures, which can be considered as instruments for the attainment of sustainability. These include economic instruments, information instruments, voluntary policy instruments, and research and development instruments, as well as regulatory instruments. Economic instruments may take several forms, such as user charges, product taxes and charges and emission taxes etc., while information instruments aim to raise public awareness through public information campaigns and performance labeling on products (Kibert, 2002). The regulatory instruments adopted by governments include policies, laws, standards and regulations, which play a crucial role in the implementation of international and national policies into practice.

Researchers and practitioners have yet to agree on the role of legislation in the implementation of sustainability, and how these measures will be integrated into the construction sector. For instance, Kibert (2007) points out the need for governments to put mandatory measures in place to encourage a transformation of the construction sector and its products towards sustainability, while many researchers assert that voluntary applications would be much more effective (Owen, 1997; Petersen and Togeby, 2001). Short et al. (2006) and Henderson (2007) claim that legislation restricts design, while Beerepoot and Beerepoot (2007) assert that governmental regulations should encourage innovation in design. Due to its inflexibility, Lee and Yik (2002) state that legislation should be used to determine minimum standards, believing that better results can be ensured through voluntary applications. Çakıcı and Sorguç (2009) assert that legislation should act as a guideline to architects in the architectural design process. It can be said that building standards, codes and regulations could be used as an effective tool for setting performance criteria.

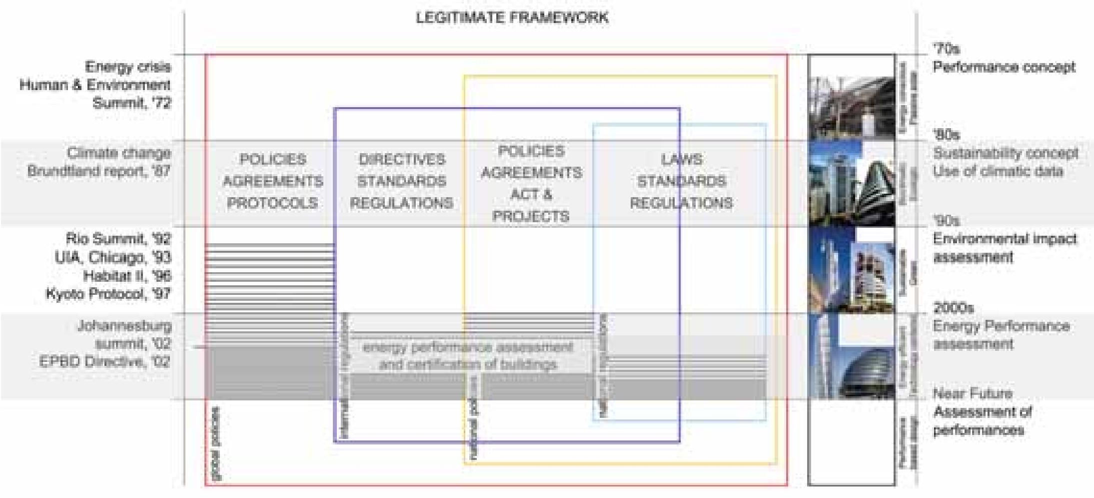


Figure 2.1 Diagram Showing the Relationship Between Global and National Policies and Regulations

As seen in Figure 2.1, global and national regulations have strong relationships with each other. The hierarchy between the legislations shows that the most comprehensive policies, agreements and protocols are accepted first at a global level before being accepted at a national level.

International summits also play an important role in the establishment of international policies, agreements and protocols regarding the sustainability concept and the energy performance of buildings. The European Union (EU) has put in place a number of directives, regulations and standards to set the global-scale regulations. The Commission of the European Parliament and the Council of the EU have taken the first steps in transforming global policies, international agreements and protocols into legislations by means of directives and regulations. For example, the Commission plays a leading role in the development of ISO and CEN standards, as well as governmental regulations in European nations.

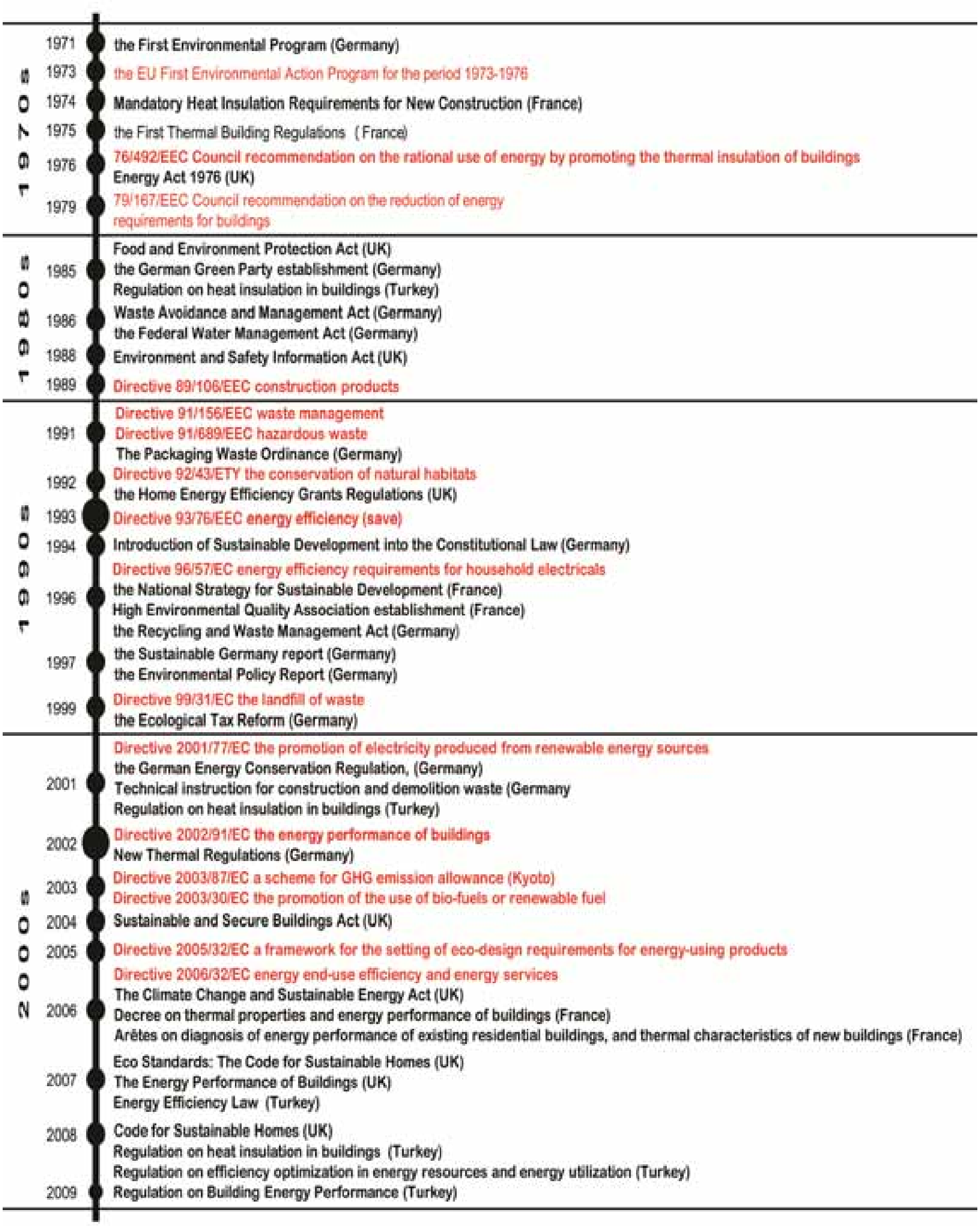


Figure 2.2 Timeline Showing EU Directives, Laws and Regulations Related to Building Energy Performance since the 1970s (Çakıcı and Sorguç, 2009)

National policies and regulations have been very effective in putting global policies into practice. Global policies and directives can be supported at a national level with the development of national policies, acts and projects and the organization of the laws, standards and regulations in harmony with global ones. This strong relationship in the legal framework can be seen in the timeline shown in Figure 2.2. In national policies, governments set their own social and economic goals, and encourage the attainment of these goals by means of laws, standards and regulations. Laws form the general framework of the subject, while regulations provide the methods and instructions for implementation. Standards allow national policies, laws and regulations to be put into practice in a systematic manner with the help of the necessary formulations and calculations.

2.3 Response of Architecture to Sustainability Movement in the Context of Energy-Related Legislations

Architecture can be considered as the art of satisfying the requirements of both the built environment and nature. The need and use of energy has been a major determinant in the evolution of approaches to building design, starting from being energy conscious, energy efficient, bioclimatic, green and sustainable and culminating in energy-based performance design. However, the terms used to describe design concepts have become confused, with terms like sustainable, green, environment-friendly, ecologic, etc. being used interchangeably. Green buildings aim to have minimum impact on the environment, while special importance is given to the use of climatic data and natural systems in bioclimatic buildings. In fact, all of these design concepts can be said to come under the wider umbrella of sustainable design, while in a broader sense, sustainable design can be defined as 'a sub-set of sustainable development', which requires balancing three systems of sustainability: economic, social and environmental (Alwaer and Croome, 2010). Finding a balance among these systems necessitates the measurement of success, that is, performance, meaning that performance-based design has become one of the most crucial keywords in contemporary architecture. In this transformation process, international summits, agreements and protocols, legislations and policies, and performance assessment tools have played important roles. These developments are presented in the timeline shown in Figure 2.3, summarizing the legal framework related to energy efficiency and the environment in relation to sustainable development in some EU countries and Turkey since the 1970s.

It can clearly be seen that since the very first introduction of the sustainability concept in 1987, many global and national measures have been proposed to reduce energy use and its impacts on the environment. These measures constitute the legal framework related to the energy performance of buildings, and in this regard it is important to look at the response of architecture to the sustainability movement and energy use in the context of legislation in order to follow how the use of energy in buildings is attempted to be optimized.

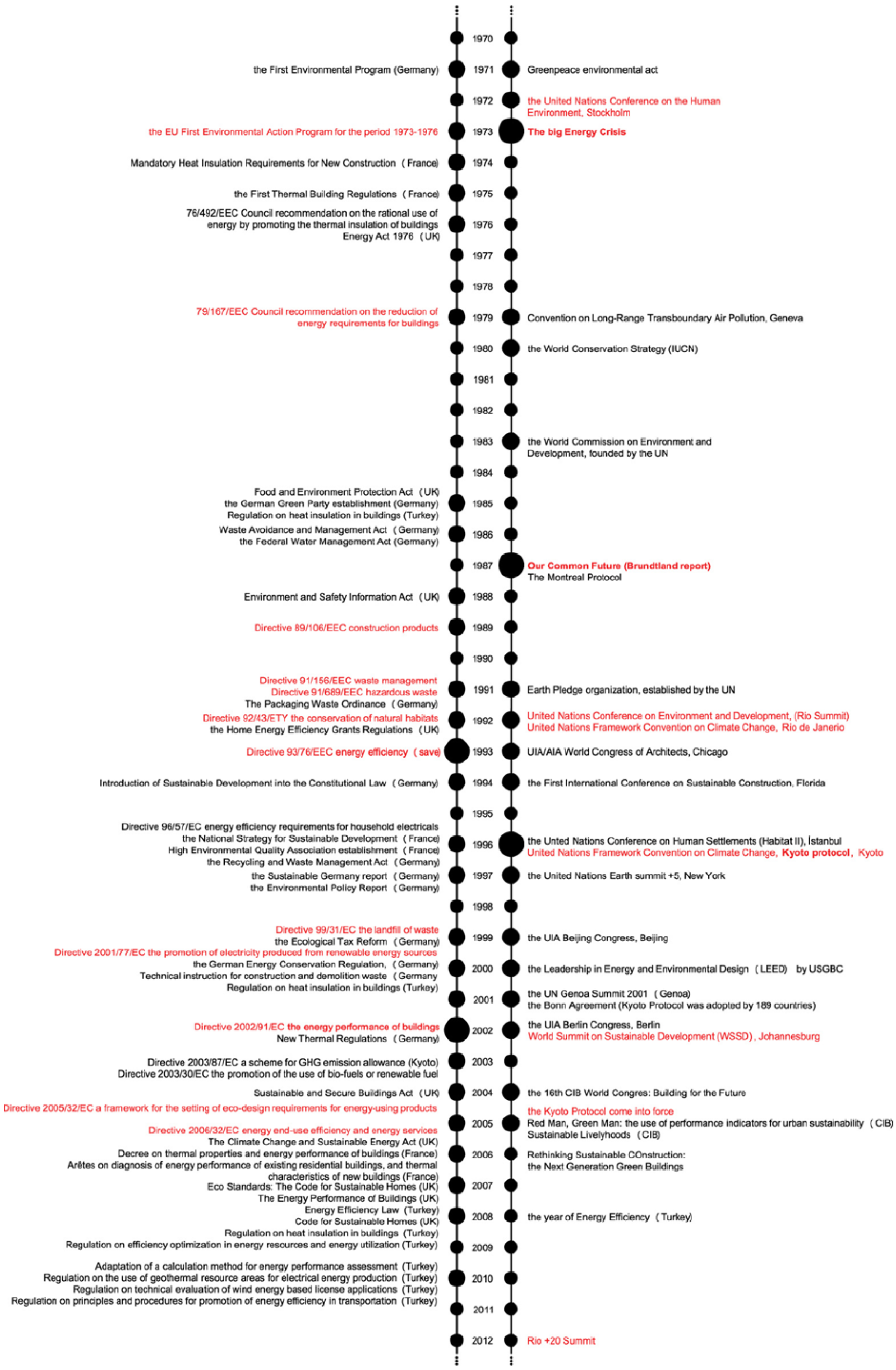


Figure 2.3 Timeline Representing Sustainability, Energy and Architecture in relation with Legislation related to Energy Performance of Buildings since the 1970s

Starting in the 1970s, architectural practices began focusing on the design of low-energy buildings and energy-conscious buildings, leading to the introduction of active and passive systems to minimize energy use, such as solar space conditioning and solar water heating that utilized solar collectors and photovoltaics (Balcomb et al., 1977; Noll and Wray, 1979; Hoffman and Moshe Feldman, 1981; Littler, 1982). In the 1980s, as a result of the Brundtland Report (1987) and the sustainability idea, the effect of environmental aspects became more pronounced in buildings. With the increasing interest in the bioclimatic design concept, special importance was given to environmental factors and passive solar strategies, and the use of climatic data and sunpath diagrams to take advantage of natural ventilation and daylight was attempted (Sala, 1998; and Tzikopoulos et al. 2005).

In the 1990s the sustainability concept emerged, along with the idea of protecting the rights of future generations, and many countries started to develop their own national development strategies. Focusing on sustainability, the UIA/AIA World Congress of Architects (1993) pointed out the importance of buildings and built environments and their impact on the natural environment, and defined sustainable design as:

> *"... sustainable design integrates consideration of resource and energy efficiency, healthy buildings and materials, ecologically and socially sensitive land-use, and an aesthetic sensitivity that inspires, affirms, and ennobles; sustainable design can significantly reduce adverse human impacts on the natural environment while simultaneously improving quality of life and economic well-being."* (UIA/AIA World Congress of Architects, 1993)

The architectural milieu has come up with a definition of sustainable and green building concepts, in which the green building concept is considered as an idea putting forward the relationship between building and the environment, yielding *"measurably less impact on the environment"* (Burnett et al., 2007).

Today, focus has moved to technology-centered buildings, in that technological advances in computational tools and materials have changed building tectonics. The systems used in buildings have become more advanced as digital technologies and performance-based simulations have become integrated into the architectural design process, and attempts have been made to make buildings respond to different environmental conditions. Accordingly, buildings have become more complex, and in this context the assessment of performance has become critical in measuring the success of the integrated systems used in buildings. To this end, many performance assessment tools and rating systems have been introduced for the measurement of environmental impact, life-cycle, whole building performance, energy performance, etc.; while legislation and policies have contributed to the control of the environmental and energy performance of buildings, and have forced architects and other actors involved in design to re-think the design process so as to maximize performance.

2.4 Performance Evaluation of Buildings

Research studies have shown that the performance concept in a modern sense, used in engineering since the 1970s, has been gaining more attention in architecture. Performance is a measure of success, and the success of a design can be determined by its performance (Ling, 2004). Building performance has become a guiding design principle in contemporary architecture (Kolarevic, 2005). Performance-based design requires the integration of a set of performance criteria into the building design process, while it can be evaluated on the basis of performance indicators (Spekkink, 2007). During the design process the designer needs to verify and validate the design according to performance goals; and as design decisions change, they need to be revised against the performance targets. For the translation of performance criteria into practice or a solution set, tools and methods for validation and/or evaluation are required. These evaluations can be carried out using very simple calculations or by complex performance simulation tools.

The performance evaluation has become an essential part of the architectural design process. For the evaluation of the performance of a building, several evaluation tools and assessment systems have been developed. Governments support building assessment tools in their sustainable development policies, both to evaluate the environmental impact of existing buildings, and to encourage sustainability in the decision-making process of new buildings. In order to promote sustainable building construction practices, several performance-based rating systems have been developed, including BREEAM in the United Kingdom, LEED in the United States, HK-BEAM in China, Green Star in Australia, DGNB in Germany, CASBEE in Japan, etc.

Performance-based rating systems have been developed that assess the performance of the entire building, and have different rating systems for different areas, such as site selection, water efficiency, materials and resources, etc. Among these, energy use is one of the major subjects in all assessment methods, and the control of energy in buildings is awarded the highest priority. Energy use tops the rating systems, and as shown in Figure 2.4, it plays a crucial role in determining the performance of the whole building.

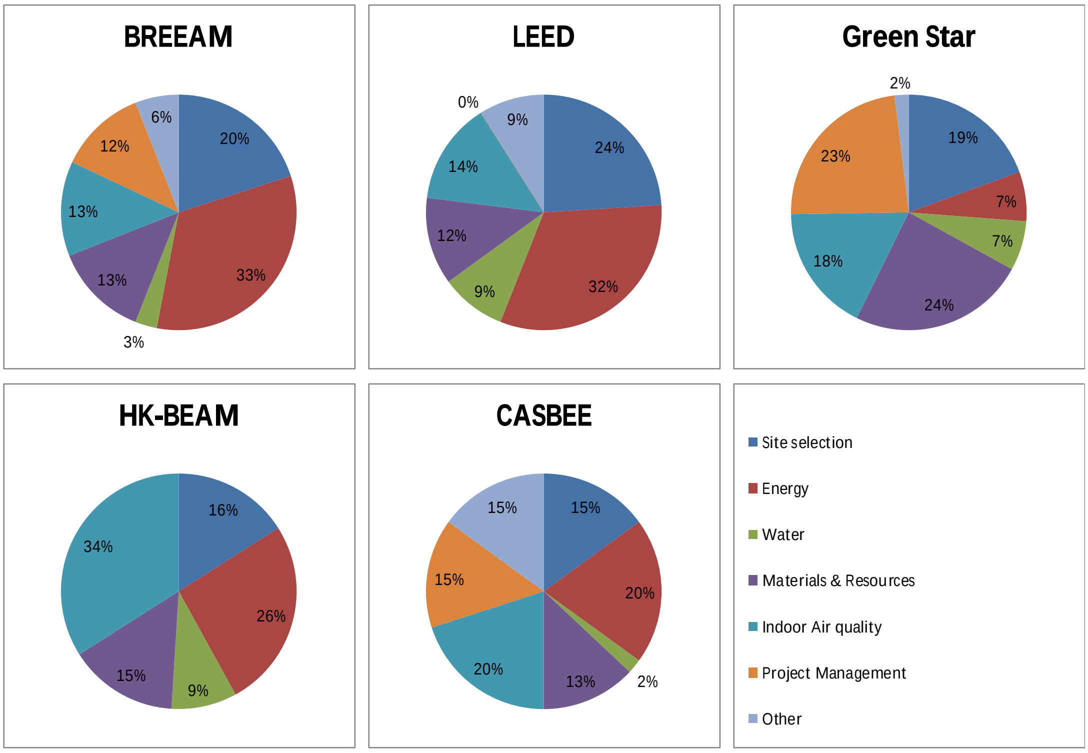


Figure 2.4 Comparison of Grades Used by the Most Widely Used Rating Systems (Sleeuw, 2011; Gorer, 2006; Fowler and Rauch, 2006).

Performance assessment is an important concept in Building Information Modeling (BIM) as well. Although BIM is intended to be a part of the design process, it is mostly used for 3D coordination, design reviews, construction management and design authorization purposes, and in this sense, it acts as a post-design evaluation tool rather than a decision-making tool. Since all design decisions have a significant effect on the performances of a building, the design process should be considered as a whole, and performance evaluations should be an integral part of the architectural design process from the very beginning.

2.5 Programs Used in Building Energy Performance Evaluation

The energy performance evaluation and optimization in a building is a very broad subject that incorporates heat loss-gains, thermal comfort analysis, indoor air quality, HVAC equipment and systems, DHW supply, lighting and renewable energy, as well as energy requirement/use evaluations, energy economics, environmental and atmospheric pollution, and certification; all of which must be addressed in compliance with building standards, codes and regulations.

There are about 400 building software tools[2] for the evaluation of energy efficiency, renewable energy and sustainability in buildings listed on the official website of the US Department of Energy (DOE)[3]. On the website, the tools are categorized according to the area of use under the following headings: whole building analysis (energy simulation, load calculation, renewable energy, retrofit analysis, sustainability/green buildings); code and standards; materials, components, equipment and systems (envelope systems, HVAC equipment and systems, lighting systems); and other applications (i.e. atmospheric pollution, energy economics, indoor air quality, water conservation). A number of programs have been developed to carry out a building performance analyses on the entire building, such as DesignBuilder, DOE-2, Ecotect, Energy-10, EnergyPlus, eQUEST and TRNSYS; while others are intended to address a specific part of the building or process, such as Indoor Humidity Tools, Microflo (CFD, airflow analysis), EMISS (atmospheric pollution), Virtualwind and Solar-5. Furthermore, there are other tools that have been developed for code compliance, including Climawin 2005 (building thermal regulations), Czech National Calculation Tool for EPBD, DIN V 18599 (German Building Standard), and VentAir 62 (ventilation design to ASHRAE Standard 62). As can be understood from their names, these tools are engineering design, performance assessment and code compliance tools, and are intended for use in the post-design phase of a building.

Table 13 Validation	BLAST	BSim	DeST	DOE-2.1E	ECOTECT	Ener-Win	Energy Express	Energy-10	EnergyPlus	eQUEST	ESP-r	HAP	HEED	IDA ICE	IES <VE>	PowerDomus	SUNREL	Tas	TRACE	TRNSYS
IEA ECBCS Annex 1											X									X
IEA ECBCS Annex 4											X									X
IEA SHC Task 8											X						X			X
IEA ECBCS Annex 10											X									X
IEA SHC Task 12																				
• Envelope BESTEST	X		X	X	P		P	X	X		X	X	X	X	X	X	X	X	X	X
• Empirical		X	X		P		P				X						X	X		X
IEA SHC Task 22																				
• HVAC BESTEST Volume 1				X					X	X	X			X					X	X
• HVAC BESTEST Volume 2				X					X		X			X					X	X
• Furnace BESTEST									X		X									
• RADTEST				X							X			X						X
IEA ECBCS Annex 41 Moisture																X				
HERS BESTEST	X			X	P								X				X			
ASHRAE 1052-RP	X			X					X											

Figure 2.5 Comparison of 20 Programs in Terms of Validation (Crawley et al., 2005, pp. 47)

Crawley et al. (2008) compared the features and capabilities of 20 notable building energy simulation programs (Figure 2.5). Not all analyze the whole building, as some rather concentrate on specific subjects like indoor climate, thermal performance, hygrothermal simulations, solar simulations, energy consumption and energy costs, i.e. TRNSYS, which is suited mostly for solar simulations and PV placement for buildings. Ecotect, on the other hand, is, according to vendor-supplied information, a performance assessment program covering acoustics, lighting, shading, thermal, energy and cost aspects, but in fact has many limitations in the introduction of input data, as well as having reliability issues. Other tools include those developed by different groups but based on previous tools, and among these,

[2] Building Energy Software Tools Directory http://apps1.eere.energy.gov/buildings/tools_ directory/, last accessed on 2nd August, 2012.
[3] The US Department of Energy (DOE) is develops, promotes and invests in new tools and software programs related to energy efficiency and renewable energy technologies.

EnergyPlus is one of the most comprehensive, combining heat and mass balance simulations and building systems simulations.

With the introduction of the EPBD in 2002, the EU Commission required countries to develop assessment tools and methods for the evaluation of performance and the certification of buildings. In this respect, the governments of many European nations have started developing their own national assessment tools and establishing private or semi-private organizations. To date, building energy performance assessment guidelines and certification software have been developed by the related ministries or national institutions in Bulgaria, the United Kingdom, Finland, France, Ireland, Lithuania, Portugal and Southern Cyprus; by private organizations in Belgium and Holland; and through government/institutional/university collaborations in Italy and Romania (Künar, 2009). Some examples of national assessment tools for the evaluation of the energy performance of buildings that have been developed by national institutions and/or organizations includes the Standard Assessment Procedure (SAP) in the United Kingdom, the Dwellings Energy Assessment Procedure (DEAP) in Ireland, and the Energy Performance Assessment for Non-Residential Buildings (EPA-NR) in Malta. In Turkey, BEP-TR, as a national tool for the evaluation of the energy performance of buildings, was launched by the Ministry of Environment in 2010, however since the validity and reliability of the tool has to date not been fully accepted, the reliability of the results of the evaluations is still in discussion.

In this thesis, EnAd, a building energy performance advisor, has been developed as a design-support tool that is to be used starting from the very early phases of the design until the end. To test the validity, precision and reliability of EnAd, three different evaluation programs are to be used. The programs to be used in the convergence tests represent different dimensions in energy performance evaluations, and include DesignBuilder, HAP and EnerCalc. DesignBuilder and HAP are among the most widely used simulation programs in the world, while EnerCalc is a calculation tool based on German standards that analyses the energy performance of buildings. These programs are to be presented in following sections.

2.6 Current State of Legislation in Turkey

Turkey accepts the EU directives in the use of energy and environmental measurement, and has made a significant start with the adoption of EPBD, and national policies have been adapted to comply with international legislation. Turkey enacted the Energy Efficiency Law in 2007, followed by the Building Energy Performance Regulation in 2008; and many ISO and CEN standards have also been adopted to support the evaluation of the energy performances of buildings. The official documents in Turkey related to the energy performance of buildings are shown in Table 2.1. As a guide to the document codes in the table, the CEN or ISO standards adopted by Turkey are prefixed ‘TS’ (Turkish Standard), such as TS EN 832 or TS EN ISO 13790; otherwise, they are presented with their original names.

Table 2.1 Umbrella Documents Related to Energy Performance in Buildings

Document	Document title	Explanations	Status
Directive 2002/91/EC	Energy performance in buildings directive	Introduction of general principles and regulations regarding evaluation and certification of energy performance of new and existing buildings	Accepted
Directive 93/76/EEC	Limit CO_2 emission by improving energy efficiency (SAVE)	limiting carbon dioxide emissions by improving energy efficiency	Accepted
Directive 2006/32/EC	Energy end-use efficiency and energy services	the cost-effective improvement of energy end-use efficiency	Accepted
Directive 2012/27/EU	Energy efficiency	a common framework of measures for the promotion of energy efficiency	
Law 5627	Energy efficiency	General principles on enhancement of energy efficiency	National law
Regulation	Energy performance of buildings	Calculation methods for energy use assessment Minimum energy performance requirements Feasibility of renewable source use	National regulation
Regulation	Energy efficiency	Definition of general principles regarding efficient use of energy sources and energy	National regulation
Regulation	Environmental impact assessment	Definition of administrative and technical method and principles, including use of renewable sources	National regulation
CEN/TR 15615	Umbrella document - Explanation of the general relationship between various CEN standards and EPBD	Explanation of the general relationship between various European standards and the Energy Performance of Buildings Directive (EPBD)	Absent
TS EN 15217	Energy performance of buildings - Methods for expressing energy performance and for energy certification of buildings	Evaluation and certification of energy performance of buildings	Accepted English document
TS EN 15603	Energy performance of buildings - Overall energy use and definition of energy ratings	Overall energy use for space heating, cooling, ventilation, domestic hot water and lighting, and definition of energy ratings	Accepted English document
TS EN 15378	Heating systems in buildings - Inspection of boilers and heating systems	Inspection of boilers	Accepted English document
TS EN 15240	Ventilation for buildings - Energy performance of buildings - Guidelines for inspection of air-conditioning systems	Inspection of Air-conditioning systems	Accepted English document
TS EN ISO 13790	Thermal performance of buildings – calculation of energy use for space heating and cooling	a simplified calculation method for assessment of the annual energy use for space heating and cooling of a residential or a non-residential building	Accepted Translation not completed yet

As can be seen in the table, most of the primary documents related to the energy performance of buildings have been accepted by Turkey, although they are yet to be translated into Turkish and/or adapted to the conditions of the country.

Turkey has also published several of its own laws and regulations, as presented in Table 2.2 below. The Energy Performance in Buildings (BEP) regulation was first published in 2008, and was updated in 2010 with the addition of calculation methods, a material library and other documents related to the evaluation of lighting and mechanical systems. The regulation provides an hourly calculation method for the evaluation of the energy performance of a building, and addresses several standards, including TS, TS EN and TS EN ISO, while applying to DIN and ASHRAE standards in some of its calculations and assumptions. Due to this eclectic form of the regulation, conflicts may arise during applications that will be discussed in the following sections.

Table 2.2 Turkish Laws and Regulations Related to Energy Efficiency

2000	Performance of heat generators for heating and hot water production in new or existing non-ındustrial buildings Regulation on energy efficiency ballasts for fluorescent lighting (2000/55/AT)
2003	Regulation on environmental impact assessment
2005	Regulation on control of air pollution due to heating Regulation on principles and procedures for granting certificates of renewable energy source
2006	Regulation on energy efficiency requirements for household electric refrigerators, freezers and combinations Regulation on energy labeling of household air-conditioners
2007	5627 Energy efficiency law
2008	Circular related to energy efficiency year Regulation to increase efficiency in the use of energy sources and energy Regulation on energy performance in buildings (BEP) Regulation on distribution of the expenses of heating and sanitary hot water in central heating and sanitary hot water systems Regulation on the use of geothermal resource areas for electrical energy production Regulation on technical evaluation of wind energy based license applications Regulation on principles and procedures for promotion of energy efficiency in transportation
2009	Lighting regulation
2010	Updates on energy performance of buildings regulation

The Turkish Standards Institute (TSE) is responsible of the preparation of national standards, and accepts ISO and CEN standards if necessary. According to Turkey's international agreements, the TSE should develop new standards with more than 90% compliance with EN and ISO standards, and in this respect, most EN and ISO standards are accepted as they are. Only the cover is translated into Turkish, while the document is adopted in its native language. The standards that are used to evaluate energy performance of buildings and energy certification of buildings are listed in Table 2.3 according to hierarchy and scope, as determined by CEN/TR 15615 (2008). The table also works as a checklist to control the status of each standard, such as 'under revision, 'English document', 'absent', etc. Here, the term 'English document' refers to a standard that has been accepted by TSE, but that no modification has yet been made; 'Absent' refers to standards that are yet to be accepted; 'Under revision' denotes standards that are being translated into Turkish and modified in accordance with the conditions in the country.

Table 2.3 Standards Used in Energy Performance Assessment and Certification of Buildings

	Document	Title	Status
Calculation of overall energy use in buildings	TS EN 15217	Energy performance of buildings - Methods for expressing energy performance and for energy certification of buildings	English document
	TS EN 15603	Energy performance of buildings - Overall energy use and definition of energy ratings	English document
	TS EN 15459	Energy performance of buildings - Economic evaluation procedure for energy systems in buildings	English document
Calculation of delivered energy	TS EN 15316-4	Heating systems in buildings - Method for calculation of system energy requirements and system efficiencies: Part 4-1: Space heating generation systems, combustion systems, boilers Part 4-2: Space heating generation systems, heat pump systems Part 4-3: Heat generation systems, thermal solar systems Part 4-4: Heat generation systems, building-integrated cogeneration systems Part 4-5: Space heating generation systems, the performance and quality of district heating and large volume systems Part 4-6: Heat generation systems, photovoltaic systems Part 4-7: Space heating generation systems, biomass combustion systems	 Absent Absent English document English document English document English document Absent

Table 2.3 Standards Used in Energy Performance Assessment and Certification of Buildings (continued)

	Document	Title	Status
Calculation of delivered energy	TS EN 15316-1	Heating systems in buildings - Method for calculation of system energy requirements and system efficiencies -Part 1: General	English document
	TS EN 15316-2-1	Heating systems in buildings – Method for calculation of system energy requirements and system efficiencies -Part 2-1: Space heating emission systems	English document
	TS EN 15316-2-3	Heating systems in buildings - Method for calculation of system energy requirements and system efficiencies -Part 2-3: Space heating distribution systems	Absent
	TS EN 15316-3	Heating systems in buildings - Method for calculation of system energy requirements and system efficiencies Part 3-1: Domestic hot water systems, characterization of needs (tapping requirements) Part 3-2: Domestic hot water systems, distribution Part 3-3: Domestic hot water systems, generation	English document English document English document
	TS EN 15243	Ventilation for buildings - Calculation of room temperatures and of load and energy for buildings with room conditioning systems	English document
	TS EN 15377	Heating systems in buildings -Design of embedded water based surface heating and cooling systems Part 1: Determination of the design heating and cooling capacity Part 2: Design, dimensioning and installation Part 3: Optimizing for use of renewable energy sources	English document English document English document
	TS EN 15241	Ventilation for buildings - Calculation methods for energy losses due to ventilation and infiltration in commercial buildings	English document
	TS EN 15232	Energy performance of buildings - Impact of building automation, controls and building management	English document
	TS EN 15193	Energy performance of buildings - Energy requirements for lighting	English document
Energy need for heating and cooling	TS EN ISO 13790	Thermal performance of buildings -Calculation of energy use for space heating and cooling	Under revision
	TS EN 15255	Energy performance of buildings - Sensible room cooling load calculation -General criteria and validation procedures	English document
	TS EN 15265	Energy performance of buildings - Calculation of energy needs for space heating and cooling using dynamic methods - General criteria and validation procedures	English document
Thermal performance of building components	TS EN ISO 13789	Thermal performance of buildings - Transmission and ventilation heat transfer coefficients - Calculation method	English document
	TS EN ISO 13786	Thermal performance of building components - Dynamic thermal characteristics - Calculation methods	English document
	TS EN ISO 6946	Building components and building elements - Thermal resistance and thermal transmittance - Calculation method	Adapted document
	TS EN ISO 13370	Thermal performance of buildings - Heat transfer via the ground - Calculation methods	English document
	TS EN 13947	Thermal performance of curtain walling - Calculation of thermal transmittance	English document
Thermal performance of building components	TS EN ISO 10077-1	Thermal performance of windows, doors and shutters - Calculation of thermal transmittance - Part 1: General	English document
	TS EN ISO 10077-2	Thermal performance of windows, doors and shutters - Calculation of thermal transmittance - Part 2: Numerical method for frames	English document
	TS EN ISO 10211	Thermal bridges in building construction - Heat flows and surface temperatures -Detailed calculations	English document
	TS EN ISO 14683	Thermal bridges in building construction - Linear thermal transmittance -Simplified methods and default values	English document
	TS EN ISO 10456	Building materials and products - Hygrothermal properties - Tabulated design values and procedures for determining declared and design thermal values	English document

Table 2.3 Standards Used in Energy Performance Assessment and Certification of Buildings (continued)

	Document	Title	Status
Ventilation and air infiltration	TS EN 13465	Ventilation for buildings - Calculation methods for the determination of air flow rates in dwellings	English document
	TS EN 15242	Ventilation for buildings - Calculation methods for the determination of air flow rates in buildings including infiltration	English document
	TS EN 13779	Ventilation for non-residential buildings - Performance requirements for ventilation and room-conditioning systems	Under revision
Overheating and solar protection	TS EN ISO 13791	Thermal performance of buildings - Calculation of internal temperatures of a room in summer without mechanical cooling -General criteria and validation procedures	English document
	TS EN ISO 13792	Thermal performance of buildings - Calculation of internal temperatures of a room in summer without mechanical cooling -Simplified methods	English document
	TS EN 13363-1 +A1	Solar protection devices combined with glazing -Calculation of solar and light transmittance - Part 1: Simplified method	English document
	TS EN 13363-2	Solar protection devices combined with glazing - Calculation of total solar energy transmittance and light transmittance - Part 2: Detailed calculation method	English document
Indoor conditions and external climate	TS CR 1752	Ventilation for buildings - Design criteria for the indoor environment	Adapted document
	TS EN 15251	Indoor environmental input parameters for design and assessment of energy performance of buildings addressing indoor air quality, thermal environment, lighting and acoustics	English document
	TS EN ISO 15927	Hygrothermal performance of buildings - Calculation and presentation of climatic data Part 1: Monthly means of single meteorological elements Part 2: Hourly data for design cooling load Part 3: Calculation of a driving rain index for vertical surfaces from hourly wind and rain Data Part 4: Hourly data for assessing the annual energy use for heating and cooling Part 5: Data for design heat load for space heating Part 6: Accumulated temperature differences (degree days)	English document English document English document English document English document English document
Definitions and terminology	TS EN ISO 7345	Thermal insulation - Physical quantities and definitions	English document
	TS EN ISO 9288	Thermal insulation - Heat transfer by radiation -Physical quantities and definitions	English document
	TS 6874 EN ISO 9251	Thermal insulation - Heat transfer conditions and properties of materials - Vocabulary	Turkish document
	TS EN 12792	Ventilation for buildings - Symbols, terminology and graphical symbols	Turkish document
Monitoring and verification of energy performance	TS EN 12599	Ventilation for buildings - Test procedures and measuring methods for handing over installed ventilation and air conditioning systems	English document
	TS EN 13829	Thermal performance of buildings - Determination of air permeability of buildings - Fan pressurization method	English document
	TS EN ISO 12569	Thermal insulation in buildings - Determination of air change in buildings - Tracer gas dilution method	English document
	TS EN 13187	Thermal performance of buildings - Qualitative detection of thermal irregularities in building envelopes - Infrared method	English document
	TS EN 15378	Heating systems in buildings - Inspection of boilers and heating systems	English document
	TS EN 15239	Ventilation for buildings - Energy performance of buildings - Guidelines for inspection of ventilation systems	English document
	TS EN 15240	Ventilation for buildings - Energy performance of buildings - Guidelines for inspection of air-conditioning systems	English document

As can be seen from Table 2.3, there are many standards to be covered for the evaluation and certification of energy performance of buildings, and while most of the standards have been accepted by the TSE, they are yet to be adapted in accordance with the conditions in the country. In respect to this research, the directives, laws, standards and regulations mentioned above constitute a general framework for EnAd, and have been grouped according to design decisions and used in the development of the program, as explained in the following sections.

2.7 Discussions and the Hypothesis of the Study

As stated in the literature review, there is a close relationship between the sustainability concept and energy and performance assessment in architecture that has resulted in transformations in the legal framework, and thus architectural design processes and practices. Many governments have introduced new legislations that are compatible with the needs of the era. Parallel to the developments in legislation, the discipline of architecture has adopted energy-conscious and low-energy building design concepts following the energy crisis of the 1970s; environmental-friendly and bioclimatic design concepts during the climate change alert in the 1980s; and ecological, green and sustainable building design concepts following the arrival of global warming to the agenda in the 1990s. Today, with technological advances and the rise of performance issues, architectural design has been transformed into performance-based design so as to satisfy different performance criteria, considering human well-being, the rational use of natural resources and the preservation of the environment. Accordingly, performance criteria can be determined by design guidelines as well as by legislation.

In Turkey, the legal framework regarding the energy performance of buildings is still a subject of interest, as is the case in EU countries. Previous literature contains several research studies relating to energy-efficient building design, sustainable building models, thermal comfort, thermal efficiency calculations, renewable energy and active and passive solar systems (i.e. Oluklulu, 2001; Ulukavak, 2001; Türkmen, 2003; Üst, 2005; Bedir, 2006; Kayıhan, 2006; Ercoşkun, 2007; Kartal, 2009), however the role of legislation is a subject of interest for further academic studies.

It can be said that laws, standards and regulations may be used as an effective tool in setting the performance criteria for buildings, and so may become instructions and guidelines for architectural design in the creation of performance-based buildings. This is one of the main assumptions of this study; however most of the standards to be used in the evaluation of energy performance of buildings are original documents that are yet to be adapted to the conditions of the country. Due to the lack of adaptation, conflicts have become inevitable in practice.

Since design decisions play an important role in determining the energy performance of buildings, assessment tools are vital for the evaluation of the energy performance of buildings throughout the design process. Such tools should be precise and reliable, while complying with the legislations and taking into account the conditions of the country. It is also important for the user to understand the reliability of any tools to be used in the decision-making process.

In this dissertation, a two-pronged study has been proposed: first, a soft tool will be developed for integration into the architectural design process for the evaluation of the energy performance of buildings; and second, legislation will be dealt with as a guideline for architects. In this respect, a computer program, EnAd, has been developed for use throughout the design process, featuring an interactive interface that allows the designer to employ data/knowledge from different domains into the design process. The program is flexible and easy to use, and guides the designer to achieve higher performances. Legislation is intended to be integrated to the design process to ensure the final design achieves the design goals and objectives in harmony with official requirements.

CHAPTER 3

THEORETICAL BACKGROUND OF EnAd

In this chapter, the computational background of the soft tool developed as part of this study, namely EnAd, is presented. EnAd is a soft tool for the evaluation of the energy performance of residential buildings considering the energy requirements for the four energy parameters: space heating, cooling, domestic hot water and artificial lighting. The mathematical models of various heat transfer mechanisms are based on EPBD, Turkish BEP Regulation and the related standards and documents. The development of EnAd is explained in detail in the following sections, and the program structure showing the data sets is illustrated in Figure 3.1.

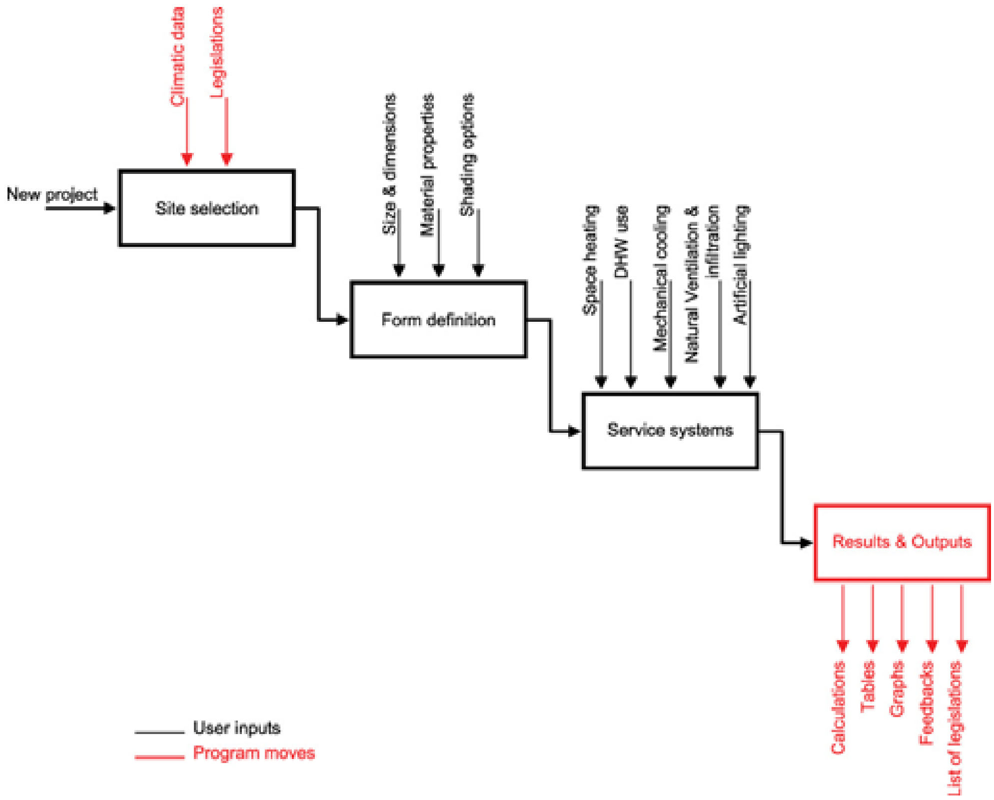


Figure 3.1 Program Structure of EnAd

3.1 Umbrella Documents

The core document in the assessment of energy performance of buildings is Directive 2002/91/EC on Energy Performance in Buildings (EPBD), which has four main objectives: adoption of a calculation methodology, definition of minimum performance criteria, certification of buildings, and inspection of heating and cooling equipment. For the implementation of these four objectives, the directive addresses several standards, the first of which is the CEN/TR 15615[4] Umbrella Document, giving the names of the standards to be

[4] prCEN/TR 15615 Explanation of the general relationship between various European standards and the Energy Performance of Buildings Directive (EPBD) - Umbrella Document

used for the four main components set out in the Directive. The European standards referenced by CEN/TR 15615 are grouped according to the four main components of the Directive and illustrated in Figure 3.2.

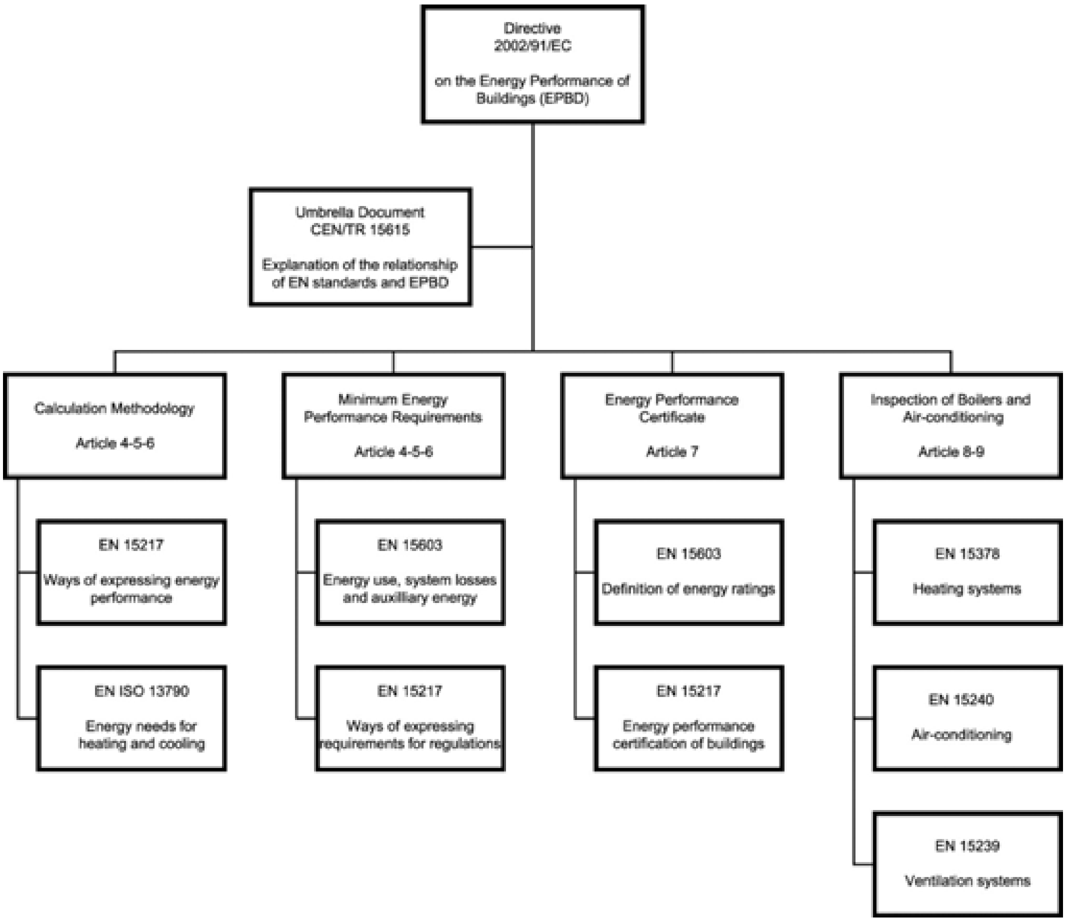


Figure 3.2 Explanation of the General Relationship between EPBD and European Standards Regarding the Energy Performance of Buildings
(adopted from CEN/TR 15615: 2008)

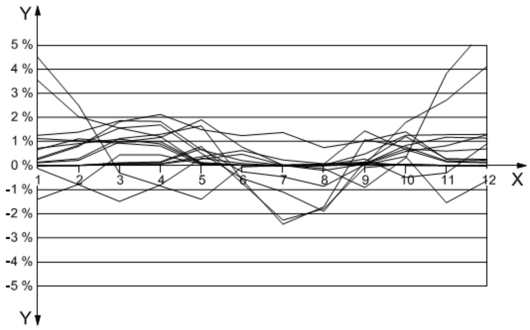
As seen in Figure 3.2, CEN/TR 15615 references EN 15217 and EN ISO 13790 for calculation methodology, while also including EN 15603 for the determination of the minimum energy performance requirements and the energy performance certification processes. The development of EnAd is based on TS EN 15217, TS EN 15603 and TS EN ISO 13790, as well as the Turkish BEP Regulation, with several assumptions in accordance with the specific conditions of Turkey. These documents are accepted as the umbrella documents of EnAd, while the standards related to inspections of heating and cooling installations are not included in the program. The formulas and assumptions used in EnAd are compiled from its umbrella documents and other related documents. These are explained in detail starting from the calculation methodology, the climatic database and energy ratings, and take in also energy requirements for space heating, cooling, domestic hot water and lighting services, and the determination of energy performance classes in the following sections.

3.2 Calculation Methods of Energy Performance of Buildings

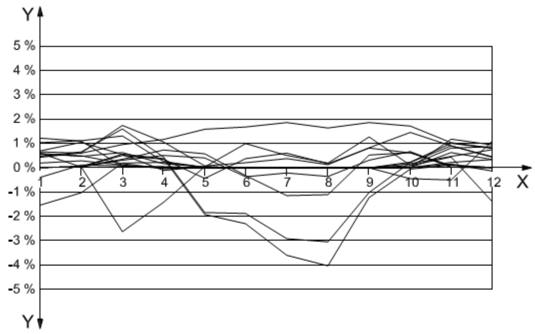
TS EN ISO 13790 introduces two basic calculation methods for the assessment of the energy performance of buildings; namely dynamic methods and quasi-steady-state methods.

Both methods offer advantages and superior features over each other, as well as drawbacks, and are classified according to the time intervals of calculations, being either simple hourly measurements or monthly or seasonal measurements. The dynamic method calculates the heat balance in short time steps, typically for one hour, during which the heat stored in (and escaping from) the mass of the building is considered. The latter method calculates the heat balance over longer time intervals, typically monthly or seasonal, and considers dynamic effects with the help of gain and loss utilization factors.

The simple hourly method uses hourly patterns, making a comparison of hourly changes in the building, the use of building systems and external climatic conditions. Since the results of the simple hourly method are obtained from direct calculations, the subsequent calculations cannot be controlled by the user or by monthly or annual correlation coefficients. Accordingly, the definition of hourly use patterns as well as the hourly climatic data used is of great importance in this method. The monthly method, on the other hand, uses correlation coefficients defined by TS EN ISO 13790, and although the monthly method is accepted as having a 10% margin of error the beginning and end of the heating and cooling seasons, it gives more reliable and accurate results for annual calculations (TS EN ISO 13790, 2008).



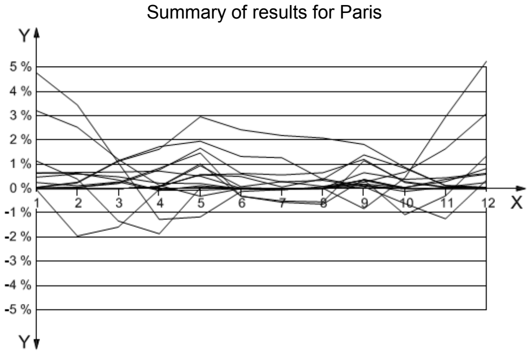
Summary of results for Paris



Summary of results for Rome

X month

Y relative difference in percent of annual heating plus cooling



Summary of results for Stockholm

Deviation	Paris	Rome	Stockholm
Heating	10 %	3 %	8 %
Cooling	6 %	8 %	7 %

Summary of results on annual basis

Figure 3.3 The Results of the Comparison of the Monthly Calculation Method and the Simple Hourly Method (TS EN ISO 13790, 2008, pp. 133-135)

TS EN ISO 13790 (2008) explores the validity of the monthly calculation method, which is subjected to the test cases of EN 15265[5]. For the test cases, the annual energy requirements of buildings in three different European cities are calculated using the monthly method and compared with the results of simple hourly method, revealing that the results of the monthly method are higher than that of the simple hourly method. The precision of the method has been exemplified in the standard. As shown in Figure 3.3, the annual energy requirement for space heating in Paris differs by 10% while cooling differs by 6% when compared to the results of the simple hourly method. The results for Rome are 3% and 8%, and for Stockholm 8% and 7% respectively.

[5] EN 15265 Energy performance of buildings - Calculation of energy needs for space heating and cooling using dynamic methods – General criteria and validation procedures

In Turkey, Building Energy Performance, Turkey (BEP-TR) has been proposed as the national assessment tool, using the simple hourly calculation method. The tool uses climate data from a representative meteorological year and an operative temperature as a set-temperature with hourly patterns. The tool is also stated to employ typical meteorological years for several cities; however neither the climate data nor the hourly patterns are in the public domain.

In EnAd, the monthly calculation method is preferred due to the advantages it offers, including the number of calculation steps, as well as the availability of convergence coefficients, allowing for the control of subsequent calculations in monthly and annual evaluations. Other reasons for choosing this method are the availability of data on hourly use patterns, and the difficulty encountered in obtaining hourly climatic data, as discussed in the following section.

3.3 The Climatic Database Used in EnAd

Databases have a crucial role in the evaluation of the energy performance of buildings, as the reliability and accuracy of the data to be used in evaluations is of paramount importance. Crawley (1998) suggests the use of typical weather data rather than average values, and such weather data sets can be created on a national level, or by international organizations. There are about 20 national and international organizations providing typical weather data for countries and cities around the world that are accepted by ASHRAE and are commonly used by many evaluation and simulation tools.

The average weather data set for Turkey is described in TS 825 (1998), and constitutes four main heating degree-day regions (HDDR), for which the monthly average outside temperatures are recorded, as well as monthly average solar radiation data for all cities. Such a dataset is insufficient for use in an hourly evaluation of the energy performance of a building, meaning that this dataset needs to be updated if it is to be used in monthly evaluations.

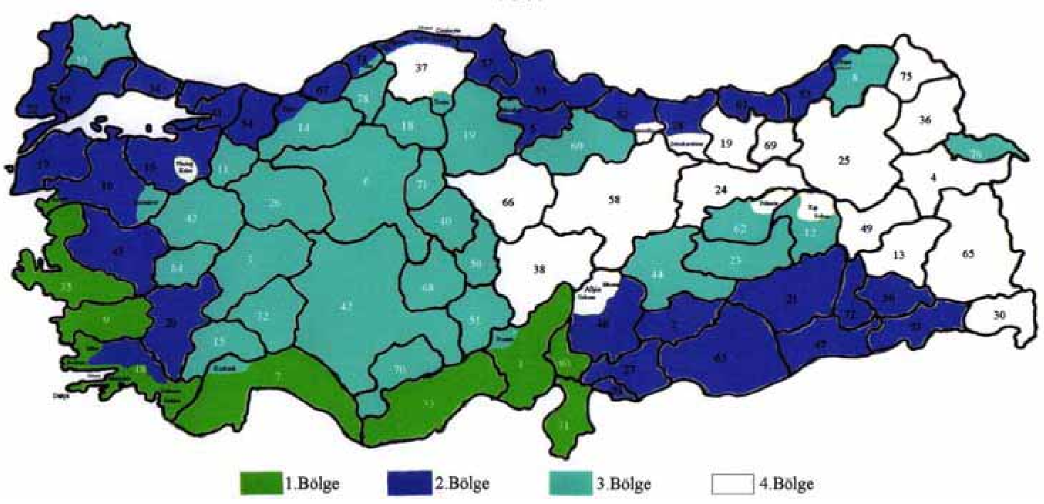


Figure 3.4 Map Showing Heating Degree-Day Regions of Turkey (TS 825, 2008; p. 75)

In order to define the design goals, as well as constraints, for heating it is necessary to determine the HDDR data of the city in which the building to be analyzed is to be located. There are four different HDDRs in Turkey: the first HDDR represents the hottest cities in which there is very little heating need, while the fourth HDDR represents the coldest cities with very high heating requirements. The HDDR map of Turkey provided by TS 825 is presented in Figure 3.4.

Cooling degree-day regions (CDDR) have yet to be determined by legislation. Especially in the Mediterranean region, the energy requirements for space cooling are much higher than for space heating, and so energy consumption for space cooling is the major factor determining the energy performance of buildings in the first and second HDDRs. The CDDR of Turkey determined in a research study (Bulut et al., 2007) is supplied in EnAd for information only, in that no constraint can be defined based on CDDR, as this is set by the Ministry.

Regarding the outside temperature data, the Turkish State Meteorological Service (DMİ) publishes temperature data for all cities in Turkey on its official website. The Service provides average temperatures measured over long periods, starting from the 1970s to the present. TS EN 15927-4[6] suggests creating a typical meteorological year (reference year) to be used in all evaluations of energy performance of buildings, and İleri and Üner (1998) conducted a study to define a typical meteorological year for 23 out of 81 cities in Turkey. At the culmination of their studies, they presented typical meteorological year data (TMY) and long-term (LT) mean temperatures for these 23 cities. The monthly average outside temperatures are exemplified for Ankara and presented in Table 3.1, which includes also the monthly mean temperature values for Ankara determined by International Weather for Energy Calculations (IWEC), one of the international organizations providing weather data for the use in energy performance evaluations.

Table 3.1 Monthly Average Temperatures for Ankara

Source	Type	Months												Year
		1	2	3	4	5	6	7	8	9	10	11	12	average
DMİ (1970-2012)	LT	0.3	2.1	6.2	11.3	16.1	20.2	23.6	23.3	18.7	13	6.7	2.3	12
İleri and Üner (1998)	LT mean	-0.1	1.3	5.4	11.2	15.9	19.8	23.1	23	18.4	12.8	7.3	2.3	11.7
	TMY	-0.5	-0.2	5.6	10.2	15.7	19.1	23.6	23	19.3	15	5.5	0.2	11.4
TS 825 3rd HDDR	Average	-0.3	0.1	4.1	10.1	14.4	18.5	21.7	21.2	17.2	11.6	5.6	1.3	10.5
IWEC	LT mean	-2.4	0.6	2.6	8.9	13.7	17	21.5	21.1	17.1	10.3	3.8	0.8	9.6

All values are dry bulb temperatures in °C. LT: Long Term TMY: Typical Meteorological Year

As seen from Table 3.1, the long-term averages calculated by DMİ and İleri and Üner's are very similar, whereas there is a very significant distinction between the results of DMİ, TS 825 and IWEC. A 3°C difference in results can be considered an extremely high discrepancy in the evaluations and the results. The difference between long-term and long-term mean temperatures is the period of time selected. DMİ's temperature values are an average of a forty-year period, while the IWEC produces long-term mean values depending on the values of a ten year period selected for evaluation purposes (as defined by TS EN 15927-4). In EnAd, İleri and Üner's TMY data for 23 cities is used, while for the other cities DMİ data is used.

[6] TS EN 15927-4 Hygrothermal performance of buildings - Calculation and presentation of climatic data - Part 4: Hourly data for assessing the annual energy use for heating and cooling

Figure 3.5 Solar Radiation Map of Turkey[7]

Regarding solar radiation data, TS 825 provides the same monthly solar radiation data for all cities of Turkey; however Turkey is a very large country, and so the solar radiation values for different cities are widely varied. Recently, Renewable Energy General Directorate of the Ministry of Energy published a solar map for Turkey, as shown in Figure 3.5. The directorate also provides hourly and monthly horizontal solar radiation data for many cities, however before it can be used in energy performance evaluations; it needs to be converted into vertical data for each direction. There are various ways of doing this, however currently no specific conversion method has been determined, nor is any common radiation data accepted by the Ministry or other authorities. For this reason, although it is not so reliable to use the same data for all cities, the monthly average solar radiation data determined by TS 825 is used in EnAd, as shown in Table 3.2.

Table 3.2 Solar Radiation Data for All Cities of Turkey

	TS 825 Monthly average solar radiation data for all cities (W/m^2)			
Month	South	East	North	West
January	72	43	26	43
February	84	57	37	57
March	87	77	52	77
April	90	90	66	90
May	92	114	79	114
June	95	122	83	122
July	93	118	81	118
August	93	106	73	106
September	89	81	57	81
October	82	59	40	59
November	67	41	27	41
December	64	37	22	37

[7] Güneş Enerjisi Potansiyel Atlası (GEPA), available online at http://www.eie.gov.tr/MyCalculator/Default.aspx, last visited in December 24th, 2012.

The Ministry of Energy and Natural Resources has produced a wind potential map for Turkey that can be used to determine renewable energy potentials for individual buildings, as well as for large wind farms. The wind map (Figure 3.6) is included in EnAd to inform the users about the wind potential of the region selected.

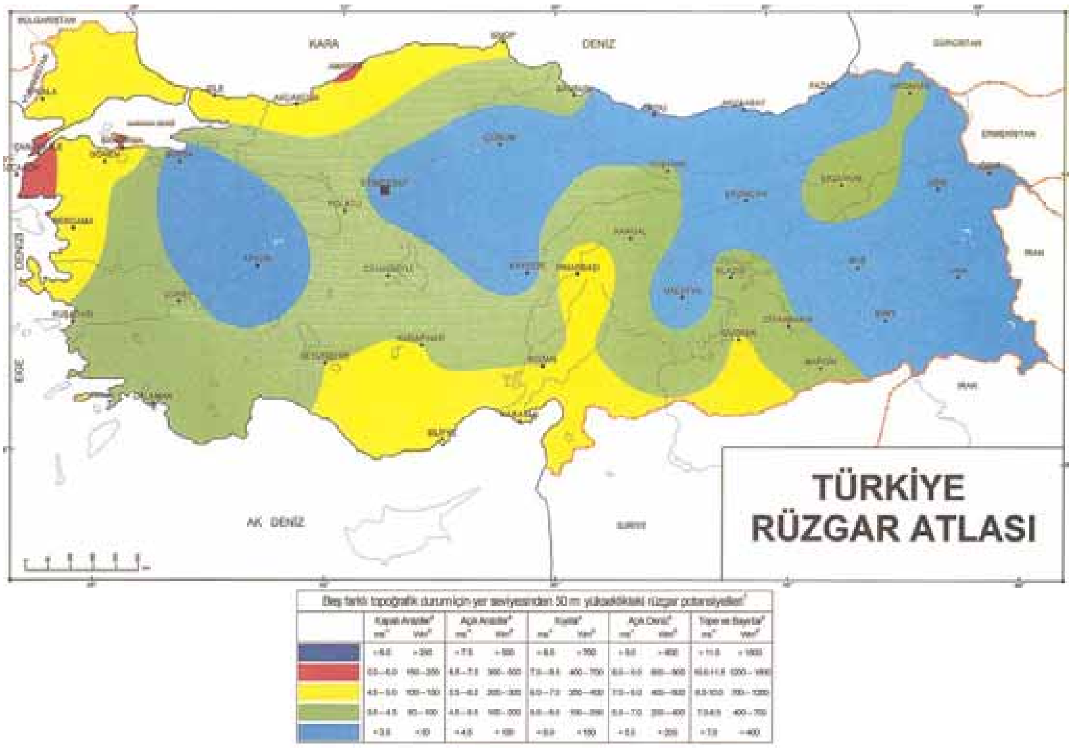


Figure 3.6 Wind Potential Map of Turkey (ETKB, 2012)

Regarding DHW supply in buildings, monthly average city water temperatures are taken from the study of Altuntop (2005) for each city for use in calculations of the monthly average energy requirement for DHW in EnAd.

3.4 Energy Ratings

TS EN 15217[8] requires the type of energy rating to be indicated on the energy performance certificate. As defined in TS EN 15603[9], the energy rating of buildings can be made according to two principal methods: (1) the calculated energy rating, and (2) the measured energy rating. The measured energy rating option can be applied to the existing building stock, while the calculated energy rating can be applied both to existing and new buildings. The measured type can be used only for certification purposes. The calculated energy rating, on the other hand, can be used for multiple purposes, such as for building permission, optimization, validation and retrofit planning, as well as energy performance certification. A calculated energy rating considers the thermal needs in a building, the technical building system performance, the weighted net delivered energy and the exported energy. TS EN 15217 requires a calculated energy rating to include the annual weighted net delivered energy used for heating, cooling and DHW, while those for lighting and other services are optional for residential buildings.

[8] TS EN 15217: Energy performance of buildings - Methods for expressing energy performance and for energy certification of buildings

[9] TS EN 15603: Energy performance of buildings - Overall energy use and definition of energy ratings

Since one of main goals of this study is to provide an evaluation tool, it is the calculated energy rating that is used in EnAd, by which the program evaluates energy requirements for the four energy parameters. Monthly and annual energy consumption and primary energy requirement are calculated according to energy requirements for the four energy parameters: heating ($Q_{H,nd}$), cooling ($Q_{C,nd}$), domestic hot water ($Q_{W,nd}$) and lighting (Q_L), including the system gains and losses. The calculation of energy requirements for the four energy parameters used in EnAd is given with the necessary formulas in the following sections.

3.5 Energy Requirement for Space Heating and Cooling

The energy requirement for space heating and cooling depends on thermal gains and losses through each conditioned and unconditioned building zone over a given period of time. The energy requirement for space heating and cooling is calculated according to TS EN ISO 13790 and the BEP Regulation. In order to show the similarities and differences of the equations used for calculating space heating and cooling, they are presented together.

The energy requirement for space heating, $Q_{H,nd}$, is determined from the difference between total heat transfer ($Q_{H,ht}$) and heat gains ($Q_{H,gn}$), which is corrected for the month with a dimensionless gain utilization factor ($\eta_{H,gn}$). In the formulas, 'H' refers to Heating and 'C' to Cooling, while the subscript 'nd' denotes need; 'tr' denotes transmission; and 'gn' denotes gains. The energy requirement for space heating is calculated monthly for each building zone, expressed in mega joules (MJ), as presented in Eq. 1.

Energy requirement for space heating:

$Q_{H,nd} = Q_{H,ht} - \eta_{H,gn} Q_{H,gn}$ (MJ) (Eq. 1)

The energy requirement for space cooling, $Q_{C,nd}$, on the other hand, is based on the difference between heat gains ($Q_{C,gn}$) from heat transfer ($Q_{C,ht}$) multiplied by a dimensionless utilization factor for heat losses ($\eta_{C,ls}$), and is calculated as:

Energy requirement for space cooling:

$Q_{C,nd} = Q_{C,gn} - \eta_{C,ls} Q_{C,ht}$ (MJ) (Eq. 2)

Heat in a building can be transferred by transmission or ventilation. According to TS EN ISO 13790, the total heat transfer, Q_{ht}, is based on the heat transfer by transmission (Q_{tr}) and by ventilation (Q_{ve}), calculated for each month, and can be referred to as heat transfer for the heating mode ($Q_{H,tr}$) and the cooling mode ($Qc_{,tr}$), as given in Eq. 3:

Total heat transfer;

$Q_{ht} = Q_{tr} + Q_{ve}$ (MJ) (Eq. 3)

The total heat transfer for the heating mode, $Q_{tr,}$ can be calculated by multiplying the overall heat transfer coefficient ($H_{tr,adj}$) by the temperature difference between the external environment (θ_e) and internal set-point for heating ($\theta_{int,set,H}$) over the duration of each month (expressed in mega seconds) (t), and shown for heating and cooling modes similarly as follows:

Heat transfer by transmission;

Heating $Q_{tr} = H_{tr,adj} (\theta_{int,set,H} - \theta_e)\, t$ (MJ) (Eq. 4)

Cooling $Q_{tr} = H_{tr,adj} (\theta_{int,set,C} - \theta_e)\, t$ (MJ) (Eq. 5)

In the BEP regulations, the internal set-point temperature for the heating mode ($\theta_{int,set,H}$) is accepted as 20°C, and for the cooling mode ($\theta_{int,set,C}$) as 26°C. The same values are accepted in the calculations of EnAd.

A very similar calculation is applied for total heat transfer by ventilation, Q_{ve}, for the heating and cooling modes; with the only difference being the overall heat transfer coefficients through ventilation ($H_{ve,adj}$).

Heat transfer by ventilation;

Heating $Q_{ve} = H_{ve,adj} (\theta_{int,set,H} - \theta_e)\, t$ (MJ) (Eq. 6)

Cooling $Q_{ve} = H_{ve,adj} (\theta_{int,set,C} - \theta_e)\, t$ (MJ) (Eq. 7)

Two types of heat gains can be observed in the buildings: internal gains and solar gains. Total heat gains, Q_{gn}, is equal to the sum of the internal heat gains (Q_{int}) and the solar heat gains (Q_{sol}). Since heat gains do not change according to set-point temperatures for heating and cooling, the calculation of internal and solar heat gains is the same for both the heating and cooling modes, and is shown as:

Total gains;

$Q_{gn} = Q_{int} + Q_{sol}$ (MJ) (Eq. 8)

The total heat gains are calculated according to a time-average heat flow rate from the solar heat source (Φ_{sol}) and from internal heat sources (Φ_{int}) for the duration of the considered month (*t*).

Internal heat gain $Q_{int} = \Phi_{int,mn}\, t$ (MJ) (Eq. 9)

Solar heat gain $Q_{sol} = \Phi_{sol,mn}\, t$ (MJ) (Eq. 10)

Therefore, for the monthly calculation method, the final equation of energy requirement for space heating and cooling can be expressed as follows:

Total monthly energy requirement for:

Heating $Q_{H,nd} = [\, (H_{tr,adj} + H_{ve,adj})(\theta_{int,set,H} - \theta_e) - \eta_{H,gn} (\Phi_{int} + \Phi_{sol})\,]\, t$ (MJ) (Eq. 11)

Cooling $Q_{C,nd} = [(\Phi_{int} + \Phi_{sol}) - \eta_{C,ls} (H_{tr,adj} + H_{ve,adj})(\theta_{int,set,C} - \theta_e)]\, t$ (MJ) (Eq. 12)

3.5.1 Transmission Heat Transfer Coefficients

Four types of heat transfer by transmission can be observed: from conditioned spaces to the external environment, to the ground, through unconditioned spaces and to unconditioned buildings. In this context, the overall transmission heat transfer coefficient, $H_{tr,adj}$, is the sum of the direct heat transfer by transmission to the external environment (H_D), to the ground (H_g), through unconditioned spaces (H_U) and to adjacent buildings (H_A). The coefficients are calculated for each transparent (such as windows) and opaque (such as walls etc.) element in a building according to TS EN ISO 13789[10], expressed in watts per kelvin and represented as:

Overall transmission heat transfer coefficient:

$H_{tr,adj} = H_D + H_g + H_U + H_A$ (W/K) (Eq. 13)

Direct transmission between internal and external environments is based on the properties of building element(s) separating the conditioned zone and the external environment. The direct transmission coefficient (H_D) is calculated from the area of the element i (A_i) and its thermal transmittance (U_i).

Direct transmission:

$H_D = \Sigma_i A_i U_i$ (W/K) (Eq. 14)

[10] TS EN ISO 13789 Thermal performance of buildings - Transmission and ventilation heat transfer coefficients - Calculation method

In general, H_x is used to represent H_D, H_g, H_U or H_A, and is calculated using the same formula given in Eq. 14. Differently, an adjustment factor (b_{tr}) is used in the calculation of heat transfer to the ground, unconditioned spaces and unconditioned buildings, while this factor is assumed to be 1 for direct transmission. Therefore, the general formula for indirect transmission is given as shown in Eq. 15:

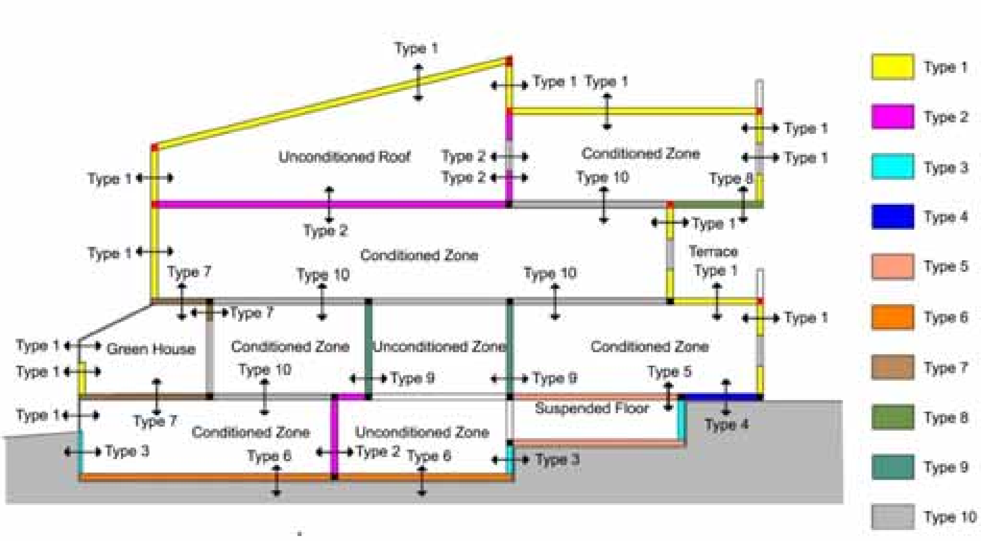
Indirect transmission;
$H_x = b_{tr} \Sigma_i A_i U_i$ (W/K) (Eq. 15)

The adjustment factor for each condition is calculated as described in the BEP Regulation. The area of each building element is calculated in meters square, and the thermal properties for each material are obtained from the national material library provided under the BEP Regulation for opaque materials. Adjustment factors (b_{tr}), on the other hand, are calculated using the formula provided in TS EN ISO 13370[11] and TS EN ISO 13789, which is shown in Table 3.3.

Similarly, the heat transmission of the transparent building elements ($H_{tr,win}$) is calculated from area of building element (A_{win}) and its heat transmission coefficient (U_{win}), as shown in Eq. 16. The overall values for thermal transmittance of windows (U_{win}) are obtained from the BEP Regulation and TS EN ISO 10077-1[12] and -2[13].

Heat transmission of transparent building elements:
$H_{tr,win} = A_{win} . U_{win}$ (W/K) (Eq. 16)

In a building it is possible to observe different types of heat transmission through different zones, and different conditions require different calculations. Although TS EN ISO 13790 defines four major types of heat transmission, the BEP Regulation re-describes these four major types under 10 conditions for ease of calculation. These conditions are presented in Figure 3.7, and the appropriate formulas for transmission and U-value calculations are provided in Table 3.3. The transmission types and formulas cited in the BEP Regulation are used in EnAd, aside from type 7 relating to greenhouses due to the lack of a greenhouse option in EnAd.



Figıre 3.7 Types of Heat Transmission between Different Zones in a Building (adapted from BEP Regulation, 2010; Net Energy Appendix, p. 21)

[11] TS EN ISO 13370 Thermal performance of buildings - Heat transfer via the ground - Calculation methods
[12] TS EN ISO 10077-1: Thermal performance of windows, doors and shutters -Calculation of thermal transmittance - Part 1: Simplified method
[13] TS EN ISO 10077-2: Thermal performance of windows, doors and shutters -Calculation of thermal transmittance - Part 2: Numerical method for frames

Table 3.3 Coefficient Calculations for Different Types of Heat Transfer by Transmission between Different Zones in a Building (BEP Regulation, 2010)

	Heat transmission through	Formula	Reference standard
	Transparent elements	$H_{tr,win} = A_{win} \,.\, U_{win}$	TS EN ISO 10077-1 TS EN ISO 10077-2
	Opaque elements	$H_{tr,op} = A_{op} \,.\, U_{op}$ U value for an element; $U_{op} = 1/\ (1/h_{si} + d_1/\lambda_1 + d_2/\lambda_2 + \ldots + 1/h_{se}) + (1/\ R_{gap})$	TS EN ISO 6946[14]
Type 1	Conditioned zone to external environment	$H_{tr,op} = A_{op} \,.\, U_{op}$	TS EN ISO 13789
Type 2	Conditioned zone to unconditioned zone	$H_{tr} = b_{tr}\ (\Sigma\ H_{tr,op} + H_{tr,win} + H_{tr,do})$ $H_{iu} = H_{T,iu} + H_{V,iu}$ $H_{ue} = H_{T,ue} + H_{V,ue}$ $b_{tr} = \frac{H_{ue}}{H_{iu} + H_{ue}}$	TS EN ISO 13789
Type 3	Conditioned basement walls contacting with earth	$d_w = \lambda\ (R_{si} + R_W + R_{se})$ $U_{bw} = \frac{2\lambda}{\pi z}\left(1 + \frac{0{,}5 d_t}{d_t + z}\right) \ln\left(\frac{z}{d_w} + 1\right)$	TS EN ISO 13370
Type 4	Slab-on-ground floor	If $d_t < B'$ (uninsulated and moderately insulated floors); $U = \frac{2\lambda}{\pi B' + d_t} \ln\left(\frac{\pi B'}{d_t} + 1\right)$ If $d_t \geq B'$ (well-insulated floors); $U = \frac{\lambda}{0{,}457\ B' + d_t}$	TS EN ISO 13370
Type 5	Suspended floor of conditioned basement	$U_x = 2\ \frac{hU_w}{B'} + 1450\ \frac{\varepsilon f_w}{B'}$ $d_g = w + \lambda\ (R_{si} + R_W + R_{se})$ $U = \frac{2\lambda}{\pi B' + d_g} \ln\left(\frac{\pi B'}{d_g} + 1\right)$	TS EN ISO 13370
Type 6	Un-/Conditioned basement floor on earth	If d_t $0{,}5z < B'$ (uninsulated and moderately insulated basement floors); $U_{bf} = \frac{2\lambda}{\pi B' + d_t + 0{,}5z} \ln\left(\frac{\pi B'}{d_t + 0{,}5z} + 1\right)$ If d_t $0{,}5z \geq B'$ (well-insulated basement floors); $U_{bf} = \frac{\lambda}{0{,}457\ B' + d_t + 0{,}5z}$	TS EN ISO 13370
Type 7	Conditioned zone to greenhouse	$H_{tr} = b_{tr}\ (\Sigma\ H_{tr,op} + H_{tr,win} + H_{tr,do})$ $H_{iu} = H_{T,iu} + H_{V,iu}$ $H_{ue} = H_{T,ue} + H_{V,ue}$ $b_{tr} = \frac{H_{ue}}{H_{iu} + H_{ue}}$	TS EN ISO 13370
Type 8	Conditioned cantilever floors	$U_{op,stnd} = 1/\ (1/h_{si} + d_1/\lambda_1 + d_2/\lambda_2 + \ldots + 1/h_{se})$ $H_{tr,op} = \Sigma\ A_{op} \,.\, U_{op}$	TS EN ISO 13370

[14] TS EN ISO 6946: Building components and building elements - Thermal resistance and thermal transmittance - Calculation method

Table 3.3 Coefficient Calculations for Different Types of Heat Transfer by Transmission between Different Zones in a Building (BEP Regulation, 2010) (continued)

	Heat transmission through	Formula	Reference standard
Type 9	Conditioned zone to unconditioned zone	$U_{op,stnd} = 1/\ (1/h_{si} + d_1/\lambda_1 + d_2/\lambda_2 + \ldots + 1/h_{se})$ $H_{tr,op} = 0.5\ (\Sigma\ H_{tr,op} + H_{tr,win} + H_{tr,do})$	TS EN ISO 13370
Type 10	Conditioned zone to conditioned zone	No heat transfer	
	Additional calculations	Characteristic dimension of floor $B' = \frac{A}{0{,}5P}$ total equivalent thickness, $d_f = W_{op} + \lambda_g (R_{si} + R_f + R_{se})$ equivalent thickness for walls of basements below ground level. $d_w = \lambda_g (R_{si} + R_{bw} + R_{se})$ total equivalent thickness for the ground floor walls, $d_g = W_{op} + \lambda_g (R_{si} + R_g + R_{se})$ equivalent thickness for floors $d_t = w + \lambda (R_{si} + R_f + R_{se})$	TS EN ISO 13370 TS EN ISO 13789 TS EN ISO 13790

Figure 3.8 Calculations of Coefficients for Heat Transfer by Transmission in EnAd

3.5.2 Ventilation Heat Transmission Coefficient

The second type of heat transfer observed in buildings occurs through ventilation. The ventilation heat transfer coefficient, H_V, is calculated according to TS EN ISO 13789 considering the airflow rate through a conditioned or unconditioned space (*q*) and the heat capacity of air per volume (*p.c*), and is expressed in watts per kelvin:

Ventilation heat transfer coefficient;
$H_V = p\ .\ c.\ q$ (W/K) (Eq. 17)

The heat capacity of air per volume (*p.c*) is taken as 0.33 W.h/(m^3.K), as determined in the BEP Regulation; the airflow rate (*q*) depends on the air change rate (*n*) and the volume of the zone considered (*V*), and is calculated using Eq. 18. The air change rate (*n*) of the zone is determined according to the air-tightness of the building envelope, which is obtained from the BEP Regulation.

Air flow rate:
$q = V\ .\ n$ (m^3/h) (Eq. 18)

3.5.3 Heat Flow Rate from Internal Heat Sources

In order to calculate the time-average heat flow rate from internal heat sources in a building, the BEP Regulation combines data from the TS EN ISO 13790 standard and the ASHRAE Handbook (2001). According to the BEP Regulation, the time-average heat flow rate from internal heat sources (Φ_{int}) includes heat from the living room and kitchen ($\Phi_{int,sen,M}$) and other spaces ($\Phi_{int,sen,D}$), metabolic heat from the occupants ($\Phi_{int,Oc}$), and dissipated heat from appliances ($\Phi_{int,App}$), hot water use ($\Phi_{int,W}$) and lighting devices ($\Phi_{int,lg}$), and is expressed in watts and calculated as shown in Eq. 19 below. Internal heat gains are calculated as sensible and lateral heat gains, for which the formulas are presented in Table 3.4.

Internal gains:

$$\Phi_{int} = \Phi_{int,sen,D} + \Phi_{int,sen,M} + \Phi_{int,App,lat} + \Phi_{int,Occ,lat} + \Phi_{int,W} + \Phi_{int,lg} \quad \text{(W) (Eq. 19)}$$

Table 3.4 Formulas for Calculating Time-Average Heat Flow Rate from Internal Heat Sources (BEP Regulation, 2010)

Sensible heat gains from occupants and living spaces	$\Phi_{int,sen} = \Phi_{int,sen,M} + \Phi_{int,sen,D}$ with $\Phi_{int,sen,M} = A_{f,M} . \Phi_{int,sen,M,unit}$ $\Phi_{int,sen,D} = A_{f,D} . \Phi_{int,sen,D,unit}$ $A_f = A_{f,D} + A_{f,M}$
Lateral heat gains from appliances	$\Phi_{int,App,lat} = \Phi_{int,App,lat,M} + \Phi_{int,App,lat,D}$ with $\Phi_{int,App,lat,M,unit} = (\Phi_{int,App,sen,M,unit} / 0,77) - \Phi_{int,App,sen,M,unit}$ $\Phi_{int,App,lat,M} = A_{f,M} . \Phi_{int,App,lat,M,unit}$ $\Phi_{int,App,lat,D,unit} = (\Phi_{int,App,sen,D,unit} / 0,77) - \Phi_{int,App,sen,D,unit}$ $\Phi_{int,App,lat,M} = A_{f,D} . \Phi_{int,App,lat,D,unit}$
Metabolic gains from occupants	$\Phi_{int,Oc,sen,unit} = 75$ (W/person) $\Phi_{int,Oc,lat,unit} = 55$ (W/person)
Heat gains from DHW use	$\Phi_{int,W} = 25 + (15 . N_p)$ Np: number of person
Heat gains from lighting devices	Use coefficients are taken from a list set in the national level (BEP Regulation, 2010, appendix II)

When internal heat gains are calculated according to the zone types defined in the BEP Regulation, the results are in the region of 10 W/m^2 for residential buildings. However, both international standards and TS 825[15] accept average internal heat gains as 5 W/m^2 for residential buildings and 10 W/m^2 for office buildings. Considering possible errors in the results due to high internal gains, EnAd provides five options to the user; three of which provide average options (5, 10 and 20 W/m^2); one of which is calculated according to the zone type, as described in the BEP Regulation; and one of which is defined by the user.
The time interval for internal gains can also be defined in EnAd.

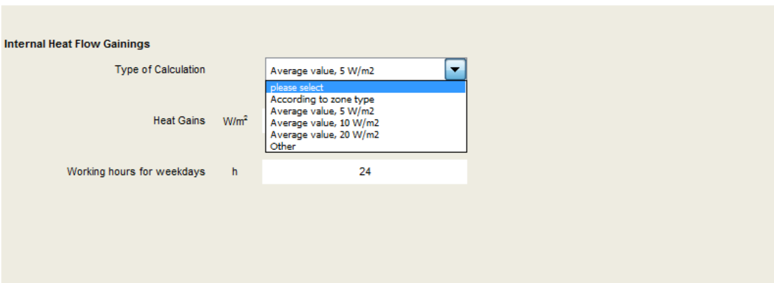


Figure 3.9 Definition of Internal Heat Gains in EnAd

[15] TS 825 Heat insulation requirements for buildings

3.5.4 Heat Flow Rate from a Solar Heat Source

The second type of heat gain comes from the solar source. According to TS EN ISO 13790, the heat flow rate of solar gains, $\Phi_{int,sol}$, is calculated in terms of the shading reduction factor for external obstacles ($F_{sh,ob}$), the effective surface solar collection area (A_{sol}), solar irradiance (I_{sol}), the form factor between the building element and the sky (F_r) and the extra heat flow due to thermal radiation to the sky from each building element (Φ_r). It is expressed in watts and is calculated using Eq. 20.

Solar gains:
$\Phi_{int,sol} = F_{sh,ob} \,.\, A_{sol} \,.\, I_{sol} - F_r \,.\, \Phi_r$ (W) (Eq. 20)

In EnAd, solar irradiance (I_{sol}) values are taken from TS 825. The form factor between the building elements and the sky (F_r) is accepted as 1 for horizontal building elements, and 0.5 for vertical elements, as indicated in the BEP Regulation. Extra heat flow due to thermal radiation to the sky from a building element (Φ_r) is calculated in terms of external surface resistance (R_{se}); thermal transmittance (U_{op}) and area of the opaque building element (A_{op}); the external radiative heat transfer coefficient (h_r); and the average difference between the external air temperature and the apparent sky temperature ($\Delta\theta_{er}$). Here, $\Delta\theta_{er}$ is accepted as 11 for Turkey while h_r is taken from the opaque material list provided in the BEP Regulation.

Extra heat flow due to thermal radiation to the sky:
$\Phi_r = R_{se} \,.\, U_{op} \,.\, A_{op} \,.\, h_r \,.\, \Delta\theta_{er}$ (W) (Eq. 21)

In order to evaluate solar gains, it is required to define the effective collecting areas (A_{sol}) for both the opaque and transparent/glazed elements in a building. As provided in TS EN ISO 13790, the effective collection area for opaque surfaces ($A_{sol,op}$) is calculated in terms of the direct solar absorbance of external surfaces ($\alpha_{sol,em}$), the external surface resistance (R_{se}) and thermal transmittance (U_{op}), and the area of each opaque building element (A_{op}). The effective collection area for glazed elements ($A_{sol,gl}$) is calculated in terms of the shading reduction factor for movable shading provisions ($F_{sh,gl}$), the total solar energy transmittance of the transparent part of the element (g_{gl}), the window area (A_{win}) and the frame area fraction (F_F).

Effective solar collection area:

Total area	$A_{sol} = A_{sol,op} + A_{sol,gl}$	(m^2)	(Eq. 22)
Opaque surfaces	$A_{sol,op} = \alpha_{sol,em} \,.\, R_{se} \,.\, U_{op} \,.\, A_{op}$	(m^2)	(Eq. 23)
Transparent surfaces	$A_{sol,gl} = F_{sh,gl} \,.\, g_{gl} \,.\, A_{win} \,.\, (1 - F_F)$	(m^2)	(Eq. 24)

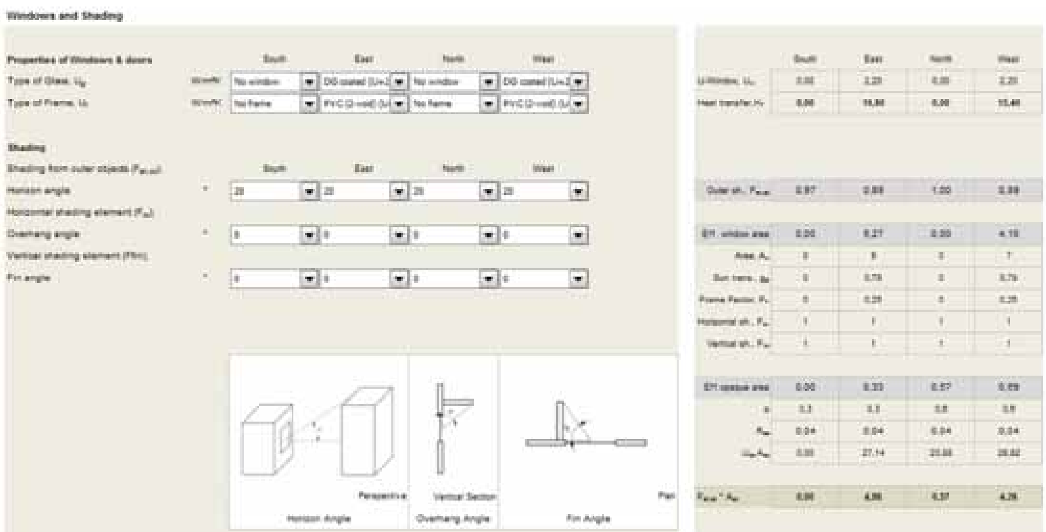


Figure 3.10 Window Properties and Shading Options on EnAd

3.6 Utilization Factors

In the monthly calculation method, heat losses and gains can be calculated in a very systematic way; however utilization factors have very crucial roles in the evaluation of energy requirements for the heating and cooling of a building. Gain utilization factors both for heating and cooling are calculated according to TS EN ISO 13790. The dimensionless gain utilization factor for heating (η_{Hgn}) is calculated from the gain-loss ratio (γ_H) and building inertia (α_H); and similarly, the dimensionless loss utilization factor for cooling ($\eta_{C,ls}$) is determined from the gain-loss ratio (γ_C) and building inertia (α_C). Building inertia (α_H) is calculated in terms of the numerical parameter (α) and the reference time constant (τ). In the monthly calculation method, the numerical parameter ($\alpha_{H,0}$ and $\alpha_{C,0}$) and reference time constant ($\tau_{H,0}$ and $\tau_{C,0}$) both for the heating and cooling modes are accepted as 1 and 15 respectively. The required formulas are presented below.

The dimensionless gain utilization factor for heating:

if $\gamma_H > 0$ and $\gamma_H \neq 1$ $$\eta_{Hgn} = \frac{1-\gamma_H^{\alpha H}}{1-\gamma_H^{\alpha H+1}} \quad \text{(Eq. 25)}$$

if $\gamma_H = 1$ $$\eta_{Hgn} = \frac{\alpha_H}{\alpha_H+1} \quad \text{(Eq. 26)}$$

if $\gamma_H < 0$ $$\eta_{Hgn} = \frac{1}{\gamma_H} \quad \text{(Eq. 27)}$$

with $$\gamma_H = \frac{Q_{H,gn}}{Q_{H,ht}} \quad \text{(Eq. 28)}$$

$$\alpha_H = \alpha_{H,0} + \frac{\tau}{\tau_{H,0}} \quad \text{(Eq. 29)}$$

The dimensionless gain utilization factor for cooling:

if $\gamma_C > 0$ and $\gamma_C \neq 1$ $$\eta_{C,ls} = \frac{1-\gamma_C^{-\alpha C}}{1-\gamma_C^{-(\alpha C+1)}} \quad \text{(Eq. 30)}$$

if $\gamma_C = 1$ $$\eta_{C,ls} = \frac{\alpha_C}{\alpha_C+1} \quad \text{(Eq. 31)}$$

if $\gamma_C < 0$ $$\eta_{C,ls} = 1 \quad \text{(Eq. 32)}$$

with $$\gamma_C = \frac{Q_{C,gn}}{Q_{C,ht}} \quad \text{(Eq. 33)}$$

$$\alpha_C = \alpha_{C,0} + \frac{\tau}{\tau_{C,0}} \quad \text{(Eq. 34)}$$

The time constant of the building or the building zone (τ) determines the internal thermal inertia of the conditioned building/zone. It is calculated both for the heating and cooling periods, and is expressed in hours.

Time constant: $$\tau = \frac{C_m/3600}{H_{tr,adj}+H_{ve,adj}} \quad \text{(Eq. 35)}$$

The internal heat capacity of the building (C_m) plays an important role in the determination of the time constant, and thus gain-loss utilization factors. The internal heat capacity is determined according to the construction type of the building and/or the properties of the materials used. The BEP Regulation accepts three types of construction, which are light construction (110,000 J/K), medium construction (165,000 J/K) and heavy construction (260,000 J/K). If the specific heat capacity is known for each material used, the internal heat capacity can be calculated according to TS EN ISO 13786[16]. EnAd offers these three types of construction as defaults while providing a manual calculation option according to ISO 13786 (Figure 3.8).

3.7 Energy Requirement for Domestic Hot Water (DHW) Supply

The energy requirement for domestic hot water (DHW) supply can be determined depending on the density (p) and specific heat capacity (c) of the water, the volume of water used (V_w), the average used water temperature ($\theta_{w,m}$) and the average monthly city water temperature (θ_k). The energy requirement for DHW is calculated using the formula given in Eq. 36, and expressed in kWh. The BEP Regulation defines daily DHW use as 45 liters for each person for multi-family houses, while this value is taken as 60 liters for each person for single-family houses. The regulation also accepts use water temperature as 50°C and supply (city) water temperature as 10°C. EnAd takes these values as defaults in the average calculations. For detailed calculations, the tool takes a monthly average of the city water temperatures from the study of Altuntop (2005) for each city. The tool provides two further options for DHW use, being kWh per person and per unit.

Energy requirement for DHW supply:

$Q_{w,b} = p \cdot c \cdot V_w \cdot (\theta_{w,m} - \theta_k)$ (kWh) (Eq. 36)

Figure 3.11 DHW Supply Options on EnAd

3.8 Energy Need for Artificial Lighting

Although the annual energy requirement for artificial lighting (W_{year}) is left optional for the BEP certification of residential buildings, EnAd includes lighting in its energy performance evaluations. According to the BEP Regulation, this can simply be calculated as the total energy requirement for artificial lighting on weekdays (P_{hi}) and weekends (P_{hs}). The hourly total energy load of the lighting system (P_{total}) is calculated by considering the power (P) and number (n) of each device.

Annual energy requirement for artificial lighting:

$W_{year} = [\,(52*5*P_{hi})+((52*2+1)*P_{hs})\,]/1000$ (kWh/year) (Eq. 37)

for weekdays:

$P_{hi} = P_{total} * 8{,}095$ (W) (Eq. 38)

for weekends:

$P_{hs} = P_{total} * 8{,}355$ (W) (Eq. 39)

hourly total energy load:

$P_{total} = P_1.n_1 + P_2.n_2 + \ldots + P_n.n_n$ (W) (Eq. 40)

[16] TS EN ISO 13786 Thermal performance of building components - Dynamic thermal characteristics - Calculation methods

Figure 3.12 Introduction of Artificial Lighting on EnAd

3.9 Conversion Coefficients for Different Energy Types

In general, after calculating the annual energy requirement of a building for space heating, space cooling, DHW and lighting, the results should be converted into energy consumption and primary energy requirement. The conversion of energy requirement to energy consumption is determined according to the efficiency of the (mechanical) system used in a building. The primary energy requirement is found from national data relating to the delivered and exported energy. Finally, CO_2 emissions are determined according to primary energy values. Since primary energy and CO_2 emissions are related to the ratio of delivered and exported energy, which are different for each energy carrier, they differ from country to country.

In EnAd, firstly, the annual energy requirement for the four energy parameters is determined according to the BEP Regulation and related standards, and these figures are then converted into energy consumption, after which the primary energy requirement and CO_2 emission values are calculated. National data regarding the conversion coefficients for primary energy is determined by the Ministry of Public Works and Settlement of Turkey using data supplied by the Turkish Statistical Institute (TUIK); while the CO_2 production coefficients are obtained from Turkish BEP Regulation.

The coefficient of performance, which is used to transform energy requirement into energy consumption data, is directly related with the type of (mechanical) system used in a building. For seasonal energy efficiency factors of several boilers, the BEP Regulation has adopted the UK's Standard Assessment Procedure (SAP) for the Energy Rating of Dwellings. SAP has for the first time determined the energy efficiency rates of all kinds of gas and oil boilers used for space heating and domestic hot water (DHW) systems to be used in energy performance evaluations. The seasonal energy efficiencies of gas and oil boilers used for space heating and DHW systems are obtained from SAP and used in EnAd. For space cooling, seasonal energy efficiency values of air conditioners determined in Directive 2010/30/EU[17] are used in EnAd.

3.10 Energy Performance Classes

The EPBD requires new and existing buildings to be labeled according to their energy requirements or consumption levels, similar to the energy classes of many types of white goods. This classification has seven levels, from A to G, with A representing the best performance class, and G the worst.

[17] Directive 2010/30/EU of the European Parliament and of the Council with regard to energy labeling of air conditioners

The energy performance class of a building is determined according to its annual primary energy consumption, while its carbon emission performance class is based on the type of energy used to power the mechanical systems in the building. TS EN 15217 requires the normalization of the energy rating of a building, which is the annual primary energy requirement for the entire building. The overall indicator 'EP' is the rating divided by the conditioned area (A_C). In short, the performance class of a building can be determined from its energy performance.

The energy performance of a building is found by comparing the annual primary energy consumption of an original and reference building, as represented in Eq. 3.41 as follows. 'EP' stands for energy performance, while subscript 'o' denotes the original building and 'r' the reference building.

$EP_{EP} = 100\ (EP_o / EP_r)$ (Eq. 41)

In a similar way, the carbon emission performance of a building ($E_{p,SEG}$) is calculated from a comparison of the carbon emissions of the original (SEG_o) and reference (SEG_r) buildings.

$EP_{SEG} = 100\ (SEG_o / SEG_r)$ (Eq. 42)

The energy classes of a building in terms of its energy and carbon emissions are determined by comparing the overall energy performance indicator of the building with the reference indicator (RG). Reference indicators are determined at a national level according to building type. The energy class and reference indicators determined by the BEP Regulation are as follows:

Table 3.5 Energy Classes According to Primary Energy Requirement

Energy class	Energy performance according to primary energy requirement (kWh/m^{2}a)
Class A	EP < 0,4*RG
Class B	0,4*RG ≤ EP <0,8*RG
Class C	0,8*RG ≤ EP < RG
Class D	RG ≤ EP < 1,20*RG
Class E	1,20*RG ≤ EP < 1,40*RG
Class F	1,40*RG ≤ EP < 1,75*RG
Class G	1,75*RG ≤ EP

Source: BEP Regulation, 2008; Appendix 5a.

Table 3.6 Reference Indicators According to Primary Energy Requirement

	Reference Indicator (RG) (kWh/m^{2}a)			
Building type	1st HDDR*	2nd HDDR	3rd HDDR	4th HDDR
Single- or twin-family houses	165	240	285	420
Apartment blocks	180	255	300	435

*HDDR: Heating degree-day region
Source: BEP Regulation, 2008; Appendix 4a.

Table 3.7 Carbon Emission Classes According to end Consumption

Energy class	SEG according to end consumption (kg. eq. CO_2/m^2a)
Class A	If SEG < 0.4*SRG
Class B	If 0.4*SRG ≤ SEG <0.8*SRG
Class C	If 0.8*SRG ≤ SEG < SRG
Class D	If SRG ≤ SEG < 1.20*SRG
Class E	If 1.20*SRG ≤ SEG < 1.40*SRG
Class F	If 1.40*SRG ≤ SEG < 1.75*SRG
Class G	If 1.75*SRG ≤ SEG

Source: BEP Regulation, 2008; Appendix 5b.

Table 3.8 Reference Indicators for Carbon Emissions

	Reference Indicator (RG) (kg. eq. CO_2/m^2a)			
Building type	1st HDDR*	2nd HDDR	3rd HDDR	4th HDDR
Single- or twin-family houses	28	40	47	70
Apartment blocks	30	43	50	73

Source: BEP Regulation, 2008; Appendix 4b.

Once the energy classes of a building for energy and carbon emissions have been determined, the final step is to present the results on a performance diagram for the building energy certificate.

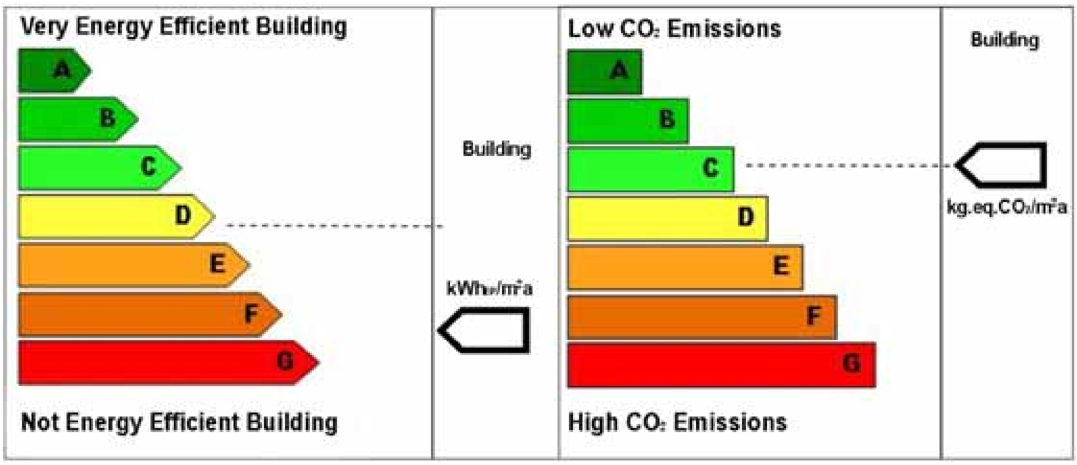
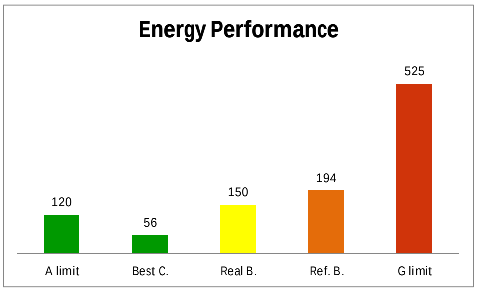


Figure 3.13 Presentation of Building Performances on a Building Energy Certificate (BEP Regulation, 2008)

Energy Performance Class of the Building

		Real Building	RG	Energy Performance Class
Energy Performance	kWh/m² year	150	300	B
GHG emission	kg eq. CO_2/m^2 year	51	50	D



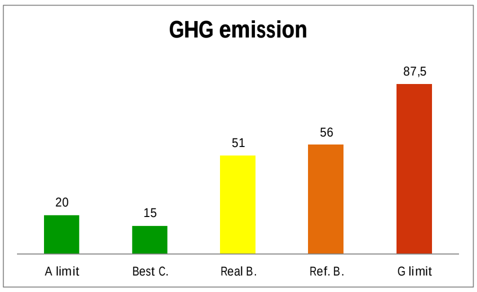


Figure 3.14 Presentation of Energy Performance Class of a Building in EnAd

It is possible to create the formulation database of EnAd, as shown in Table 3.9. This database has enabled the structure of EnAd to be created in a very systematic manner, and presents the design decisions, the related legislations to be covered, the necessary formulas and the design goals and/or constraints. Such a database also enables the determination of the missing or contradictory parts in the legislation, which are explained in the following section.

Table 3.9 Formulation Database of EnAd

	Design Decisions	Directives, Standards, Law and Regulations	Norms and conditions (Values, Formulas & material properties)	Design Goals/ Constraints
Umbrella documents		2002/91/EC EPBD 2006/32/EC Energy efficiency CEN CEN/TR 15615 ISO 16818 ISO 23045 prEN 15315 prEN 15203 prEN 15603 prEN 15429 TS EN 15459 TS EN 15217 * 5627 Energy efficiency law * BEP Regulation * Regulation on energy sources and energy use efficiency enhancement * Environmental impact assessment regulation		
Macro decisions	City Heating Degree-Day Region (HDDR) Cooling Degree-Day Region Wind potential Solar radiation Neighborhood Orientation Functional use of building Dwelling type	 TS 825 HDDR map No legislation Wind map TS 825 Solar radiation map TS EN ISO 15927-1 TS EN ISO 15927-4 TS EN ISO 15927-6	Need for ease of use Need for updates	
Design decisions	Building size and dimensions Conditioned area Conditioned volume Building shape factor Compactness ratio Window/Wall ratio	TS EN 15217 EN ISO 13789 EN ISO 13790 TS 825 TS EN 832	A_C V_C $f=A_E/A_C$; $EP_r=EP_0(a+b.f)$ $c = A_E/V_C$ A_w/A_E	$A_w/A_E< 0.60$; else $U_w \leq 2.1$ W/m^{2}K (for all HDDR) $U_W< 0.75U_W$, $U_r< 0.75U_r$, $U_g<0.75U_g$ (TS 825)
Transmission and ventilation heat transfer coefficients	Heat losing External wall (plaster+wall+insulation+coating)	89/106/EC EN ISO 10456 EN ISO 13789 TS EN 12524 TS 825 TS EN 832 TS EN ISO 13786 TS EN 13947 TS EN ISO 13788 Construction Products Regulation	$H= H_T + H_V$ $H_T = H_D + H_g + H_U + H_A$ Mat.Prop. & $H_D = A_W.U_W$	$U_W \leq 0.50$ W/m^{2}K (3rd HDDR)
	Cantilever floor/ceiling	BEP Regulation		No performance criteria
	Windows	TS EN ISO 10077-1 TS EN ISO 10077-2 ISO 15099 TS 825 TS EN 12207 TS EN ISO 14438	Mat.Prop. & $H_D = A_w.U_w$	$U_w \leq 0.24$ W/m^{2}K (3rd HDDR)
	Ceiling & roof Flat roof Conditioned inclined roof Unconditioned inclined roof	ISO 7345 ISO 7726 ISO 9869 EN ISO 10211 EN ISO 10456 EN ISO 13370 EN ISO 13789 EN ISO 13792 EN ISO 14683 TS 825 TS EN 832 TS EN 12524 TS EN ISO 6946	Mat.Prop. & $H_D = A_r.U_r$ Mat.Prop. & $H_U= A_r.U_r$; $U=\lambda/[(0,457*B')+dt]$ (ISO 13789)	$U_r \leq 0.30$ W/m^{2}K (3rd HDDR)
	Ground floor or Basement floor contacting with earth	ISO 7345 ISO 7726 ISO 9869 EN ISO 10211 EN ISO 10456 EN ISO 13370 EN ISO 13789 EN ISO 13792 EN ISO 14683 TS 825 TS EN 832 TS EN 12524 TS EN ISO 6946	Mat.Prop. & $H_g=0.5.A_g.U_g$; $U=1/(Re+d/\lambda+Ri)$ (TS 825) $H_g=A_g.U_g$; $U=\lambda/[(0,457*B')+dt]$ (ISO 13789)	$U_g \leq 0.45$ W/m^{2}K (3rd HDDR)
	Basement Conditioned Unconditioned No basement	ISO 7345 ISO 7726 ISO 9869 EN ISO 10211 EN ISO 10456 EN ISO 13370 EN ISO 13789 EN ISO 13792 EN ISO 14683 TS 825 TS EN 832 TS EN 12524 TS EN ISO 6946	Mat.Prop. & $H_g=0,5\ A_b.U_b$; $U=1/(Re+R+Ri)$ (TS 825) $H_g=A_b.U_b$; $U=\lambda/[(0,457*B')+dt]$ (ISO 13789) $U_b \leq 0,45$ W/m^{2}K (TS 825)	$U_g \leq 0.45$ W/m^{2}K (3rd HDDR)
	Walls contacting with earth	No legislation		No performance criteria
	To adjacent buildings (if there is a temperature difference between two buildings)	EN ISO 13789 TS 825 TS EN 832	Mat.Prop. & $H_U=H_{iu}(H_{ue}/(H_{iu}+ H_{ue})$ $H_A = b.H_{ia}$; $b = (\theta_i-\theta_a)/(\theta_i-\theta_e)$	$U_U \leq 0.45$ W/m^{2}K (3rd HDDR)
	Ventilation	EN ISO 13789 TS 825 TS 3419 TS 5895 TS CR 1752 TS EN 832 TS EN 13141-6 TS EN 13142 TS EN 15243	$H_V = \rho.c.n.h.V$	No performance criteria
Heat gaining	Heat gaining Solar gaining (transparent surfaces) Interior gaining (users & equipment)	EN ISO 13789 TS 825 TS EN 832 Contradicting TS 825 EN ISO 13791	$\varphi_s = \sum I.\ \sum A$, $A=A.g.F_s$ (TS 825) $A=A.g.F_s.F_f.F_c$ (TS EN 832) $As =\alpha_{S,c}.R_{se}.U_c.A_c$ (ISO 13790) $\varphi_i = A_n.5(W)$	No performance criteria No performance criteria
Energy related decisions	Energy requirement for Heating	TS EN ISO 13790 TS 825 TS EN 832 TS EN 14336 TS EN 14337 TS EN 15265 TS EN 15316-1 TS EN 15316-2-1 TS EN 15316-4-5 TS EN 15377-3 TS EN 15450	$Q = \Sigma Qm$ [kJ/year, kWh, year] $Q_m = [H(\theta_i-\theta_e) - \eta(\varphi_i+\varphi_s)].t$ [kWh, m] $Q = Q_H /A_n$ [kWh/m^2, year]	Q_H, kWh/m^2, year
	Hot water	BEP Regulation	$Q_W=4.182.V_{W,day} (\theta_{W,del}-\theta_{W,0})$ [MJ/day] $Q_W= Q_{W,A,day}.A$ [MJ/m^2]	Q_W, MJ/m^2, kWh/m^2, year
	Cooling	TS ETS EN 15316-3-1 TS EN 15316-3-2 TS EN 15316-3-3 TS EN 15316-4-3 TS EN 15316-4-4N 15255 TS EN 15265 EN ISO 13790	$Q_{C,nd} = Q_{C,nd,cont} = Q_{C,gn} - \eta_{C,ls}.Q_{C,ht}$ [MJ]	Q_C, MJ => 1/ m^2, year kWh/m^2, year
	Lighting and appliances	TS EN 15193 TS EN 15251	$W = WL + WP$ [kWh/year] $LENI = W/A$ [kWh/(m^2 × year)]	Q_L, kWh/m^2, year
Energy Performance	Primary Energy Consumption Energy Performance Class	TS EN 15217 BEP Regulation	$EP= Q_H + Q_W + Q_C + Q_L$ (kWh/m^2, year)	Rr (*RG*) = 285 kWh/m^2,year (single family house, row house) Rr (*RG*) = 300 kWh/m^2,year (apartment block) (3rd HDDR)
GHG Emission	Greenhouse gas emission according to primary energy consumption and fuel type selected	BEP Regulation		*R*r = 47 (kgCO_2/m^2,year (single family house, row house) *R*r = 50 kWh/m^2,year (apartment block) (3rd HDDR)

3.11 Inconsistencies in Legislation

In order to conduct a consistent energy performance evaluation for buildings, the measurability of the design decisions affecting energy performance is of paramount importance. The performance goals, as well as the design constraints for each decision have also crucial role in guiding the designer in making proper design decisions. The formulation database of EnAd contains a feedback system for the diagnosis of design decisions affecting energy performance in relation to the related legislations to be covered, as well as the necessary formulas and design goals and/or constraints determined in these legislations. The database also facilitates the diagnosis of missing, overlapping or contradictory parts in the Turkish legislation, as well as its contradictions with international legislation, and so it can be employed as a diagnostic tool for further explorations of energy use.

During the preparation of the formulation database, that is, the computational database of EnAd, several inconsistencies and problems were encountered. These included gaps in the databases, missing standards, missing parts in the standards and regulations, and inconsistencies between documents. These contradictions affected the development process of EnAd, and so TS EN ISO 13790 and the related standards were again consulted to determine the default values, while TS 825 and previously referenced research papers were applied to fill the missing parts in the database, which will be explained in Chapter 5.

For the climatic database, new legislation is needed to determine the cooling degree-day regions. Solar radiation data needs to be updated, while official data needs to be made available related to the wind potential of the site. The hourly and monthly average temperature values to be used in the evaluation of the energy performance of buildings are also required to be determined for each city, and on the other hand, a definition of the hourly, daily and/or monthly use patterns is of great importance in the evaluations. As stated in TS EN ISO 13790, a 5% uncertainty in the input data can result in a 30% discrepancy in the results. For instance, the use of high daily use patterns for DHW results in high consumption values, and accordingly high energy requirements in the results; and this is the case also in the calculation of internal heat gains.

Besides the gaps in the use patterns and the climatic database, the Turkish standards are also incomplete. Some of the international standards relating to the BEP evaluation have not been accepted by the TSE, while most of those that have been accepted have not been adapted to Turkish conditions. Besides the use patterns, some assumptions and coefficients in the formulas need to be modified to comply with the use and/or consumption profiles of the country. This subject will be discussed in detail in the following sections (convergence tests). In addition to the missing standards in Turkey, new legislation is needed for the evaluation of cavity walls in terms of energy performance, both at an international and national level.

Although most of the design decisions can be evaluated according to the current legislations, further elaboration of the legislations is needed to include performance criteria for natural ventilation, mechanical ventilation, energy-producing components and similar services. Certain limit values when evaluating the thermal envelope of a building also need to be asserted by in legislation, including thermal conductivity limits for walls in contacting with the ground, cantilever floors, and walls and other building components that are adjacent to unconditioned zones. The utilization of certain limit values for the thermal envelope is also required to be indicated clearly, showing which value is to be used for which building component. For instance, the limit U-value for roofs is defined as 0.30 W/m^2K (for 3rd HDDR); however it is not clear whether this value is valid for the ceiling or the inclined surface of the unconditioned roof, or both.

There are also some overlaps and contradictions between Turkish and international legislation. For instance, many ISO and CEN standards have been accepted as they are, or directly translated from the original texts into Turkish. Although they are significant documents for the evaluation of the energy performance of buildings, they do not include performance criteria for Turkey. This causes complications in practice, since they have not been adapted to the specific conditions in the country.

Furthermore, TS 825 and TS EN 832, which are previously accepted standards explaining the calculation steps for the energy requirements for space heating, as well as heat loss and heat gains, have inconsistencies with each other and with the new ISO standards in terms of the coefficients and assumptions used in the calculations. Since they are still in use, and have not yet been amended, they can also cause confusion among users about the choice of coefficients and the assumptions to be used.

During the compilation of the formulas to be used in the energy performance evaluations, several differences were noted between the ISO standards and the Turkish BEP Regulation. In the regulation, some formulas are presented in a manner that may mislead/confuse the user in terms of the order the process steps are to be taken. Table 3.10 presents some examples of the indication differences between the ISO standards and the BEP Regulation.

Table 3.10 Some Examples of Indication Differences in the Documents

$(d_f + 0{,}5z) < B'$ $U_{bf} = (2\lambda_g / (\pi B' + d_f))\ \ln (\pi B' / (d_f + 0{,}5z) + 1)$ $(d_f + 0{,}5z) > B'$ $U_{bf} = \lambda_g / (0{,}457 B' + d_f + 0{,}5z)$ BEP Regulation, net energy appendix, p. 35	If $(d_t + 0{,}5z) < B'$ (uninsulated and moderately insulated basement floors), $U_{bf} = \frac{2\lambda}{\pi B' + d_t + 0{,}5z} \ln\left(\frac{\pi B'}{d_t + 0{,}5z} + 1\right)$ If $(d_t + 0{,}5z) \geqslant B'$ (well-insulated basement floors), $U_{bf} = \frac{\lambda}{0{,}457 B' + d_t + 0{,}5z}$ ISO 13370, 2008, p.11
$d_w > d_f$ $U_{bw} = 2\lambda / (\pi z) (1 + 0{,}5\, d_f / (d_f + z))\ \ln (z / d_f + 1)$ $d_w < d_f$ $U_{bw} = 2\lambda / (\pi z) (1 + 0{,}5\, d_w / (d_w + z))\ \ln (z / d_w + 1)$ BEP Regulation, net energy appendix, p. 33	$U_{bw} = \frac{2\lambda}{\pi z}\left(1 + \frac{0{,}5 d_t}{d_t + z}\right) \ln\left(\frac{z}{d_w} + 1\right)$ ISO 13370, 2008, p.13

In the Turkish standards and the BEP Regulation, some of the symbols and subscripts are in English, while others are in Turkish. This causes confusion in the use of the regulations and standards. For example, in the calculation of internal heat gains, subscript ‘f’ denotes ‘floor’ while subscript ‘M’ denotes *‘Mutfak’* (Kitchen) and ‘D’ denotes *‘Diğer’* (Other) in Turkish. Similarly, in the lighting appendix of the BEP Regulation, both English and Turkish symbols and subscripts are used at the same time. Furthermore, English symbols and subscripts are used in heat loss and gain calculations, while the limit values for the reference building are given in Turkish. Some examples of the use of different symbols and subscripts in the documents are provided in Table 3.11.

Table 3.11 Some Examples of the Use of Different Symbols and Subscripts in the Documents

<table>
<tr><th>Formula in the documents</th><th>Explanation of symbols and subscripts</th></tr>
<tr><td>$A_{f} = A_{f,D} + A_{f,M}$

BEP Regulation, net energy appendix, p. 45</td><td>A : Area
f : floor
M : ‘Mutfak’ (Kitchen) in Turkish
D : ‘Diğer’ (Other) in Turkish
A_f : total floor area
$A_{f,M}$: area of kitchen and saloon
$A_{f,D}$: other areas except from kitchen and saloon</td></tr>
<tr><td>$W_{YIL} = (52 \times 5 \times P_{Hİ}) + ((52 \times 2 + 1)) \times P_{HS}$ (kWh)

BEP Regulation, lighting appendix, p. 11</td><td>W : Annual lighting energy
P : Lighting power
‘YIL’ : Year
‘Hİ’ : ‘Haftaiçi’ (Weekdays) in Turkish
‘HS’ : ‘Haftasonu’ (Weekends) in Turkish</td></tr>
<tr><td>$P_{em} = \Sigma P_{ei}$ (W)

BEP Regulation, lighting appendix, p. 6</td><td>P : Lighting power
em : emergency</td></tr>
<tr><td>$AESG = W / A$ (kWh/m^2 x yıl)
BEP Regulation, lighting appendix, p. 9</td><td>AESG: ‘Aydınlatma Enerjisi Sayısal Göstergesi’ (Lighting energy numeric indicator) in Turkish</td></tr>
<tr><td>$H_{tr,win} = A_{win} \cdot U_{win}$
BEP Regulation, net energy appendix, p. 25</td><td>$H_{tr,win}$: Heat transfer by Windows
A_{win} : Area of Windows
U_{win} : U-value of windows</td></tr>
<tr><td>Tablo 4: İllere göre maksimum U değerleri
<table>
<tr><th></th><th>U_D*</th><th>U_T*</th><th>U_t*</th><th>U_P*</th><th>g_gl*</th></tr>
<tr><td colspan="6">1. Bölge</td></tr>
<tr><td>Adana</td><td rowspan="10">0,7</td><td rowspan="10">0,45</td><td rowspan="10">0,7</td><td rowspan="10">2,4</td><td rowspan="10">0,75</td></tr>
<tr><td>Antalya</td></tr>
<tr><td>Aydın</td></tr>
<tr><td>Hatay</td></tr>
<tr><td>İçel</td></tr>
<tr><td>İzmir</td></tr>
<tr><td>Osmaniye</td></tr>
<tr><td>Ayvalık (Balıkesir)</td></tr>
<tr><td>Bodrum (Muğla)</td></tr>
<tr><td>Dalaman (Muğla)</td></tr>
</table>

BEP Regulation, reference building appendix, p. 9</td><td>Symbol;
U : U-value
Subscripts;
D : ‘Duvar’ (Wall) in Turkish
T : ‘Tavan’ (Ceiling) in Turkish
t : ‘taban’ (ground floor) in Turkish
P : ‘Pencere’ (Window) in Turkish
gl : Glazing</td></tr>
</table>

CHAPTER 4

MATERIALS AND METHODOLOGY

This chapter presents the materials used and the methodology followed in this thesis. First, a literature review on the subject was carried out in order to define the research problem. The intention is to point out the role of environmental sustainability, energy performance assessments and energy-related legislation in the architectural design process. The research studies have permitted a determination of the factors affecting the energy performance of buildings; while a thorough investigation and comparison of legislation has helped to identify the energy performance goals, requirements and limit values for buildings. For the evaluation of energy performance the study focused on building energy performance assessment methods and tools. This revealed a need to develop an energy performance evaluation tool that is flexible and easy to use, while guiding the designer in decision making processes considering the objectives and constraints of the current legislation.

In the course of the study a soft tool with the name building Energy performance Advisor (EnAd) was developed for the evaluation of the energy performance of buildings based on data sheets, and several macros are written in Visual Basic. Usability tests were conducted to test the flexibility and ease of use of the tool, after which several case studies were conducted to evaluate the accuracy and reliability of EnAd. For comparative studies, three different BEP evaluation tools were selected: DesignBuilder, which is a comprehensive simulation tool with embedded CAD modeling and a rich library; HAP, which is a text-based simulation tool used for the design of HVAC systems; and EnerCalc, which is a calculation tool based on German standards. These three programs, developed by different countries and using different methods of calculation, are internationally acknowledged for their accuracy. These three programs were assessed to gain an idea of their general features and capacities; after which a comparison was made of their structures, including their program modules, data sources and user interfaces, as well as program inputs and outputs. These comparisons revealed reasons for possible differences in results, as well as differences between the evaluation methods, assumptions, databases and data sets of each tool. The sample cases were then subjected to these programs. The first case is a reference case, comprising the evaluation of a single office room, which is a worked example in TS EN ISO 13790 (2008). This was followed by a generic case, being an apartment for a single family with a floor area of $100m^2$. Around 150 variations of this generic case were developed by changing one feature for each step to examine the effect of each parameter/assumption on the results. For the benchmarking study, five existing buildings were assessed by the tools. Finally, the use and potentials of EnAd were demonstrated through a simulation of the previously studied building. This dissertation focuses on these issues and the following materials and methods are presented.

4.1 Materials

The materials used in this study can be listed as follows:

i. A literature review, conducted at the Middle East Technical University (METU) library, the Karlsruhe Institute of Technology (KIT) library and the ULAKBIM[18] library, and their electronic resources including online books, scientific journals, conference papers, reports and other published materials on the subject.

[18] The Turkish Academic Network and Information Centre

ii. Research papers published in national and international refereed journals and conferences, including Building Research and Information, Energy and Buildings, Energy Policy, and IBPSA[19] Conference Proceedings.
iii. Printed and digital copies of Master and PhD theses on the subject, searched from the libraries and databases of the METU thesis center and e-theses database, the KIT thesis center and e-theses database, the YÖK[20] National thesis center online database, and the ProQuest dissertations and theses database.
iv. A survey of the relationship between sustainability, energy and performance assessment tools in architecture.
v. A survey on the role of legislation in the architectural design process.
vi. A survey on the legal framework regarding building energy performance, including EU Directives, international standards (ASHRAE, CEN, DIN and ISO), national standards (TS), laws, regulations and notices.
vii. A survey of building energy performance assessment methods and tools.
viii. A study of the computational background of EnAd with the help of building standards and regulations.
ix. A soft tool that can easily be integrated into early design phase of buildings.
x. A protocol for the usability test.
xi. The usability test with eleven participants.
xii. Three different building energy performance evaluation tools.
xiii. A reference case with worked example from TS EN ISO 13790.
xiv. Around 150 generic cases for convergence tests.
xv. Architectural projects and energy consumption data of five existing buildings for the benchmarking study.

4.2 Methodology

Starting in 2008, websites visited have been checked regularly for developments and updates in the subject. These websites are as follows:

i. For recent advances in the field of building energy performance assessment and certification issues, the official websites of the related institutions were visited during the study, including the Ministry of Environment and Urbanization (Çevre ve Şehircilik Bakanlığı)[21], the Ministry of Energy and Natural Resources (Enerji ve Tabi Kaynaklar Bakanlığı)[22], the General Directorate of Renewable Energy (Yenilenebilir Enerji Genel Müdürlüğü)[23] and the Turkish Statistical Institute (Turkiye İstatistik Kurumu, TÜİK)[24].
ii. For the official publications including the laws, regulations, notices, updates and other publications from past to the present, the *Resmi Gazete* (the Official Gazette of the Republic of Turkey) online database[25] was followed.
iii. The online standard database of the Turkish Standards Institution (Türk Standartları Enstitüsü, TSE)[26] was followed for recent advances in the Turkish standards.
iv. The IHS Standards Store website[27] for ISO standards, the Perinorm website[28] for DIN standards and the BSI website for British Standards[29] were also followed for developments related to building standards.
v. For developments in the European Union, the official website is the EU Law database (Eur-Lex)[30], which provides access to the Official Journal of the EU, EU

[19] The International Building Performance Simulation Association
[20] The Council of Higher Education
[21] http://www.csb.gov.tr/
[22] http://www.enerji.gov.tr/
[23] http://www.eie.gov.tr/
[24] http://www.tuik.gov.tr/
[25] http://www.resmigazete.gov.tr/
[26] http://www.tse.org.tr/
[27] http://global.ihs.com/
[28] http://www.redi-bw.de/
[29] http://www.bsigroup.com/
[30] http://eur-lex.europa.eu

laws, directives, international agreements, legislations, commission regulations, reports and other documents.

Besides the websites visited, this study followed the following procedure.

i. A literature survey was conducted to define the research problem, involving a review of scientific studies and updates on BEP assessment through legislation and evaluation tools.
ii. Preparation of the computational background of the EnAd, drawing upon information from research papers as well as the related legislations, including definitions, tables and necessary formulations.
iii. Development of the soft tool for building energy performance assessment.
iv. Preparation of a protocol for the usability test.
v. Application of the usability test protocol to test the ease of use, understandability and efficiency of the program.
vi. The selection of three different assessment tools for comparative studies.
vii. The development of generic cases for comparative studies.
viii. Convergence tests for the determination of accuracy and reliability of the program.
ix. Evaluation of five existing buildings for benchmarking.
x. Simulation of the design phase of the previously studied building.
xi. Discussion of the results of the study, and findings and its contribution to literature.
xii. Preparation of future remarks and feedback to different fields.

CHAPTER 5

PROPOSAL FOR A BUILDING ENERGY PERFORMANCE EVALUATION PROGRAM: DEVELOPMENT PROCESS

This chapter introduces the building energy performance evaluation program that has been developed within the scope of this thesis and given the name building Energy performance Advisor (EnAd). The chapter explains the need for energy performance evaluation tools, while presenting the scope, objectives and development process of EnAd. The background studies of EnAd are explained, including the determination of energy-related design decisions, the selection of legislation related to design decisions, and the extraction of performance goals and constraints from legislation. This is followed by an introduction to the program structure of EnAd, showing the dataflow. The inputs and outputs of the program are explained with the help of figures showing the program interface; and the results of the usability tests conducted to test the flexibility and ease of use of the tool is presented at the end of the chapter.

5.1 The Need for a Performance Evaluation Tool

There are several tools assessing different performances of buildings available on the market. Building performances such as thermal comfort, acoustics, energy etc. can be evaluated by several programs and BIM tools through complex 3D solid models, which can only be created towards the end of the design. However, the most crucial decisions affecting performance, such as the energy use of a building, are taken in the pre-design and design phases, including orientation, building envelope, window/wall ratio and material properties etc. In this respect, there is a need for evaluation tools that can be used from the very early phases of the design process.

In the scope of this thesis, it is proposed an assessment tool entitled building Energy performance Advisor (EnAd) be used throughout the design process for the evaluation of the energy performance of buildings. The tool is capable of computing the energy requirements of a building for heating, cooling, DHW and lighting, and assesses the building’s energy performance through evaluations while providing feedback to improve the design. To use this program, it is not necessary to complete the project, or even to have a project at all. Another significant feature of EnAd is that it features a flexible user-friendly interface that does not require any advanced expertise. The program also shows how architectural design should be evaluated according to current legislation.

In EnAd, the directives, standards, laws and regulations have been employed as constraints and objectives, and in this regard its purpose is two-fold: it can be used as a “guide” for energy-conscious design, endorsing all design decisions; and as a "diagnostic tool," determining inconsistencies/deficiencies in the legal framework. Hence, the tool can be considered not only as a design and evaluation interface, but also as a schema for performance-based design, having performance objectives and constraints derived from legislation. This research topic, which never before been studied, is expected to promote energy-based performance building design, and in this way contribute to the preservation of energy, limit the use of natural resources and thus help the environment towards a sustainable future.

5.2 Objectives of EnAd

The EnAd program has been designed to support the architect throughout the design process. One of the primary purposes for developing such a program is to raise the awareness of architects about the subject of energy efficiency, and to show them how their decisions affect the energy performance of buildings. EnAd is intended to motivate users to re-think the building design process, considering energy as the performance criterion. The main objective of the program is to orientate legislation efficiently and beneficially into the architectural design process. The other objectives for the program are as follows:

a) To operate as an evaluation tool for the assessment of the energy performance of buildings that can be used even in the early phases of the design process.
b) To fill the gap related to energy performance that exists between design and evaluation.
c) To help the designer determine the level of energy performance at any stage of the design process, which will be shown on the energy performance certificate of the building.
d) To be flexible and easy to use.
e) To be used recursively in the design of new buildings as well as in retrofitting practices.
f) To guide the designer towards achieving higher energy performances with the help of explanations related to design decisions and feedback, both on legislation and the design decisions made for each step, if possible.
g) To evaluate the energy requirements, energy consumption, primary energy need, and accordingly, CO_2 emissions of a building.
h) To help design buildings with high energy performance and low CO_2 emissions.
i) To assess the energy performance class and GHG emission class according to consumption data.

5.3 Development Process of the Tool

The motivation behind the development of EnAd grew out of the realization that there was a need for a performance assessment tool in the field of architecture that could be used from the earliest phases of design. The development process of EnAd followed many steps, listed below:

a) Design decisions and factors affecting energy use in buildings were determined.
b) The relationship between energy-related design decisions and legislation was questioned.
c) Related legislation was listed accordingly.
d) The conceptual structure of EnAd was developed to show how design decisions affect the energy performance of buildings.
e) A flowchart was developed to map the relationship between design decisions and related legislation.
f) Performance criteria and calculation steps were obtained from legislation for each design decision.
g) The mapping of the computational model of EnAd allowed the missing and contradicting parts in legislation to be determined.
h) The general structure of EnAd was formed based on the computational model.
i) The structure was transformed into code with the addition of the necessary data sources and libraries.
j) A usability test was conducted to test the usability of the tool.
k) In order to assess the validity, reliability and precision of EnAd, convergence tests were performed through several case studies.

These development steps are explained in detail in the following sections.

5.4 Data Structure of EnAd

Firstly, design decisions and factors affecting the energy performance of buildings were explored, defined by TS EN 15217[31] as the thermal characteristics of buildings, space heating, domestic hot water supply, air conditioning, ventilation, lighting, passive solar heat sources, solar protection and energy production (in particular, through renewable sources and co-generation). However, this standard disregards outside conditions such as region, location and climatic conditions. TS 825[32] defines the factors affecting the energy demand for the heating of a building as the thermal characteristics of the building, types of heating system, indoor air quality, climatic conditions, inner heat gain resources and solar radiation. Furthermore, previous research studies have highlighted other decisions and factors affecting the energy performance of buildings (Bilge, 2007; Civan, 2006; Gür, 2007; Özçuhadar, 2007; Özmehmet, 2005; Rassam, 2004; Zhai, 2003), which can be summarized as follows:

Design decisions	Factors
• orientation • building type • functional use • dwelling type • building form • spatial planning • properties of building thermal envelope	• climate • site conditions • solar gains • internal heat gains • heating system • cooling system • ventilation type • energy performance of HVAC equipment • lighting appliances

These decisions and factors are taken into consideration to produce an outline that will form the basis of the conceptual structure of EnAd, which suggests investigating them under four main headings:

- **Site-related characteristics: Location;** regarding regional characteristics and the climatic conditions of the site
- **Form-related decisions: Definition of the building form;** including orientation, size and dimensions of the building
- **Construction-related decisions: Properties of the building envelope;** regarding the properties of the materials and components used in buildings, while determining window properties and shade from external objects
- **Energy-related decisions: Building systems;** regarding the properties of the mechanical systems used for the heating, cooling, mechanical ventilation, DHW supply and lighting of buildings, natural ventilation and infiltration options, as well as energy producing systems and renewable energy systems.

A concept diagram showing how decisions are taken considering current legislation and the objectives of the project is presented in Figure 5.1. The program structure is based on these four decisions groups. The first group, which is related to the characteristics of the site, takes into consideration the regional characteristics and climatic conditions of the site, which are default situation and independent to any design decisions. Site-related characteristics such as city and region (rural-urban), and accordingly the heating and cooling degree-day region, the sun and wind potential of the region according to solar and wind maps, and the dwelling type (detached, semi-detached, terraced) are included under this heading.

The second group, which is related to form-related decisions, inquires the size and dimensions of the building. Decisions related to the ground and covering, that is, the types of basement and roof, are taken in this step. This group also examines the orientation of the

[31] TS EN 15217 Energy performance of buildings - Methods for expressing energy performance for the energy certification of buildings.
[32] TS 825 Thermal insulation requirements for buildings.

building (east, west, south, west), building size (low-, mid-, high-rise), thermal envelope area, conditioned area, conditioned volume and window area. Among the factors affecting the energy performance of buildings, however, the building form and spatial planning, cited by Özmehmet (2005), are excluded from the list since there is no constraint in legislation assessing these criteria aside from a recommendation in TS 825 (last revised in May 2008) that the design of a less thermal envelope area will reduce the energy loss of a building.

As seen in Figure 5.1, the third group relates to construction-related decisions, and aims to identify the thermal properties of the building envelope, including exterior walls, fenestration, the ground and basement floors and walls, cantilever floors, ceilings and roofs, which constitute the heat-losing surfaces in a building. This group also investigates how obstacles present in the building's surroundings affect the natural ventilation and solar gains of the building.

The fourth group deals with decisions affecting the energy performance of buildings, and relates to energy consuming and energy generating systems. This group includes mechanical systems used for space heating, mechanical cooling and domestic hot water (DHW) supply, and decisions about natural ventilation, mechanical ventilation, infiltration and artificial lighting. The group also deals with the energy requirements for cooking and circulation, as well as renewable energy and energy producing systems. Decisions taken in this step will help to determine the annual energy demand according to the installed consuming and generating systems determined in the previous steps.

The conceptual diagram (like the program itself) does not take into account the geological features of the site, such as the potential for erosion, sedimentation or earthquakes; the presence of swamps or rocky areas; the planning decisions of local authorities, such as those related to construction heights; and other case-specific decisions such as the availability of renewable energy resources, since this would require too much data to be uploaded into the diagram, and is subject to change. Moreover these factors are not related directly with the energy performance of buildings. Additionally, since passive energy systems depend on case-specific design decisions and outcomes, this diagram cannot respond the determination of the performance of this kind of building design. Finally, the diagram additionally does not take into account other building performance criteria, such as fire safety, earthquake resistance, and water, material and resource efficiency.

The second step of the development process of EnAd was to investigate the relationship between design decisions and factors affecting the energy requirement of buildings and legislation, which includes directives, standards, laws and regulations. To this end, the Turkish legislation regarding the energy performance of buildings was reviewed and grouped according to the design decisions. The flowchart of the program is presented in detail in Figure 5.2. Furthermore, Turkish legislation was compared with EU and ISO standards and German legislation, which has a proven consistency and reliability, and is presented on the flowchart in Figure 5.3. This comparative study helped to determine the incomplete or missing documents in Turkish legislation, which require further elaboration. A complete list of the directives, standards, laws and regulations included in the program is presented in Appendix A.

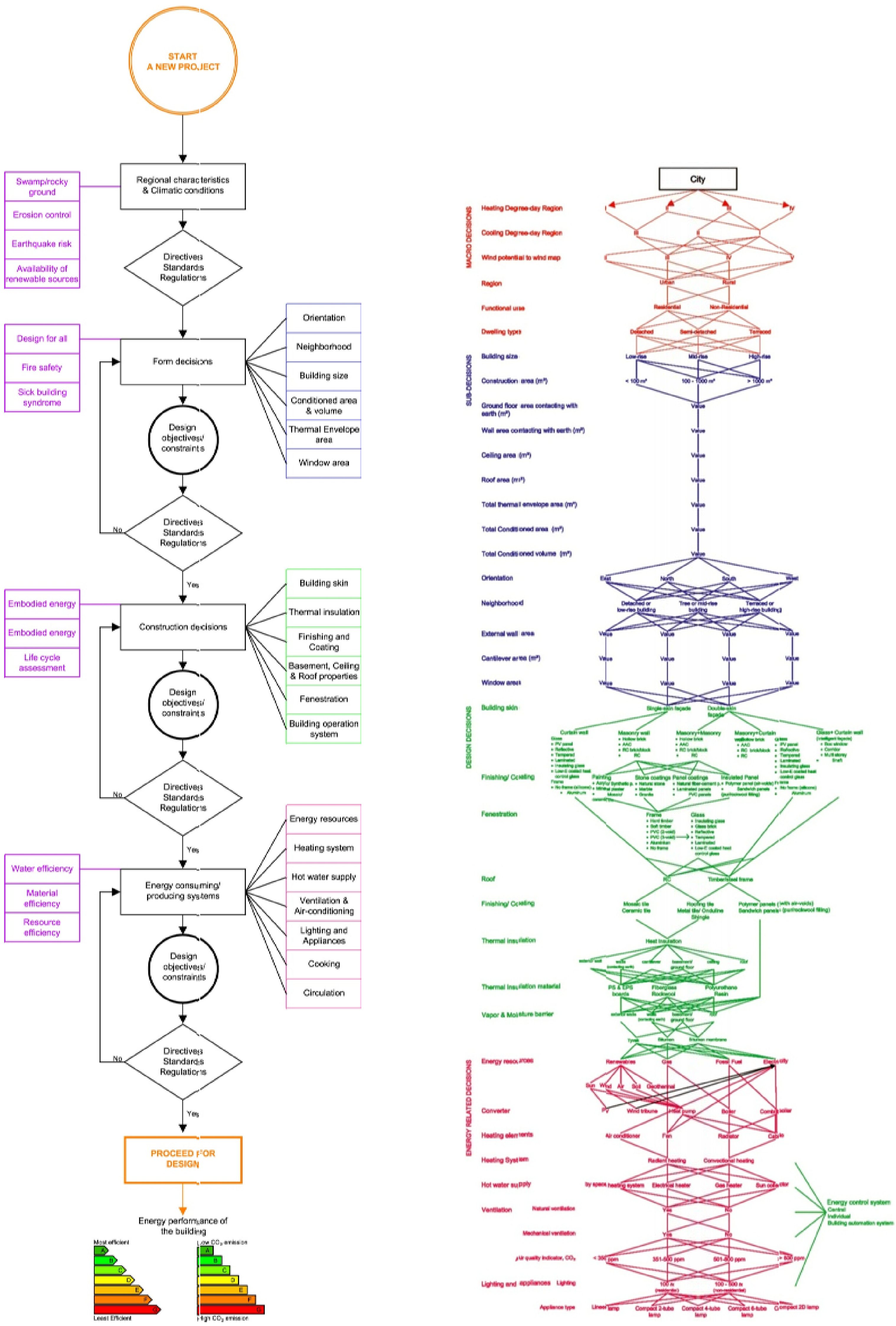


Figure 5.1 Conceptual Diagram Showing the Design Decisions in Four Groups

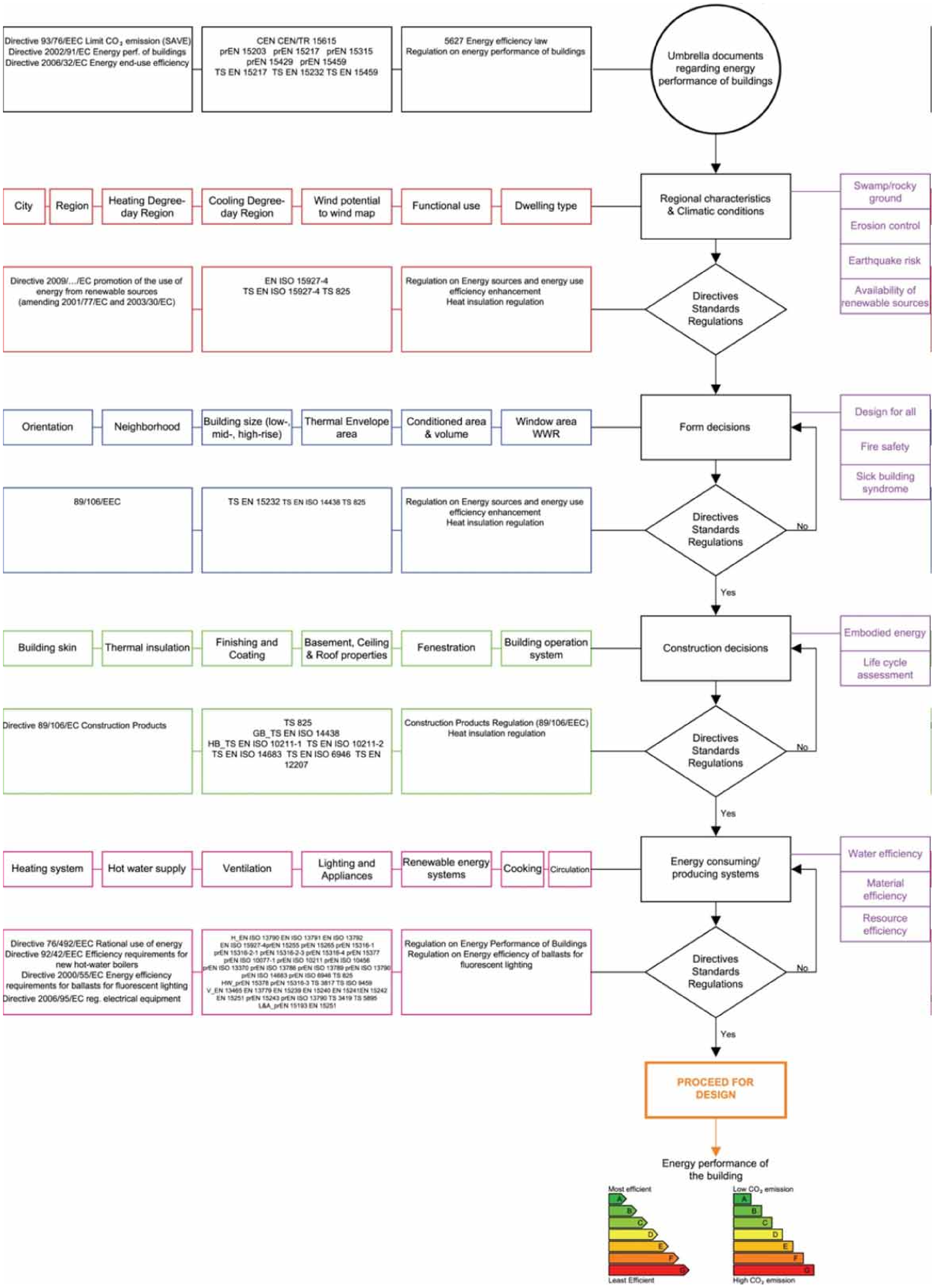


Figure 5.2 Flowchart Showing the Design Decisions in Relation to Turkish Legislation

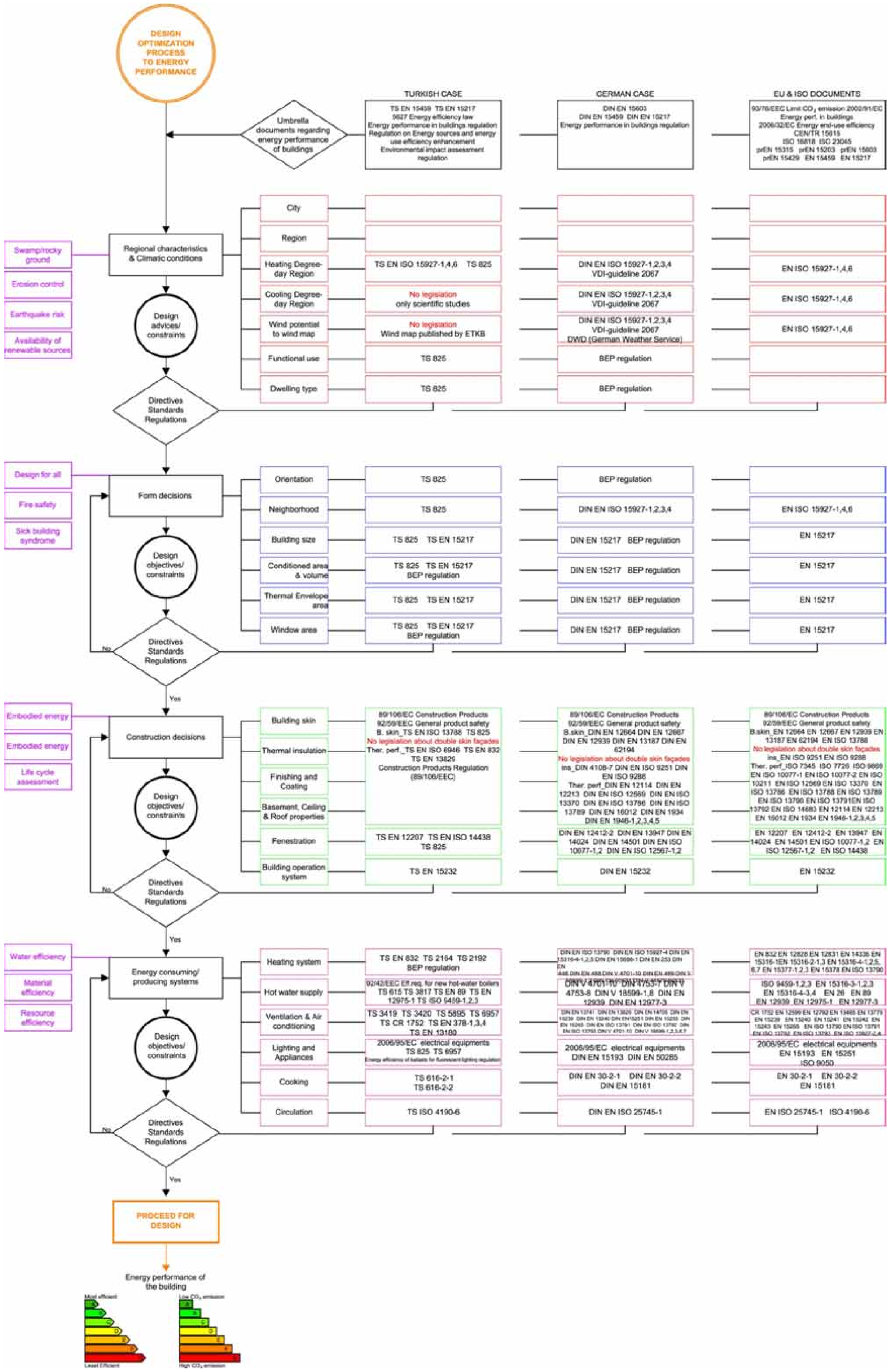


Figure 5.3 Comparison of Turkish Legislation with German Legislation and EU and ISO Standards Regarding the Energy Performance of Buildings

The structure of EnAd has been integrated with the performance goals cited in the current legislation, by which the database of EnAd was produced (as explained in Chapter 3) linking design decisions with performance objectives and formulas, and the codes of related legislation.

As a result of this inquiry, several decision paths were generated/observed on the conceptual diagram, and these paths, that is, the list of design decisions, were translated into codes for the creation of an assessment tool. EnAd evaluates the energy performance of a building using the calculation methods and assumptions determined in legislation, and the program structure, input and output of the tool are presented in the following sections.

5.5 Program Structure of EnAd

Firstly, the program requires the uploading of input data, that is, the design decisions. According to the location selected, the program produces a reference building and an improved case, which is explained below. During the data input (design of a building) phase, the designer can follow the design objectives and/or the constraints of legislation, as well as the related legislations to be covered. Explanations and feedback are provided for the reference building with the limit values defined in legislation, and to improved case of the program guiding for higher performances. According to the design decisions, EnAd calculates the energy need, evaluates the energy performance, and makes an assessment of the energy performance class of the building by comparing the results with the reference building. If the user follows the feedback provided, s/he can improve the design in terms of optimum energy performance. After analyzing the results, decisions can be changed/modified by the user, after which changes in the results can be followed, and finally design decisions can be improved and optimized. The data flow and general structure of the program is presented in Figure 5.4.

As mentioned in section 3.10, the energy performance of a building is found by comparing the annual primary energy consumptions of the original and reference buildings. TS EN 15217 requires the use of reference values in the comparison with the original building, and the selection of the energy performance of the original building depending on the results. Reference values can be selected from either the ‘building stock reference’, representing the mean value of the national building stock; or the ‘energy performance regulation reference’, corresponding to the typical requirements of the regulation for new buildings. EnAd uses the energy performance regulation reference for reference values, as described in the BEP Regulation, according to which a reference building is created, both to compare with the original building in the energy performance assessment, and to provide feedback according to the reference building. Since the reference building features the limit values defined by the regulation, the first step feedback from the program is given according to the reference building. As the intention with the program is to guide the user to achieve higher performances, an ‘improved case’ is also created, representing the performance objectives to be achieved, and the second step feedback relates to this improved case. The given explanations notify the user about the decision selected. If the designer follows the effects of his/her decisions in the results and takes the explanations and notifications from the program into consideration during the design process, the design will converge to the optimum, and thus, it will be easier to achieve higher performances.

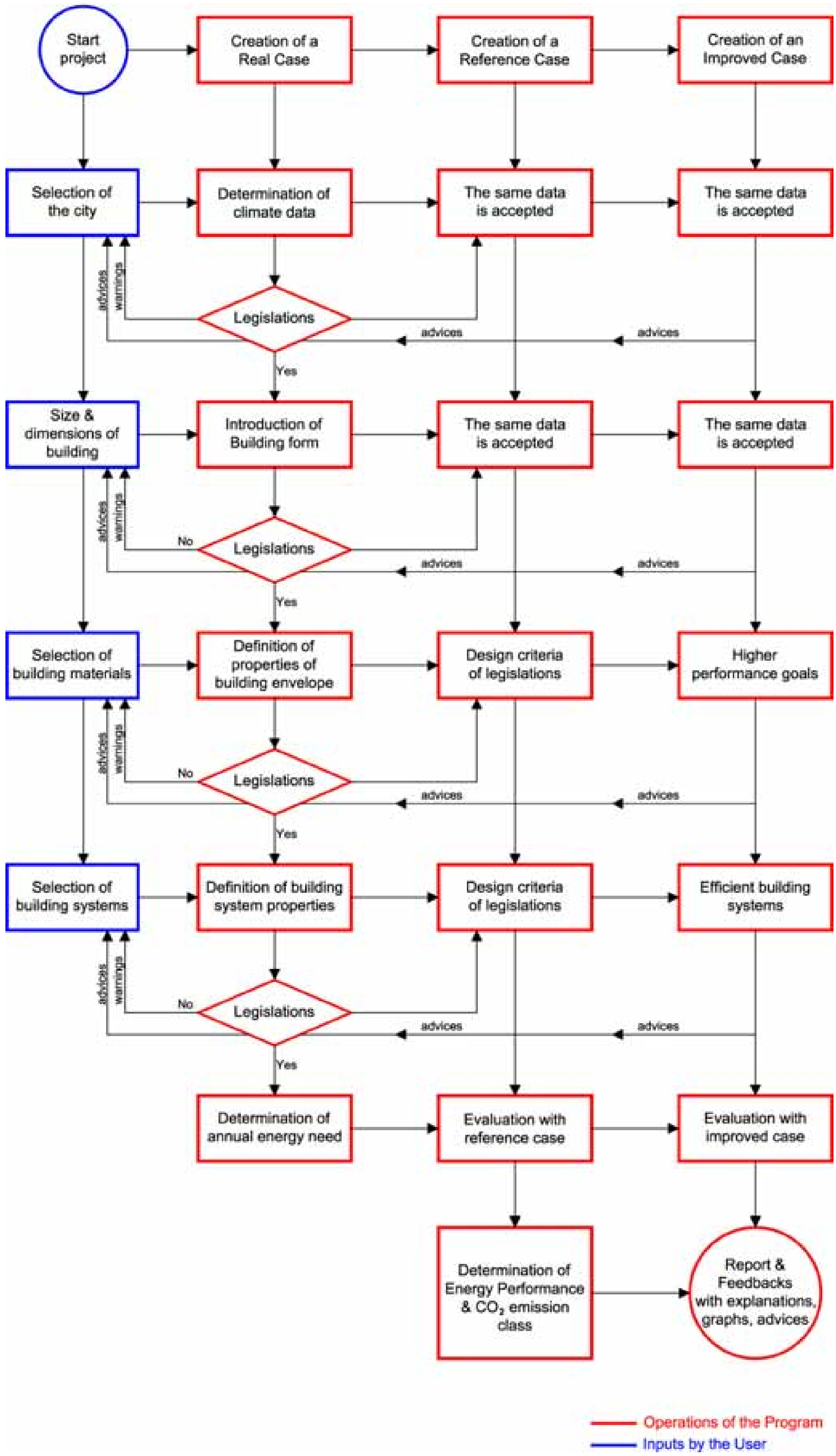


Figure 5.4 Data Handling and Decision Making in the Program

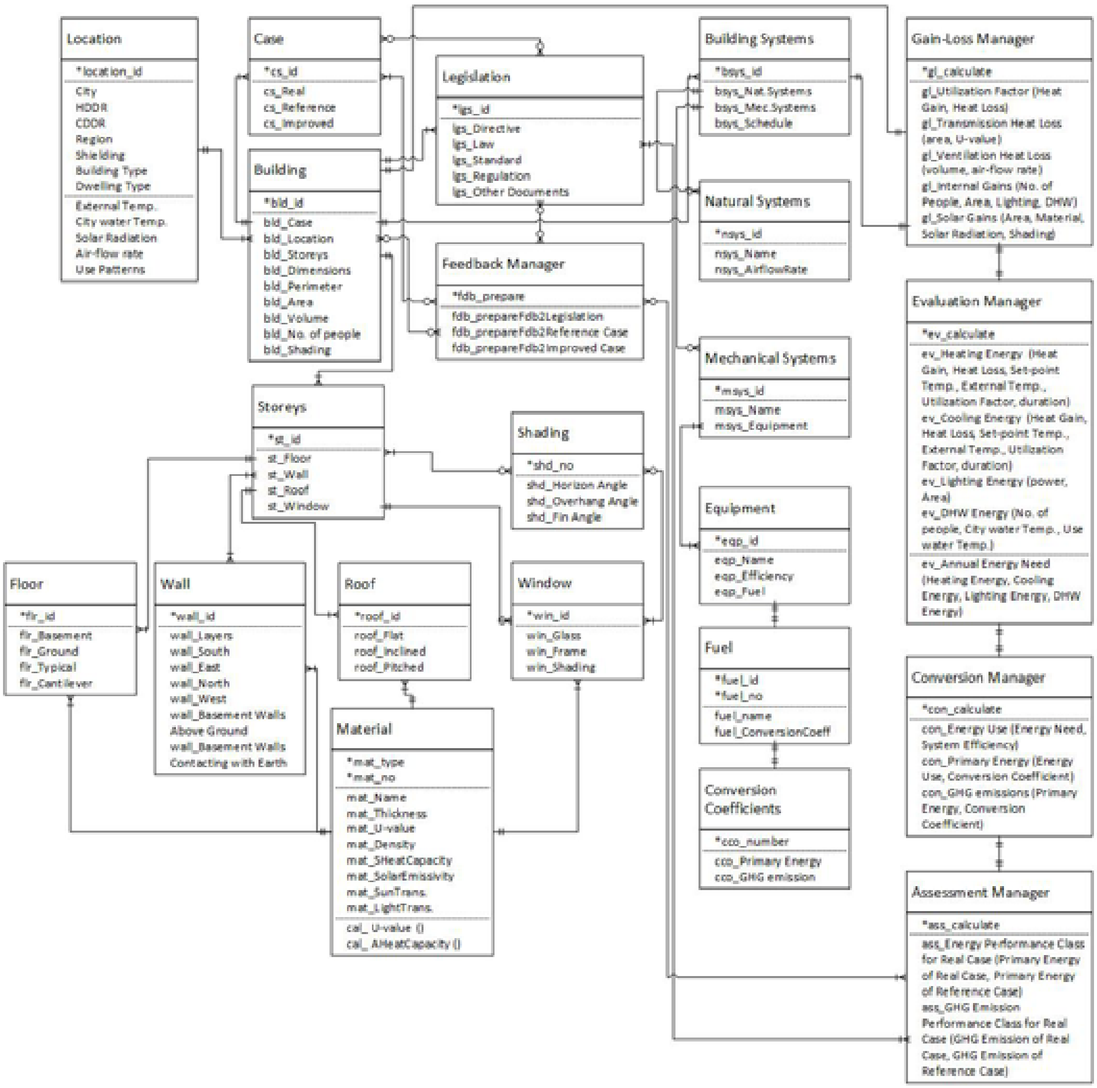


Figure 5.5 Data Structure of the Program

The interface comprises the following parts:

a) Data input page, which is the main screen of the program, and includes data inputs, explanations, feedbacks and the legislations related to the design decisions.
b) Several data input and output pages, including:
   i. Weather data page, presenting the climatic data for 81 cities of Turkey, and allowing the addition of data for new cities,
   ii. Calculations page, providing the tables and graphs showing the calculation steps of the evaluation,
   iii. Results page, presenting the results of the energy performance evaluation of the building, and
   iv. Feedback page, providing feedback related to the design.

The interface layout of the data input and output sheets is presented in Figures 5.6-5.10.

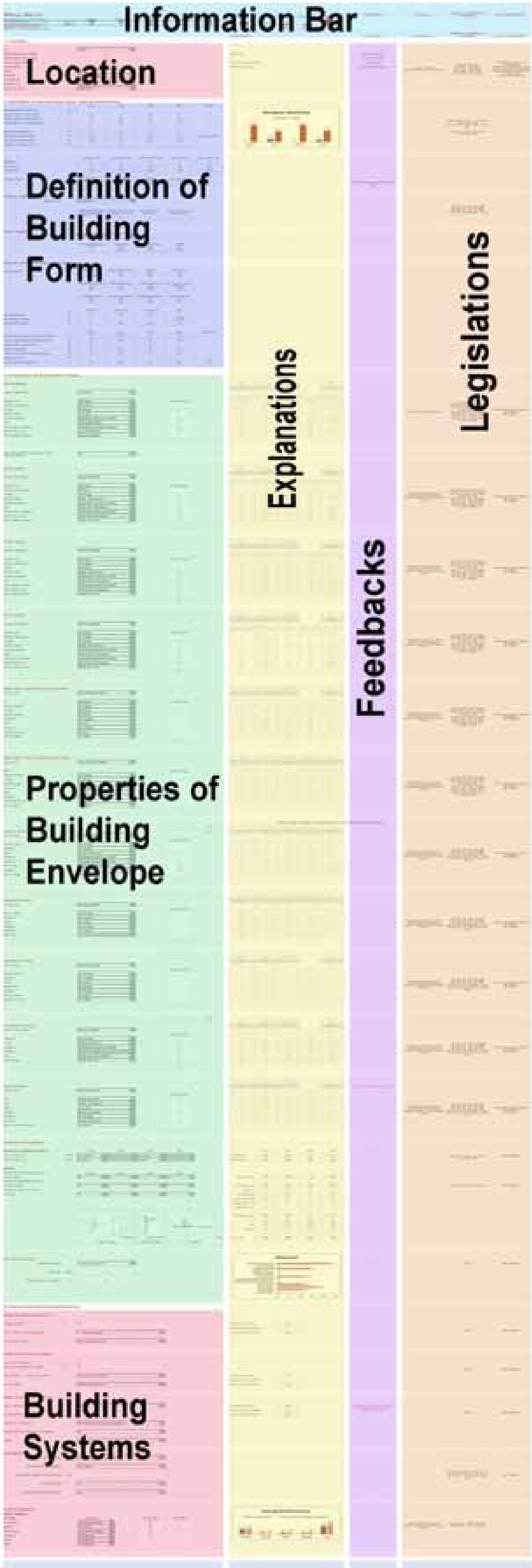


Figure 5.6 Interface Layout of the Data Input Sheet

Figure 5.7 Interface Layout of the Weather Data Sheet

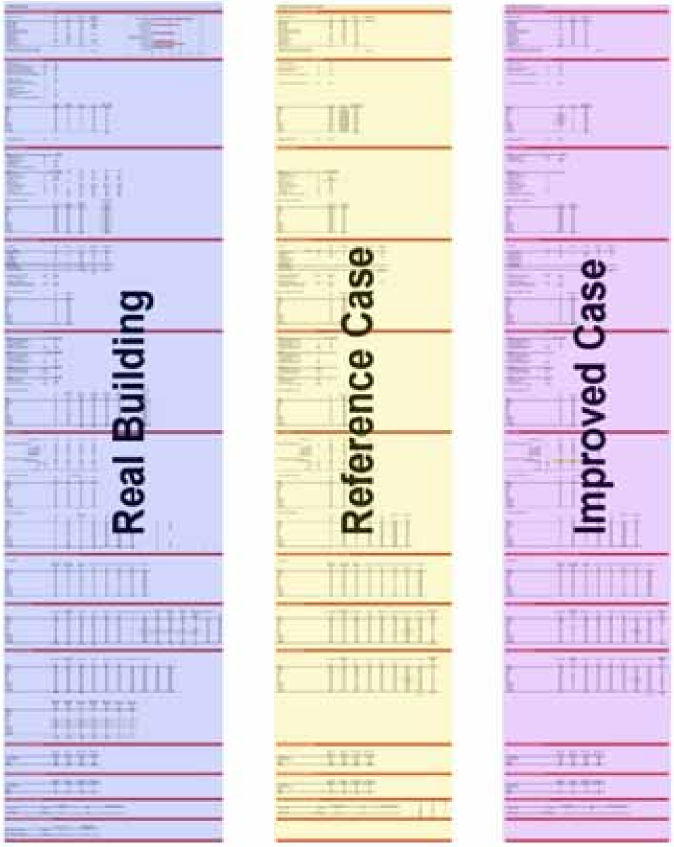


Figure 5.8 Interface Layout of the Calculations Sheet

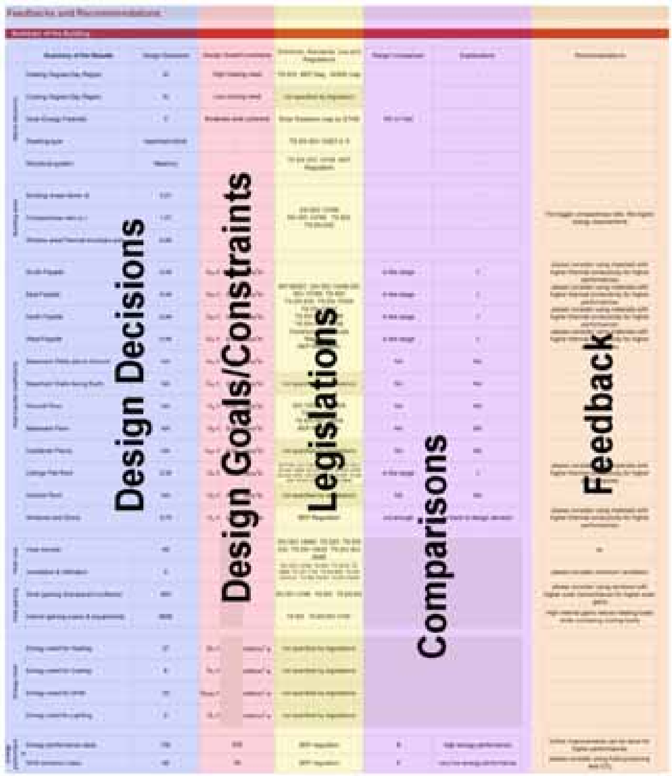


Figure 5.9 Interface Layout of the Feedback Sheet

Figure 5.10 Interface Layout of the Results Sheet

5.6 Input Data Required in the Program

As suggested in the conceptual diagram presented in section 5.11, energy-related design decisions, such as those related to location, form definition, building envelope and building system, can be implemented in the program as input data. The location input requires an evaluation of the climatic conditions and immediate surroundings of the building; while decisions related to the region, shielding and dwelling type help to define the protection level of the building.

Figure 5.11 Example of Input Data for Location

As seen in Figure 5.6, the first step in this phase is the selection of the city. TS EN ISO 15927-1, -4, -6 and TS 825 require the use of regional and climatic data in the evaluation of energy use for heating and cooling purposes. In this context, the program provides climatic data for 81 cities in Turkey, and if required, the existing climatic data can be modified and new cities/locations can be added to the Weather data sheet, as shown in Figure 5.12. According to the location selected, the tool presents data and feedback related to the city, including its HDDR (I-IV), CDDR (I-III), solar energy (I-IX) and wind potentials (I-V). This information helps to define the limit values for the city based on current legislation. A reference building and an improved case for the comparison of design decisions are also created. In this step, the user can also preview related maps showing the HDDR, solar energy potential and wind potential of Turkey, and can obtain general information about the annual heating and cooling energy demands of a building according to the region. For instance, a building in Antalya needs very high levels of energy for cooling; while in contrast, a building in Erzurum requires much more energy for heating rather than cooling.

Weather Data

Add New

Ankara		January	February	March	April	May	June	July	August	September	October	November	December
Heating degree-day region	HDDR	III											
Cooling degree-day region	CDDR	III											
Wind Potential	WP	V											
Outdoor temperature	°C	-2,4	0,6	2,6	8,9	13,7	17	21,5	21,1	17,1	10,3	3,8	0,8
City water temperature	°C	8,2	6,6	7,8	10,7	14,5	18	20,9	22,8	21,6	18,1	14,6	10,9
Solar Radiation, South	W/m^2	72	84	87	90	92	95	93	93	89	82	67	64
Solar Radiation, East	W/m^2	43	57	77	90	114	122	118	106	81	59	41	37
Solar Radiation, North	W/m^2	26	37	52	66	79	83	81	73	57	40	27	22
Solar Radiation, West	W/m^2	43	57	77	90	114	122	118	106	81	59	41	37
Solar Radiation, Horizontal	W/m^2	0	0	0	0	0	0	0	0	0	0	0	0
Adana													
Heating degree-day region	HDDR	I											
Cooling degree-day region	CDDR	I											
Wind Potential	WP	III											
Outdoor temperature	°C	9,6	10,5	13,6	17,6	21,8	25,7	28,2	28,5	26,1	21,6	15,3	10,9
City water temperature	°C	10	10	10	10	10	10	10	10	10	10	10	10
Solar Radiation, South	W/m^2	72	84	87	90	92	95	93	93	89	82	67	64
Solar Radiation, East	W/m^2	43	57	77	90	114	122	118	106	81	59	41	37
Solar Radiation, North	W/m^2	26	37	52	66	79	83	81	73	57	40	27	22
Solar Radiation, West	W/m^2	43	57	77	90	114	122	118	106	81	59	41	37
Solar Radiation, Horizontal	W/m^2												
NEW													
Heating degree-day region	HDDR												
Cooling degree-day region	CDDR												
Wind Potential	WP												
Outdoor temperature	°C												
City water temperature	°C												
Solar Radiation, South	W/m2												
Solar Radiation, East	W/m2												
Solar Radiation, North	W/m2												
Solar Radiation, West	W/m2												
Solar Radiation, Horizontal	W/m2												

Figure 5.12 Weather Data Sheet

The second step of data inputs is the definition of the building form. Considering the orientation of the building, the dimensions of each façade and window are entered for different types of floors. On the screen, the white cells represent the input cells, while the present information (Figure 5.13). The general properties of the basement and roof are also defined in this step (Figure 5.14). According to the data provided, the program calculates the construction area, the conditioned area and volume, the thermal envelope area and compactness ratio, etc.

2. Definition of the Building Form; Size & Dimensions

		South	East	North	West	Height
Façade length for basement	m					
Façade length for ground floor	m	12	8	12	8	3
Facade length for typical floors	m					
Total length for Door & Windows	m	4,5	3	4,5	3	1,5
Basement façade area	m^2	0	0	0	0	
Ground floor façade area	m^2	36	24	36	24	# of typical floors
Typical floor façade area	m^2	0	0	0	0	
Total Door & Window area	m^2	6,75	4,5	6,75	4,5	

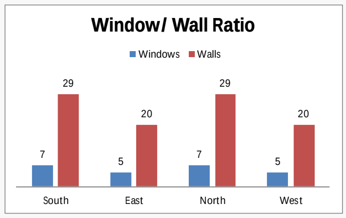


Figure 5.13 Data Input Example for Form Definition

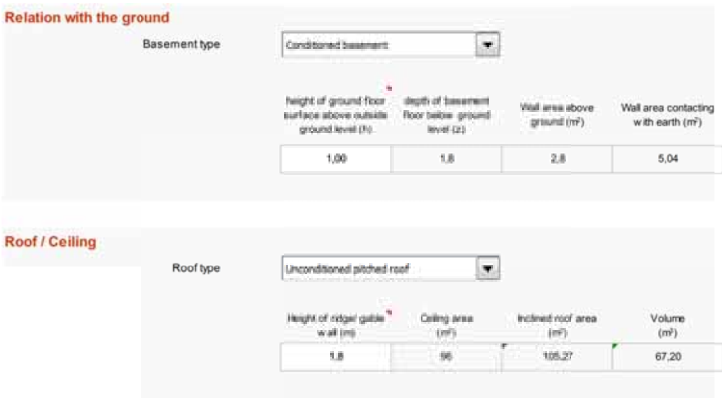


Figure 5.14 Definitions of General Properties of Basement and Roof

The properties of the building envelope are determined in the third step. Since EnAd has been developed especially for use by architects, paramount importance is given to design decisions. For this reason, unlike the other tools, which prioritize the mechanical systems, the main focus of this tool is on the pre-design phase, in which most critical design decisions regarding the energy performance of buildings are taken. The program allows a definition of the properties of all surfaces of the building envelope, including the four façades, the below-ground basement walls earth and above-ground walls, the ground floor, the basement floor, any cantilever floors, ceilings or flat roofs, inclined roofs, windows and doors. Several options are provided in the program for each surface, such as default construction type, the manual definition of layers, as well as adjacency to conditioned or unconditioned spaces and interior surfaces (Figure 5.15). It offers three options of default construction type, which are heavy construction, medium construction and light construction, as defined by the BEP Regulation. For the manual option, the program features a rich material library that details the thermal properties of all listed materials. The material layers for different surfaces have been produced in line with the current construction trends in Turkey, whereas the material lists and their thermal properties have been formed considering the most commonly used materials. The thermal properties are taken from the opaque material library of the Turkish BEP Regulation, TS 825, EN 12524 and EN ISO 10456.

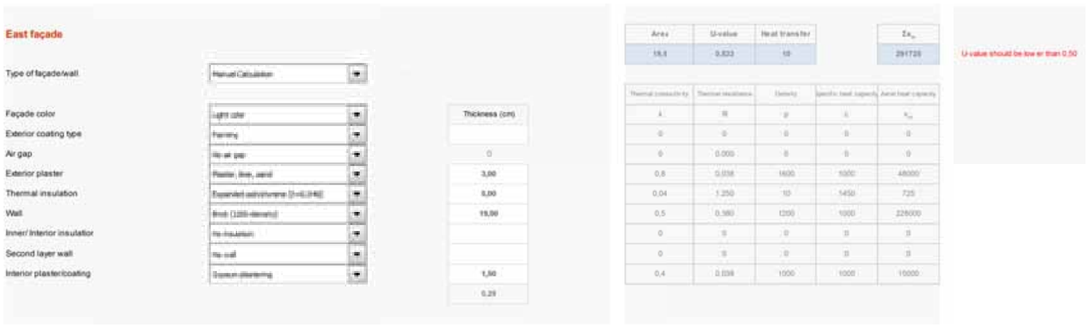


Figure 5.15 Definition of Properties of the Building Envelope

The user can select different material layers from dropdown menus provided for each material. When selecting one material on the list, the user can see thermal properties of the material on the table provided. If a material to be used is absent from the list, the user can define the new material by its thermal properties. The program allows the definition of different types of exterior wall for each direction; however, it is not possible to define two types in one façade, which is the same for all other surfaces. Each surface is assumed to have uniform thickness and the same material layer(s) across the entire surface. The thickness of the materials can be defined in cells in centimeters, which is a common unit in architectural detailing. Furthermore, the color of the façades can be selected as light, medium or dark, being relevant in the determination of the radiation absorbance level of an opaque surface.

Options for windows and shade are also defined in this step in the program, including single, double and triple glazing with different types of window frames. As with the construction materials, new windows can also be defined by the user. Figure 5.16 shows the page on which shade from outside objects and horizontal and vertical shading elements can be defined using a dropdown menu. In the scope of this study, only external shade is taken into account, disregarding shade from internal elements like curtains, etc.

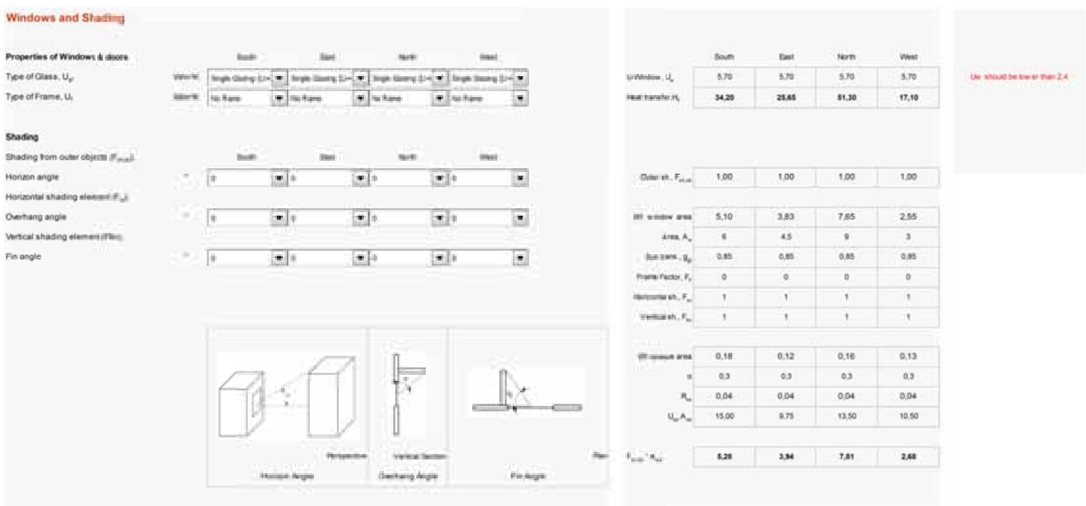


Figure 5.16 Definition of Window Properties and Shade from External Objects

The last input in this step is the determination of the type of internal heat gains (Figure 5.17). In the program, heat gain can be computed according to five options: zone type, three average values, user-defined values, default values (as mentioned in Section 3.5.3, the BEP Regulation suggests calculating internal heat gain according to zone type, citing 5 W/m^2 for residential buildings, 10 W/m^2 for office buildings and 20 W/m^2 for other types of buildings), and the manual definition of internal heat gain.

Figure 5.17 Definition of Internal Heat Gain on EnAd

The final step in the data input phase is the determination of the natural and mechanical systems used in the building. Contrary to many other tools, this phase is kept brief, since the tool has not been developed for system design or sizing. The primary goal of such an informative step is to give the designer an idea of building systems, and their approximate effects on the results, and in turn, on the energy performance of buildings. Once design decisions are made and the energy requirements of the building from different systems are determined, the building systems can be decided upon according to the region and climatic conditions, as well as the availability and applicability of a system, the demands of the owner of the building, the cost and maintenance of the system, etc. In this respect, only design decisions affecting the energy requirements are provided in the program, as the design of such systems and other details fall outside the scope of this study. The program includes decisions related to heating, cooling, DHW, lighting, natural and mechanical ventilation and infiltration, but excludes requirements for cooking, circulation and lifting, daylighting, energy generating systems and renewable energy systems due to lack of data sources and evaluation methods related to such systems.

The program provides several options for space heating, mechanical cooling and water heating systems. The space heating systems include community heating systems, central heating systems, warm air systems, room heaters, electric under-floor heating, electric ceiling heating and air conditioners. The list of cooling equipment consists of three types of air conditioner with ten energy efficiency classes, as described in EU Directive 2010/30. The water heating equipment can be selected from among stand-alone water heaters, or it can be provided by space heating system if required. Since equipment types and efficiency values are provided only to inform the designer, newly available heating and cooling equipment cannot be introduced to the program. Furthermore, the efficiency values provided in the tool relate only to equipment efficiency, not system efficiency, and it does not include the energy requirement for air system fans, pumps, cooling tower fans, etc.

As mentioned in Section 3.9, the BEP Regulation uses the boiler efficiency values listed in the Standard Assessment Program (SAP) 2009, which is the UK government's methodology developed for the evaluation of the energy performance of buildings in the UK. In this respect, the efficiency values for space heating systems and water heaters are obtained from the SAP 2009 annual efficiency database for boilers for domestic purposes. On the other hand, the types of air conditioners, their energy efficiency classes, the seasonal coefficient of performance (SCoP) for heating season average, and the energy efficiency ratio (EER) and coefficient of performance (CoP) for standard conditions are obtained from EU Directive 2010/30 related to the energy labeling of air conditioners.

Space heating decisions include the heating set point temperature, the heating equipment and the type of thermostatic control. A set point temperature of 20°C is assumed as default, as determined by TS EN ISO 13790, however this can be changed by the user. The heating equipment and thermostatic control options are selected by the user, and approximate efficiency values for the equipment, the primary energy conversion coefficients and the GHG conversion coefficients are displayed on the screen (Figure 5.18). Since TS EN ISO 13790 and the BEP Regulation assume continuous heating for residential buildings, space heating is assumed to be working continuously.

Figure 5.18 Definition of the Space Heating System

In order to form a common ground between the tools, four alternatives are provided for DHW supply, being both monthly and average options as well as per person and per unit options. For the calculation of the monthly and average DHW use, the used water temperatures and supplied water temperatures can be defined by the user, or default values can be used. The used water temperature is assumed to be 50°C, while the supplied water temperature is decided at 10°C. A more realistic energy requirement for DHW can be calculated if the monthly values of the supplied city water temperatures are used instead of average values. The energy requirement for DHW can also be computed according to daily consumption data as 33 Wh per unit daily, or 1.4 kWh per person daily, as defined in DIN V 18599-10. As shown in Figure 5.19, the type of DHW equipment can be selected as a space heating system or a stand-alone water heater from the list provided.

Figure 5.19 Introduction of Data Related to DHW Supply

The program provides three options for mechanical cooling, which are ‘no cooling’, ‘continuous cooling’ and ‘intermittent cooling’. Since cities in the third and fourth heating-degree day regions, that is, the third cooling degree-day region, have a very low requirement for cooling, space cooling is not imperative, and consequently mechanical cooling is not a significant requirement in these cities. According to TS EN ISO 13790, the cooling requirement in residential buildings can also be disregarded, and for this reason mechanical cooling is left optional in the program. For intermittent cooling, the system is assumed to work six hours a day according to TS EN ISO 13790. As shown in Figure 5.20, the user can define a cooling set point temperature or accept TS EN ISO 13790’s 26°C default value. Finally, the type of air conditioner can be selected from the single duct, double duct and air conditioner except single or double duct options, and an energy efficiency class ranging from A+++ to G.

Figure 5.20 Definition of Space Cooling System in EnAd

The user can define the properties of natural ventilation and mechanical ventilation in EnAd, as shown in Figure 5.21. Ventilation options include ‘no ventilation’, ‘minimum ventilation’, ‘natural ventilation’ and ‘mechanical ventilation’. Mechanical ventilation is only included in heat loss assessments, while air system fans and other special equipment and their energy requirements are disregarded in the tool. Similar to ventilation, infiltration, which can be defined as the airtightness level of the building envelope, can be activated or deactivated in the evaluations.

Figure 5.21 Definition of Ventilation and Infiltration in EnAd

The last step in the data input phase is the definition of artificial lighting. As seen in Figure 5.22, interior lighting can be introduced using the average values per unit, or it can be defined manually by indicating the type, power and number of lamps for one flat, multiplied by the number of flats in the building. Exterior lighting can be defined and its annual energy requirement can be displayed; however the energy need for exterior lighting is not included in the evaluation results showing the energy performance of the building.

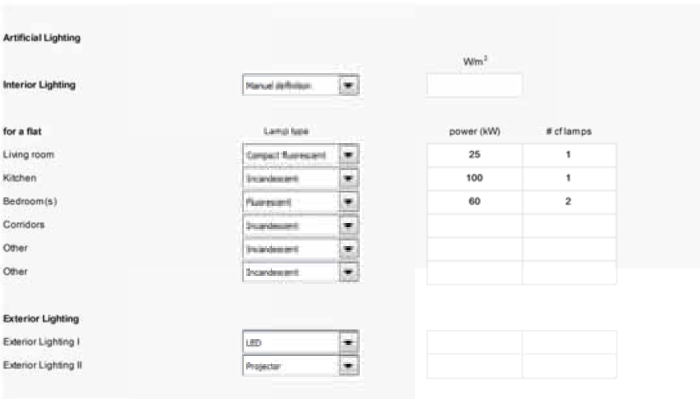


Figure 5.22 Introduction of Artificial Lighting

5.7 Output Provided by the Program

In order to maintain flexibility and speed when using EnAd, four output groups are provided by the program: quick results, shown on the data input sheet, as well as calculations, results and feedback. The first group comprises the quick results of the evaluation of the energy performance of a building. Since the program has been developed to be informative and to raise the consciousness of the designers, the quick results on the input page have great significance, aiming to provide feedback information that relates to the design decisions and performance goals, from which the user is expected to adjust her/his decisions accordingly. The quick results include an ‘information bar’, ‘explanations, ‘feedback’, ‘related legislation’ and ‘other resources’, as shown in Figures 5.23 and 5.24.

Explanations	Feedbacks	Related Legislations: Directives	Related Legislations: Standards	Related Legislations: Law & Regulations	Other Resources
HDDR map	High heating need	2002/91/EC EPBD 2006/32/EC Energy end-use efficiency	CEN CEN/TR 15615 ISO 16818 ISO 23045 prEN 15315 prEN 15203 prEN 15603 prEN 15429 TS EN 15459 TS EN 15217	* 5627 Energy efficiency law * EPB regulation * Regulation on Energy sources and energy use efficiency enhancement * Environmental impact assessment regulation, ÇED * Heat insulation regulation	Ministry of Environment (ÇŞB)
	Low cooling need				Bulut et. al., 2007
Solar energy potential map	Low solar gains				Ministry of Energy and Natural Resources (ETKB)
Wind potential map	Very low wind potential				Ministry of Energy and Natural Resources (ETKB)

Figure 5.23 Text-based Feedback on the Input Page

One of the most important features of the program is the information it provides on the energy performance class and GHG emission class of the building. The interface features an information bar at the top of the data input screen, as can be seen in Figure 5.24, that shows the annual energy requirement and primary energy use for heating, cooling, DHW and lighting, as well as the energy performance class and GHG emission class of the building. When defining/modifying the design decisions, the user can follow changes in the results from the information bar throughout the input phase, which can help the user to make a more informed decision.

Energy Advisor

Energy Performance of the Building		Heating	Cooling	DHW	Lighting	Total
Annual Energy Need	kWh/m² a	369	34	44		448
Annual Primary Energy Consumption	kWh/m² a	535		68		603
Energy Performance Class	-					G
GHG Emission Perfomance Class	-					G

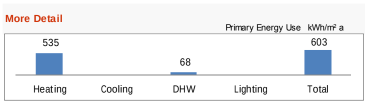


Figure 5.24 Information Bar at the Top of the Input Page

Text-based explanations, feedback, warnings and graphs related to design decisions are provided on the input page. The explanations section provides maps, tables and graphs to summarize and illustrate the current situation; while the feedback part provides information and warnings related to the performance goals to be achieved. These quick outputs are updated after each change in the design, and show the effects of each decision on the results. If the user reviews her/his decisions considering the results and the feedback provided, and makes improvements from the beginning of the design, better results may be achieved. Examples of text-based outputs, informative tables and graphical outputs are presented in Figures 5.25 and 5.26.

Total values for	Construction area (m²)	Height of the building (m)	Volume (m³)	Net volume (m³)
	96	3	288	230
	Thermal envelope area (A_F)	Window & door area (A_w)	Thermal wall area (A_W)	Window area/ Thermal wall area
	312	22,5	97,5	0,19
	Conditioned area (A_C)	Conditioned volume (V_C)	Building shape factor (f)	Compactness ratio (c)
	96	288	3,25	1,08

		Basement	Ground floor	Typical floors	Roof
Conditioned areas	m²	0	96	0	0
Unconditioned areas	m²	0			0
Conditioned volumes	m³	0	288	0	0,0

Figure 5.25 Informative Tables on the Input Page

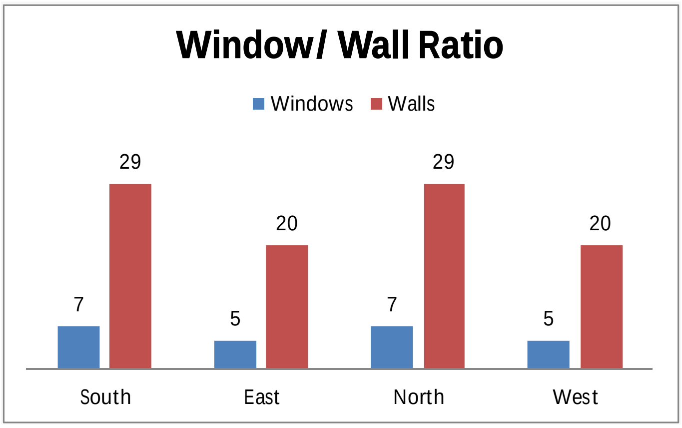


Figure 5.26 Example of Graphical Outputs on the Input Page

The program also provides lists of related legislation, including EU directives, international and national standards, and Turkish laws and regulations, which determine the performance criteria to be covered during the building design phase. Listing the related legislation related to design decisions allows the user to follow which design decision should comply with which legislation. The initial intention with the program was to link the listed legislation to their full text; however this could not be achieved due to copyright issues.

The second type of output provided by the program is the calculations. During data entry, design decisions are implemented on the computational model of the program, as explained in Chapter 3, and all decisions are evaluated, with detailed calculation steps presented in the form of tables (Figure 5.27). Detailed calculations, including heat losses through transmission and ventilation, internal and solar heat gains, and the energy requirement to satisfy the energy parameters for heating, cooling, DHW and lighting are carried out. The user can follow the calculation steps and the intermediate steps of the evaluation, as well as the monthly results, in detail, and can also print out all calculation tables in the form of a report of the energy performance evaluation of the building.

Heat Transfer by Transmision through Building Envelope

Building Component	Area, A m²	U-value, U W/m²K	Heat trans., H_T W/K	Aeral heat capacity, κm J/(m²K)
South Façade	29,25	0,87	25,4	288 290
East Façade	19,5	0,87	17,0	288 290
North Façade	29,25	0,87	25,4	288 290
West Façade	19,5	0,87	17,0	288 290
Basement Walls above Ground	0	0	0,0	
Basement Walls facing Earth	0	0	0,0	
Ground Floor	96	0,54	51,5	388 290
Basement Floor	0	0,00	0,0	
Cantilever Floors	0	0,00	0,0	
Ceiling/ Flat Roof	96	1,33	128,1	388 290
Inclined Roof	0	0,00	0,0	
Windows and Doors			128,3	
	290			
Heat transmision through building envelope			**393**	
Average heat capacity of building envelope				**354 611**

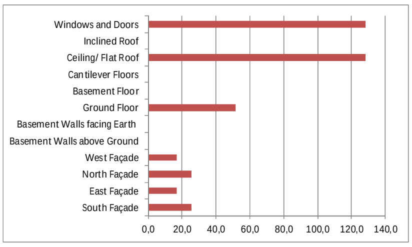


Figure 5.27 Calculation Steps Presented in Form of Tables and Graphs

The results of the evaluations are also organized in a user-friendly way. Once the data input phase is completed, the user can click on ‘proceed for design’ button at the bottom of the input page, which causes the ‘Results’ page to open automatically. The Results page is not as technical as the calculations section, as its function is to present a summary of the calculations. One of the most important outputs in the results is the indication of performance classes. As shown in Figure 5.28, the results sheet presents the energy performance class and GHG emissions class of the original building, the reference building and the improved case, as well as A and G limits of the legislation in both table and graphical forms. These performance tables and graphs notify the user of the status of the design and give indicates suggested actions for the achievement of better results.

Energy Performance Class of the Building

		Real Building	RG	Energy Performance Class
Energy Performance	kWh/m² year	150	300	B
GHG emission	kg eq. CO_2/m² year	51	50	D

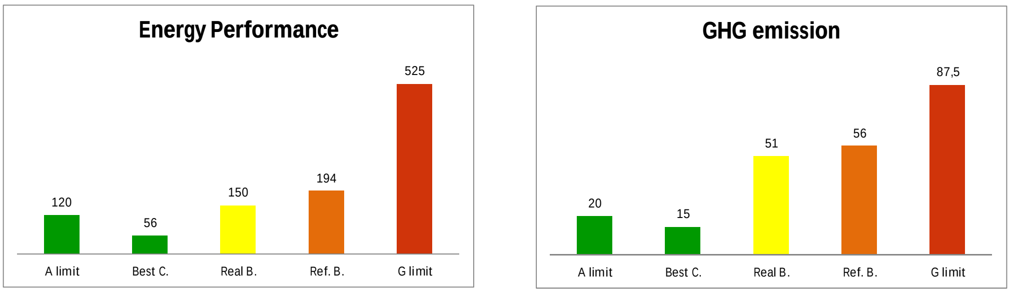
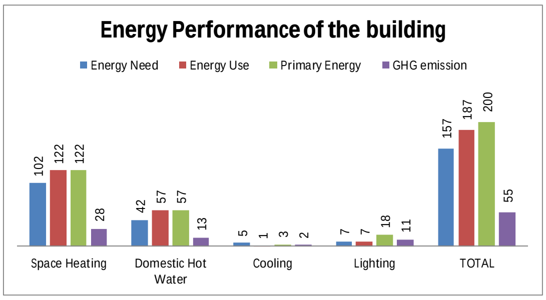


Figure 5.28 Presentation of Performance Class of the Building

The Results sheet also presents the monthly and annual energy requirements, the energy use and the primary energy requirement for heating, cooling, DHW and lighting. Although results for each unit are preferred to permit ease in comparison, the results are provided for both the entire building and for each unit. The monthly and annual results are presented as both tabulated numerical outputs and graphical outputs, as presented in Figure 5.29.

Energy Performance of the Building for per m²



for per m²	Energy Need kWh /m² year	Energy Use kWh /m² year	Primary Energy kWh /m² year	GHG emission kg eq. CO2 /m² year
Space Heating	102	122	122	28
Domestic Hot Water	42	57	57	13
Cooling	5	1	3	2
Lighting	7	7	18	11
TOTAL	**157**	**187**	**200**	**55**

Figure 5.29 Presentation of Energy Performance of the Building per Unit

The most important output provided by the program is the feedback, which is compiled and presented on the feedback page in tabular form, and also on the data input sheet to facilitate design decisions. The feedback page provides summary information about the design decisions, making a comparison with the performance criteria defined in a provided list of legislation, and making recommendations related to the decisions.

The program provides feedback in two steps. The first step aims to compare the design with the performance goals in the current Turkish legislation, while in the second step it is intended to achieve higher performances. For this reason, the program creates a reference building and an improved case. As mentioned in Section 5.5, the reference building is created according to the limit values determined in the BEP Regulation, and the first step feedback is provided according to this reference building. The program's improved case is created to achieve a higher performance, considering the location of the building as well as decisions affecting energy performance, such as those related to the thermal properties of the building envelope, external shade and building systems. The general features of the reference building and the improved case are presented in Table 5.1. Regarding the maximum U-values that are missing from the BEP Regulation, assumed values are used for the reference building, as provided in Table 5.2.

Table 5.1 General Features of Reference Building and Improved Case of the Program

	Reference Building	Improved Case
Climatic data	Same as the original building	Same as the original building
Size and dimensions of the building	Same as the original building	Same as the original building
Shading from outer objects	Same as the original building	Same as the original building
Window shade	None	None
Properties of building envelope	Limit values determined by BEP Regulation (given in Table 5.2)	75% reduced values of the limit values
Building systems	Determined by BEP Regulation	
Heating	Central, natural gas, standard boiler with thermostatic valve	Central, natural gas, condensed boiler with thermostatic valve
DHW supply	Stand-alone water heater, natural gas	Provided by heating system
Cooling	Air-conditioner, D Class	No cooling for 3rd & 4th HHDR Air-conditioner, A Class for 1st & 2nd HDDR
Ventilation	Natural ventilation (0.5 ac/h)	Minimum ventilation (0.3 ac/h)
Infiltration	The same as the original building	0.1 ac/h (the goal of European Nations)
Lighting	70% fluorescent, 30% incandescent	100% compact fluorescent

Table 5.2 Maximum U-values According to Heating Degree-day Regions

	1st HDDR	2nd HDDR	3rd HDDR	4th HDDR
External walls	0.70	0.60	0.50	0.40
Basement walls above ground*	0.70	0.60	0.50	0.40
Basement walls facing earth**	0.70 * 1.25	0.60 * 1.25	0.50 * 1.25	0.40 * 1.25
Ground floor	0.70	0.60	0.45	0.40
Basement floor*	0.70	0.60	0.45	0.40
Cantilever floor*	0.45	0.40	0.30	0.25
Ceiling/flat roof	0.45	0.40	0.30	0.25
Inclined roof*	0.45	0.40	0.30	0.25
Windows	2.40	2.40	2.40	2.40
Window glazing	0.75	0.75	0.30	0.30

* Not determined by BEP Regulation, assumed value.
** Not determined by BEP Regulation, values 25% higher than external walls are assumed as in DIN standards.

5.8 Protocol for Usability Test of the Program

One of the main goals of EnAd is to make the tool easy to use. Although it has been developed primarily for the use of architects, the program should be usable, understandable, efficient and sufficient for all users. Usability refers here to the measure of ease of use of any program, and EnAd, starting from the data input, the use of input cells and option boxes to switch between applications and drawing results. Understandability refers to the clarity of the questions and outputs (including text-based, tabulated numeric and graphical outputs) of the tool; while efficiency is related to time, and refers to the length of time required for the user to enter input data, to gain feedback and to improve their design. In this respect, it is important that the program provides results and feedback quickly. Sufficiency refers to the ability of the program to provide sufficient information during use, including explanations, feedback, related legislation, evaluations and results.

The usability of the program was tested by means of a prepared protocol, a think aloud protocol that was designed to check the circumstances under which users had trouble with questions, options, values, explanations and activities. In order to conduct a controlled test case, a single-family one-story house in Ankara with a 100m^2 floor area was determined for the sake of simplicity. This test case features 3-layer low-insulated surfaces with G class energy performance and G class GHG emission performance, while the selection of the building system is left to the user. The reason for choosing such a case is to maintain simplicity and to facilitate the use of the different potentials of the tool; to ensure the clarity and usefulness of the explanations, results and feedbacks; and to measure the time required for data input and design improvement.

Participants with different educational backgrounds were requested to complete two tasks; first, to enter input data into the tool, and second, to improve the design from energy performance class of G to at least B. The protocol was applied to two groups in two ways. The first group was allowed to follow the explanations and feedback provided by the program, while the explanations and feedback were deactivated for the second group, although the calculations and results were allowed to be seen. In this way, the role of the feedback in the decision-making process could also be explored.

The participants were subjected to the protocol one at a time rather than as a group. The task was explained to the users verbally in one minute, and a hard copy was also provided giving the size and dimensions of the building and the material properties to be followed. In order to follow progress and the time taken for each step, the participants were asked to think aloud when using the program. When the users had a problem with a question or the selection of a value, they were advised to look at the explanations provided by the program. While conducting the protocol, the sessions were recorded using a sound recorder and a camera.

For the usability test, eleven participants were subjected to the protocol; seven of which were part of the first group, which had been provided with feedback, and four from the second group. All of the participants were undergraduate or graduate students in the Department of Architecture at Middle East Technical University, eight of which were fourth-grade architecture students, one of which was a master student with an bachelor’s degree in architecture, one of which was a master student with bachelor’s degree in mechanical engineering, and one of which was a PhD student with a bachelor’s degree in physics. All of the participants declared that they had no previous experience with building energy performance evaluation tools, and that they were using EnAd for the first time.

The protocols are evaluated in two aspects: one, the time taken for each step, and two, the number of evaluation parameters satisfied by the participants. For the first part, each participant was timed to ascertain how long they spent on each step; and for the second part, the number of parameters satisfied by each user was compared. The results of the two groups were compared, as presented below.

The usability test features eleven steps covering the two tasks. The first task, involving data input, has four steps, which are the four main titles of the design decisions of the program; location, definition of building form, properties of building envelope and building systems. The other seven steps make up the second task, and involve the improvement of the design, for which the participants were expected to make improvements in five different areas after considering the feedback and results, with the intention being to achieve the desired energy performance. This was done through improvements to the thermal properties of the building envelope and the building systems. The test steps can be named as follows:

Step 1 : Definition of the site
Step 2 : Definition of building size and dimensions
Step 3 : Definition of properties of the building envelope
Step 4 : Selection of building systems
Step 5 : Evaluation of results (and feedback)
Step 6 : Improvement of exterior wall properties
Step 7 : Improvement of ground floor properties
Step 8 : Improvement of roof properties
Step 9 : Improvement of window properties

Step 10 : Improvement of building systems
Step 11 : Achievement of required energy performance

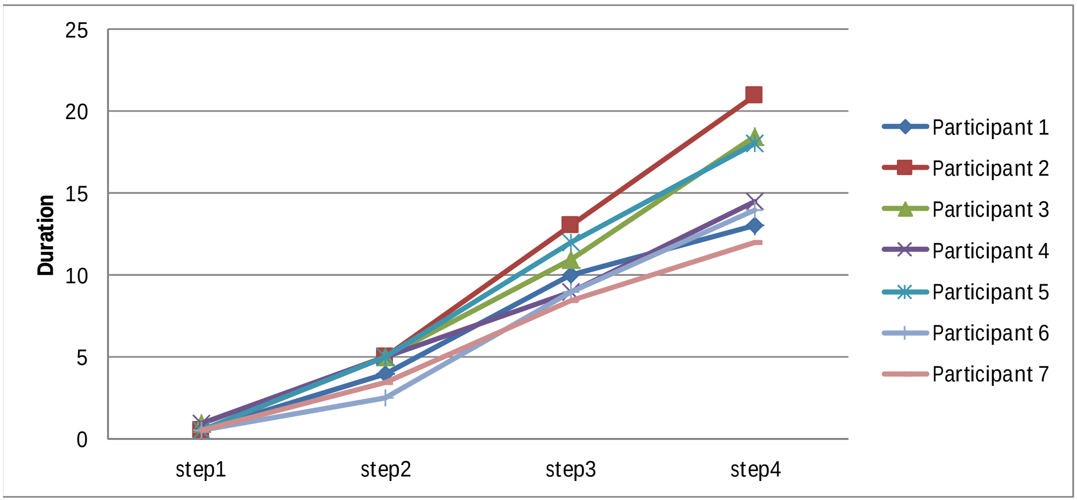


Figure 5.30 Time Spent for Each Step of Data Input for the First Group

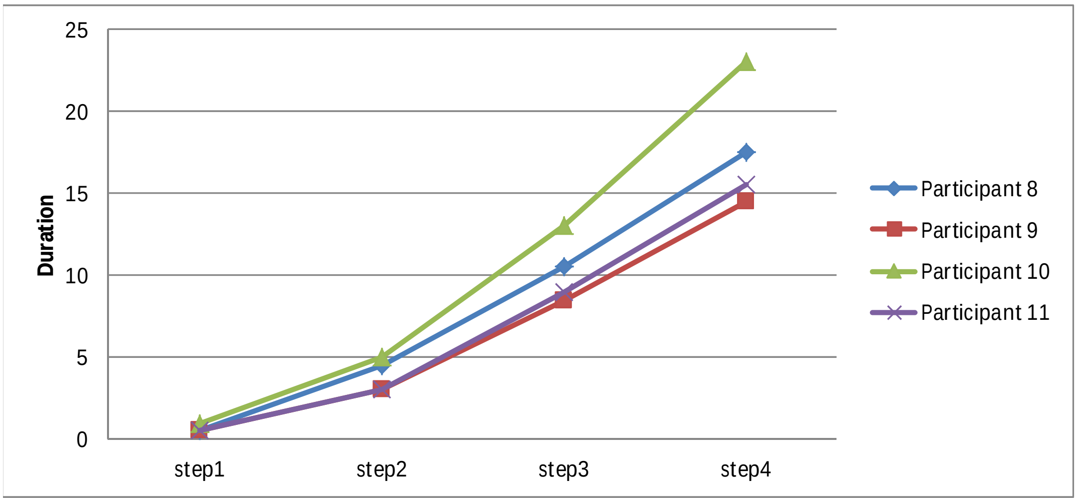


Figure 5.31 Time Spent for Each Step of Data Input for the Second Group

As can be seen in Figures 5.30 and 5.31, the participants of the first group accomplished the first task in an average of 16 minutes, with a range of 12 to 21 minutes; while the second group completed the first task in an average of 18 minutes, with times ranging from 14 to 23 minutes. Regardless of their educational background or level of expertise, all participants spent a similar time carrying out the first four data input steps. The slight difference between the two groups in terms of the time spent carrying out the task may be due to the fact that the first group had access to explanations and feedback. Since all the participants live in Ankara, they would be aware that the heating need would be high and the cooling need would be low for the city. None of the participants experienced problems entering the input data, while they did have some difficulty in deciding upon building systems.

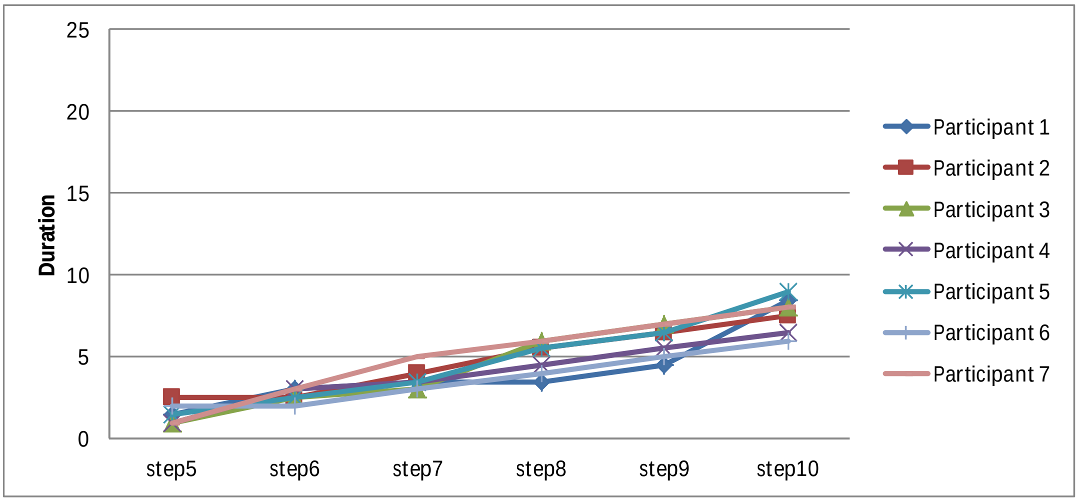


Figure 5.32 Time Spent for Each Step of Improvement of the Design for the First Group

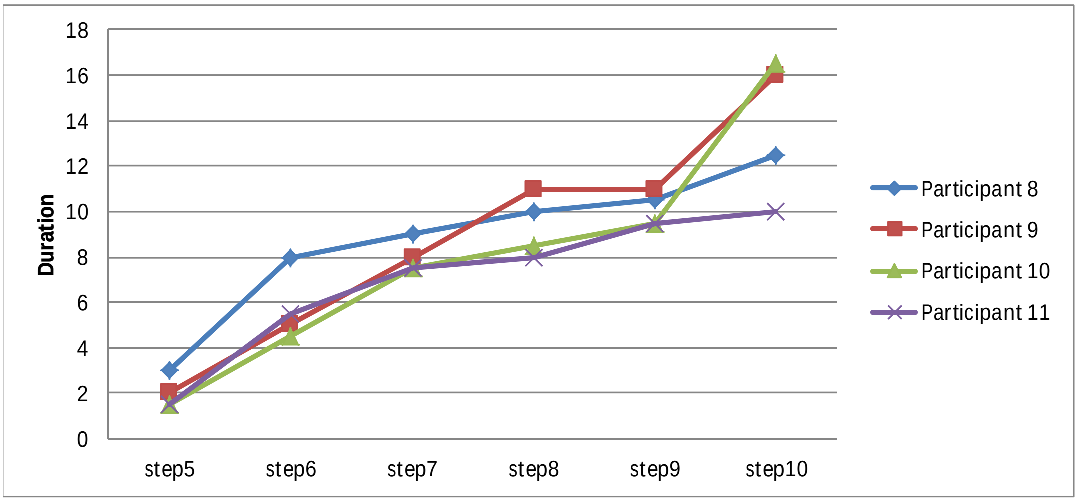


Figure 5.33 Time Spent for Each Step of Improvement of the Design for the Second Group

In the second stage, in which the design was to be improved, the participants in the first group managed to complete the task in an average of 8 minutes, with times ranging between 6 and 9 minutes (Figure 5.32). The participants of the second group, on the other hand, completed the second task in an average of 14 minutes, within a time range of between 10 and 17 minutes, as shown in Figure 5.33. A significant difference is thus apparent between the two groups in terms of time spent on the improvement of the design and the achievement of the second task. After entering the input data into the tool, all of the participants spent between 1 and 3 minutes evaluating the results and feedback (if available), and deciding what to do next. The second group, who received no feedback from EnAd, spent longer evaluating the results and making decisions on what to do to improve the results than the first group. Since all of the participants of the first group followed the explanations and feedbacks, they completed the improvement process in a very short time due to their ability to refer to the performance goals to be achieved in the feedback. On the other hand, all of the participants of the second group spent longer on the improvement of the design, since they were not provided with any explanations or feedback. Although they had an awareness of the factors affecting energy performance, they had difficulty in deciding on what could be done and how much improvement would be required to achieve the performance goal. Other reasons for the second group taking longer over the task may include their lack of knowledge of the performance limits to be achieved, and their inability to follow the effects of their design decisions on the results during the design process. In addition, although the time spent on improving the design differed between the two groups, no difference was observed based on the level of expertise of the individual participants, aside from in those with a better knowledge of materials, who made more conscious selections during their improvements.

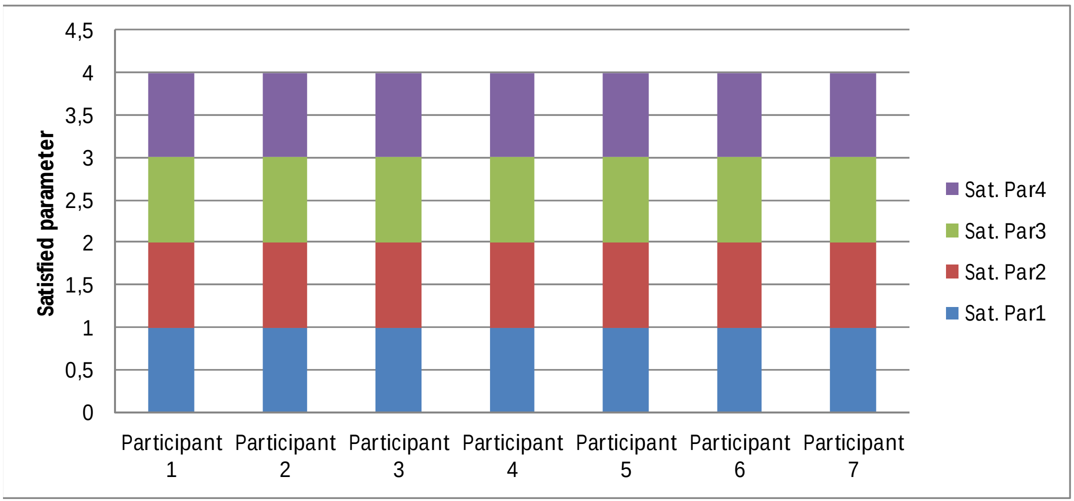


Figure 5.34 Number of Parameters Satisfied Regarding Data Input for the First Group

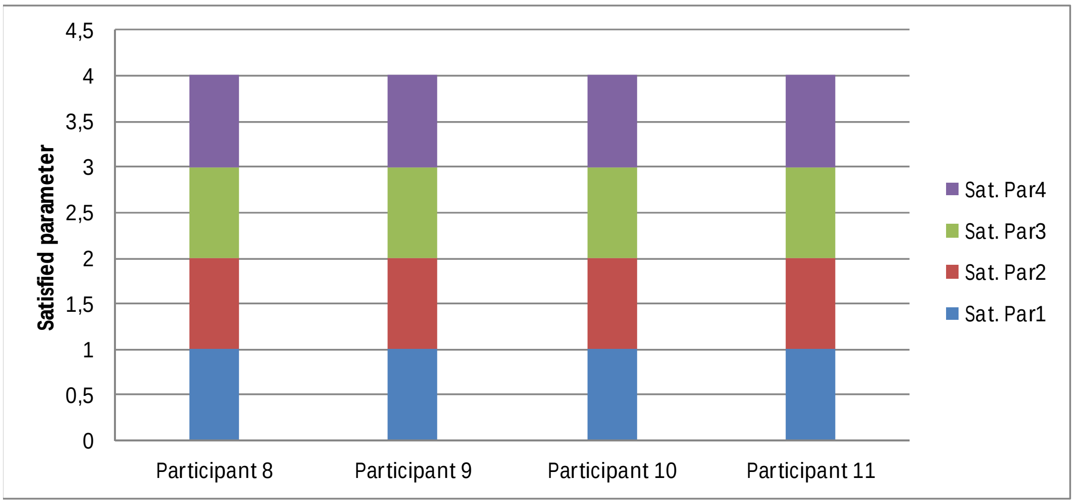


Figure 5.35 Number of Parameters Satisfied Regarding Data Input for the Second Group

As the second aspect of the protocol, participants were expected to satisfy eleven parameters; four of which were in the data input phase, and seven of which were in the improvement of the design. All of the participants of the two groups, regardless of their level of expertise, fulfilled the first four parameters by completing the data input phase, as shown in Figures 5.34 and 5.35. In contrast, not all participants satisfied all of the other seven parameters regarding the improvement of the design. As shown in Figures 5.36 and 5.37, one or two parameters were not satisfied by the participants of the two groups, however, there was a difference between the two groups in terms of their conscious. Three of the participants in the first group who had access to the feedback related to the improvement required did not bother to satisfy that parameter, since they had already achieved the energy performance goal. On the other hand, two participants in the second group failed to notice one or two parameters that should be improved.

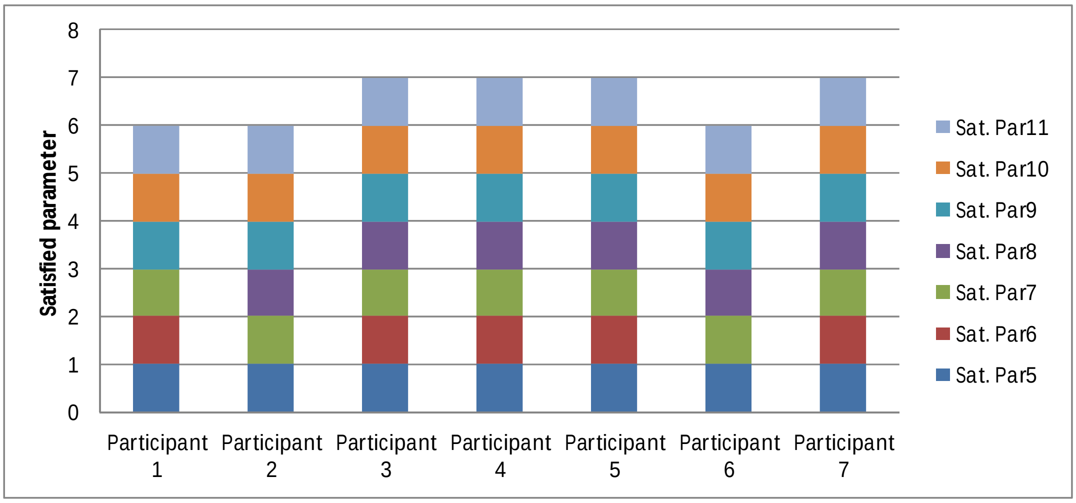


Figure 5.36 Number of Parameters Satisfied Regarding Improvements for the First Group

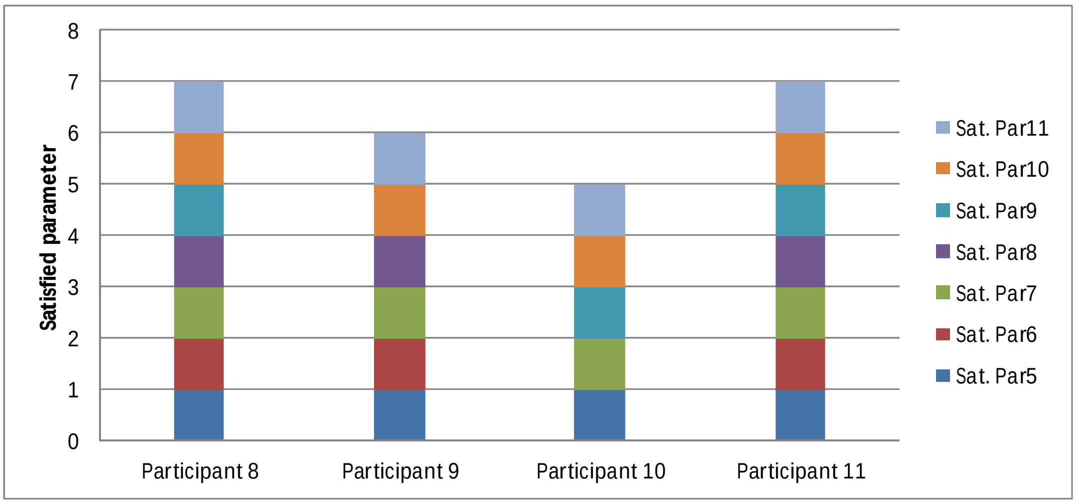


Figure 5.37 Number of Parameters Satisfied Regarding Improvements for the Second Group

All of the participants of the two groups, regardless of their level of expertise, managed to improve the design to the required performance level. The first group was able to complete the test in an average of 24 minutes, within a range of 20 to 30 minutes. The second group, on the other hand, accomplished the test in an average of 32 minutes, within a range of between 26 and 40 minutes. This validates the usefulness of the explanations and feedback provided by the program in improving the design. The durations recorded reveal that using EnAd to assess the energy performance of a building is not a time consuming process, and can be done without the need for complex models. The results of the usability test reveal that the program is proven in its usability, understandability, efficiency and sufficiency, while also being informative for the user. Another important outcome of the usability test came in the form of feedback from the participants, who voiced suggestions related to the means of data input and further explanations and feedback required in the program. Taking this feedback into consideration, improvements have been made to the program interface. The usability test also revealed the need for a wise-guess viewpoint to improve the design, in that the feedback from the tool is provided considering only one or two design decisions, while better improvements could be achieved by evaluating more parameters together. This is related with the expertise level of the user in the subject. The precision and reliability of the program, together with the case studies, are studied in next chapter.

CHAPTER 6

THE EVALUATION OF EnAd: CONVERGENCE, PRECISION, RELIABILITY AND USE OF THE PROGRAM

In this chapter, the validity, reliability range and precision of EnAd is explored in detail through several case studies. To allow a comparison on the results, three different highly acknowledged energy performance evaluation tools have been selected. In addition, several case studies have been sourced, including a reference case that is the worked example in TS EN ISO 13790; generic cases, in which the major features of buildings affecting energy performance were studied in order to observe the validity of EnAd; and five existing building projects for which the energy consumption data is known so as to observe the convergence of the results of EnAd with those of the other programs. The use and potentials of EnAd were demonstrated in a simulation of the previously studied building.

6.1 Programs Selected for Comparative Studies

Evaluation tools in general have several limitations in the benefits they bring to the user so as EnAd. Regardless of the development method or purpose of a computer program, it is imperative that the accuracy of the results is ensured so as to determine the limitations of the program (Özgenel, 2012). In this context, several case studies were conducted to explore the convergence of the results of EnAd with other evaluation programs, for which three different building energy performance (BEP) evaluation tools were selected, namely DesignBuilder, HAP and EnerCalc. Research studies have shown that these are most widely used programs, and are internationally acknowledged with their accuracy and reliability. The programs, developed in different countries, have different calculation methods: DesignBuilder is a comprehensive simulation program, while HAP is mostly used for sizing of HVAC systems. EnerCalc, on the other hand, represents another dimension of BEP analysis, and is based on German building standards. These three programs were analyzed to understand their general features and capacities, and a comparison was made of their program structures, data input requirements and program outputs, as well as the calculation methods used. This comparison allowed the identification of possible reasons for differences between the results of the different programs. It is not the intention in this study to praise or criticize the other programs; as the aim is rather to exemplify the different discussions and approaches to the subject, and in this way, to show where EnAd stands among others. The use of the program names in the comparisons is deemed necessary in the discussion of required input and output data and the results of the programs. The common features of the programs are presented in Table 6.1.

As seen in Table 6.1, EnAd is used for the evaluation of residential and office buildings, while HAP and EnerCalc are developed for commercial buildings. Design Builder can be used for residential buildings as well. Two of the selected programs, HAP and Design Builder, are commercial programs requiring high license fees, while EnerCalc is a freeware program, intended to be used for educational purposes. Similar to EnAd, EnerCalc is developed based on legislation, while HAP and DesignBuilder are simulation programs. EnAd and EnerCalc can be used by any user, whereas HAP and Design Builder require an advanced technical background on the subject. Similar to EnAd, EnerCalc and HAP are text-based tools, while DesignBuilder requires a solid 3D model. Finally, the program language of EnerCalc is German, while the others are in English. The programs are explained in more detail in the following section.

Table 6.1 Common Features of the Selected Programs

	Design Builder	HAP	EnerCalc	EnAd
Area of use	Commercial and residential buildings	Commercial buildings	Commercial buildings	Residential & Office buildings
Availability	Commercial	Commercial	Freeware Educational	Freeware
Primary goal of the tool	Simulation, evaluation	Simulation, evaluation	Evaluation	Evaluation and feedback for design decisions
User profile	Professionals	Professionals	Students and professionals	Any user
Level of expertise to use program	Middle to upper	Middle to upper	Novice to Middle	Novice
Program Language	English	English	German	English
Data Input	Model-based[1]	Text-based Model based[2]	Text-based[3]	Text-based[3]

[1] Images and 2D drawings in dxf file format may be imported for dimension use, while a 3D model should be created in the DB medium, or BIM models may be imported in the gbXML format
[2] Only BIM models in the gbXML format can be imported.
[3] No drawing or modeling file canbe accepted for data input.

6.1.1 DesignBuilder

EnergyPlus is a simulation program that has been developed by the US Department of Energy (DOE), based on the most popular features and capabilities of BLAST and DOE-2, which were the first tools for the energy performance analysis of entire buildings. The tool is validated against IEA BESTEST[33], ASHRAE Standard 140[34] and other analytical tests of ASHRAE[35]. EnergyPlus works in text inputs without a user friendly graphical interface, which makes the program difficult to use for decision making.

DesignBuilder, as a new program, has been developed based on EnergyPlus with the added feature of a user-friendly interface (Figure 6.1). Similar to EnAd, the results of the program can be used for BEP certification purposes in the UK and Ireland. It also contains the EnergyPlus construction library and the UK construction library as standard, while allowing new libraries to be created by the user. It features an integrated solid modeler – OpenGL – which is used for modeling simple buildings. The tool also accepts solid 3D models produced by BIM tools. Depending on user preference, the tool can work with its own simulation engine or with the EnergyPlus engine. One disadvantage of DesignBuilder is that it requires some expertise for detailed data input, and offers no guidance regarding the minimum or maximum values for the inputs.

[33] IEA BESTEST, standing for International Energy Agency Building Energy Simulation TEST, is a test program to check the simulation capabilities of building energy design and analysis tools for detailed hourly (or shorter) time-step simulations.
[34] ANSI/ASHRAE Standard 140-2001 Standard Method of Test for the Evaluation of Building Energy Analysis Computer Programs
[35] EnergyPlus Energy Simulation Software, Testing and Validation. http://apps1.eere.energy.gov/buildings/energyplus/energyplus_testing.cfm, last accessed on 14th August 2012.

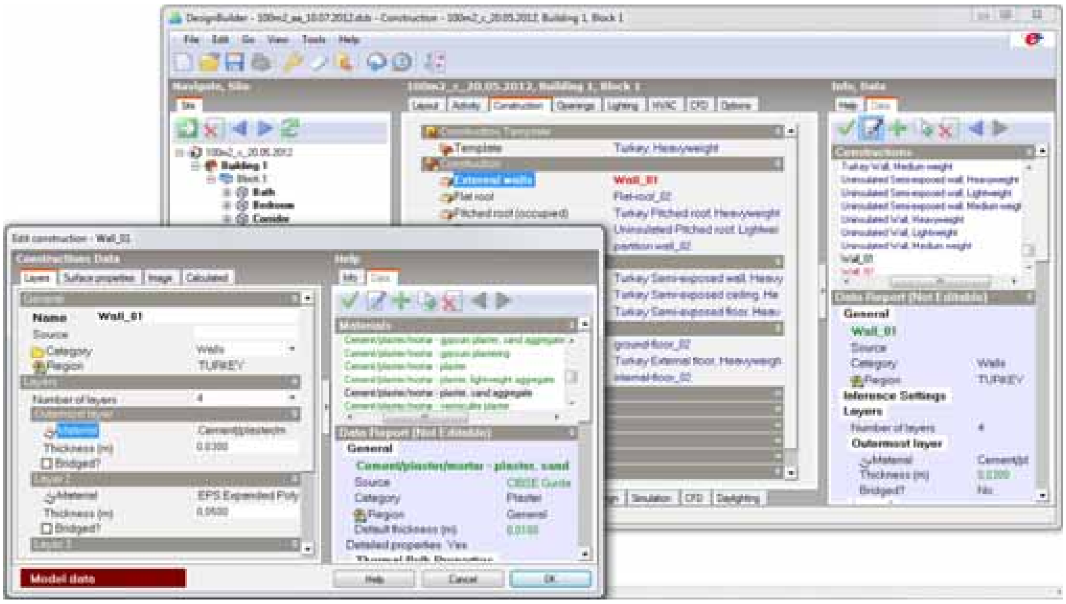


Figure 6.1 DesignBuilder User Interface for Data Inputs

6.1.2 Hourly Analysis Program (HAP)

The Hourly Analysis Program (HAP), developed by Carrier, has two functions: hourly building energy assessment and commercial HVAC sizing. The tool is validated by the ASHRAE Standard 140, and the evaluation results can be used in LEED certification. It is the most widely used program in Turkey for system sizing and cooling load calculations.

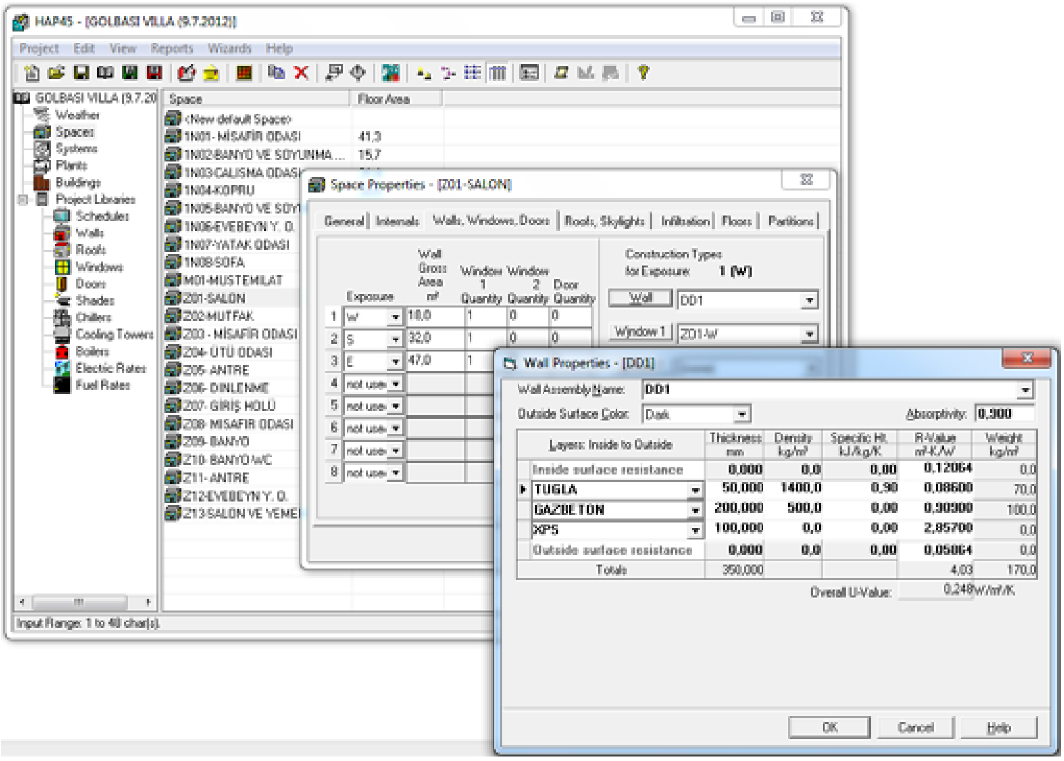


Figure 6.2 HAP User Interface for Data Inputs

HAP is very similar to EnAd in the sense that it is a text-based tool that requires entering the sizes of each surface according to orientation. It also has a very rich material library and a user-friendly interface (Figure 6.2). HAP has no integrated modeling tool; however it does accept the import of BIM models. Since the tool is developed for the sizing of HVAC systems, it requires advanced technical knowledge on the subject. The program provides very rich output files for input data and simulation results, including graphs and tables, which can be used in energy reports, but the preparation of results can take time, depending on the desired set of outputs, which include comparative reports for annual cost and energy, detailed reports for monthly energy use and cost, summary reports for annual energy budgets and component cost, and graphs and tables.

6.1.3 EnerCalc

In parallel to the development and evaluation approach of EnAd, EnerCalc has also been developed based on building standards, though in this case German, which are both reliable, consistent. In order to control the code compliance of buildings, DIN V 18599 has been developed as a calculation tool on the standard series of DIN V 18599 for the energy efficiency of buildings, describing the calculation of energy needs, and the delivered energy and primary energy for heating, cooling, ventilation, domestic hot water and lighting. The tool is validated by DIN V 18599 standards. On the downside, the data sheet-based calculation tool consists of more than 20 sheets, and is very complicated, requiring a high level of expertise.

Figure 6.3 EnerCalc User Interface for Data Inputs

As shown in Figure 6.3, EnerCalc, a data sheet-based calculation tool, is a simplified version of the DIN V 18599 tool. The freely available tool was developed as part of a PhD study by Markus Lichtmess, and is mostly used for educational purposes in Germany. Similar to EnAd, it provides explanations for some input data, and graphs on the input page allowing the effect of changes to be seen in the results. It is an easy-use tool, but does not permit any files to be imported, but on the downside, the tool does not control the accuracy or consistency of the data entered, and it lacks a material library. In addition, the software only allows three U-values to be entered, for the walls, ground floor and roof. Window types can be selected from a list provided, but no changes to window properties can be made.

6.1.4 EnAd

Here, it is important to position of EnAd as a soft tool among the above examples. EnAd is intended primarily as a decision support tool for architectural design processes. It aims to evaluate the energy performance of residential and office buildings and to provide feedback to the user in order to improve energy performance. The tool has been developed based on EPBD, TS EN ISO 13790 and Turkish BEP Regulations and related documents, and treats legislation as the design goal and the constraints.

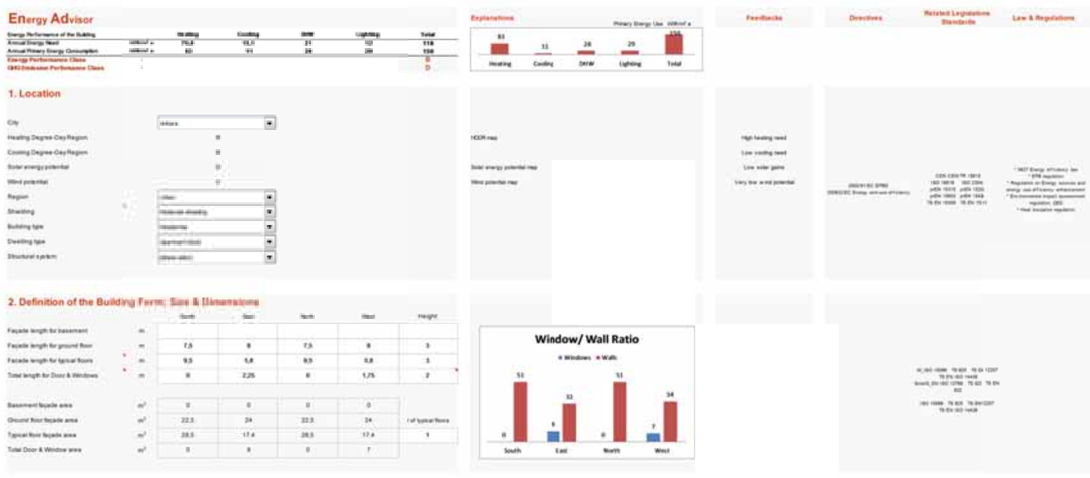


Figure 6.4 EnAd User Interface for Data Inputs

The tool offers a user-friendly flexible interface that does not require any advanced expertise. It features a rich material library that permits the addition of new materials. The graphical and text-based feedback helps the user to improve designs during the decision-making process.

6.2 Structures of Evaluation Programs Selected

The evaluation tools selected for comparison studies all have different program structures, including several data packages, grouping inputs and outputs depending on the analysis methodology followed. Similarities and differences can be noted in the data inputs and outputs of the programs. In terms of similarities, each program follows almost the same logic. Data input begins with the selection of location or weather data, after which it is necessary to define a building form and material properties. The final step is to determine the HVAC system options with a schedule of use. According to the design, each tool produces the energy requirement and/or use scales for a given period of time. Figure 6.5 presents the general structure of building energy performance assessment tools; however the number or order of steps or data packages differs between tools.

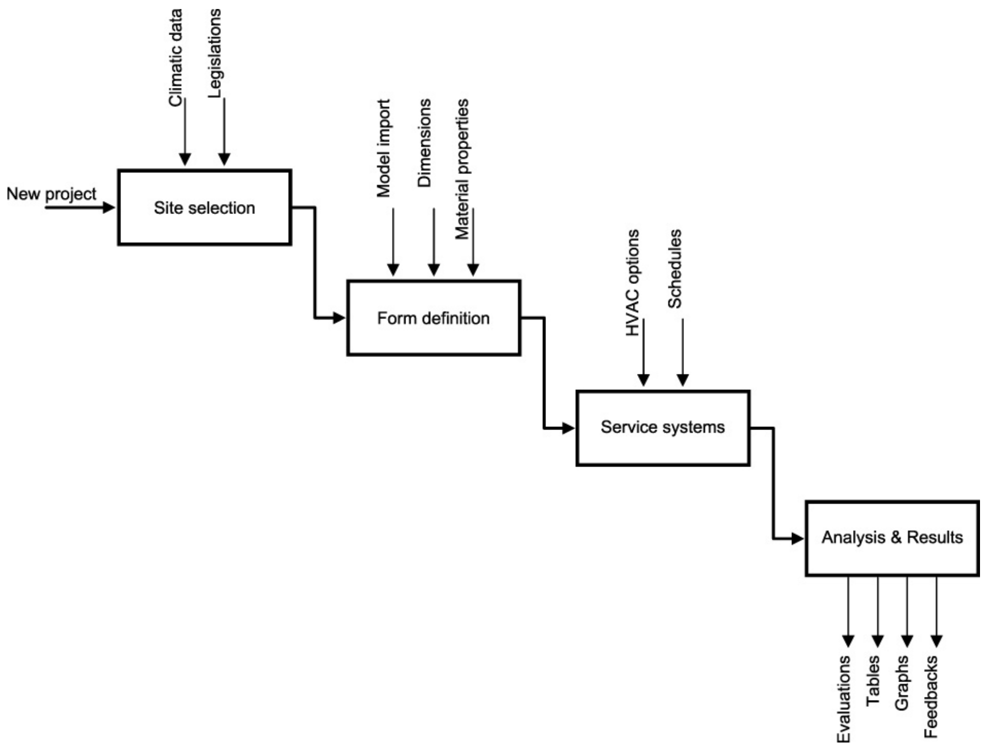


Figure 6.5 General Structure of Building Energy Performance Assessment Tools

In order to map systematically the differences in program structures, the main objectives of these programs are summarized in Figure 6.6, providing details on their common features and differences. In all three programs, and in EnAd, the input of the location is the first step in the evaluation process; however one of the major differences between the programs is the use of different climatic data. EnAd and EnerCalc use national climatic data, while the others use the international weather data approved by ASHRAE. Another difference can be noted in the code compliance. Since these programs are developed by different countries, they are required to comply with different standards and legislations. EnAd is based on Turkish legislation; EnerCalc is compatible with German standards; HAP is based on ASHRAE standards; while DesignBuilder is compatible with Part-L of the UK and Ireland Building Regulations, as well as ASHRAE standards.

As seen in Figure 6.6, all these programs and EnAd require defining building form as thermal zones in text-based data input, except DesignBuilder requiring 3D solid model. In all programs, properties of building envelope are determined by U-values, material layers, window properties, shade, thermal bridges and infiltration while EnAd does not include thermal bridges in the evaluations. And EnerCalc does not provide a material library or material layers for the building envelope.

Figure 6.6 also shows that all these programs and EnAd evaluate all service systems used in a building, some of which are not available in HAP including natural ventilation and DHW use. Regarding schedules, EnAd uses the schedules defined by TS EN ISO 13790 and BEP Regulation as default while allowing the user to define duration of use for the service systems. Other programs provide default schedules allowing changes to be made.

As can be seen in Figure 6.6, each of the four tools performs performance analyses for different time intervals. All four programs make monthly and annual evaluations, while the simulation tools, DesignBuilder and HAP, allow for hourly and daily analysis as well. All of the programs present the evaluation results in graphs and tables as well as reports. Besides these, EnAd also provides feedback to the user to assist in improving design decisions, and informs the user of the related legislations to be covered during the design process.

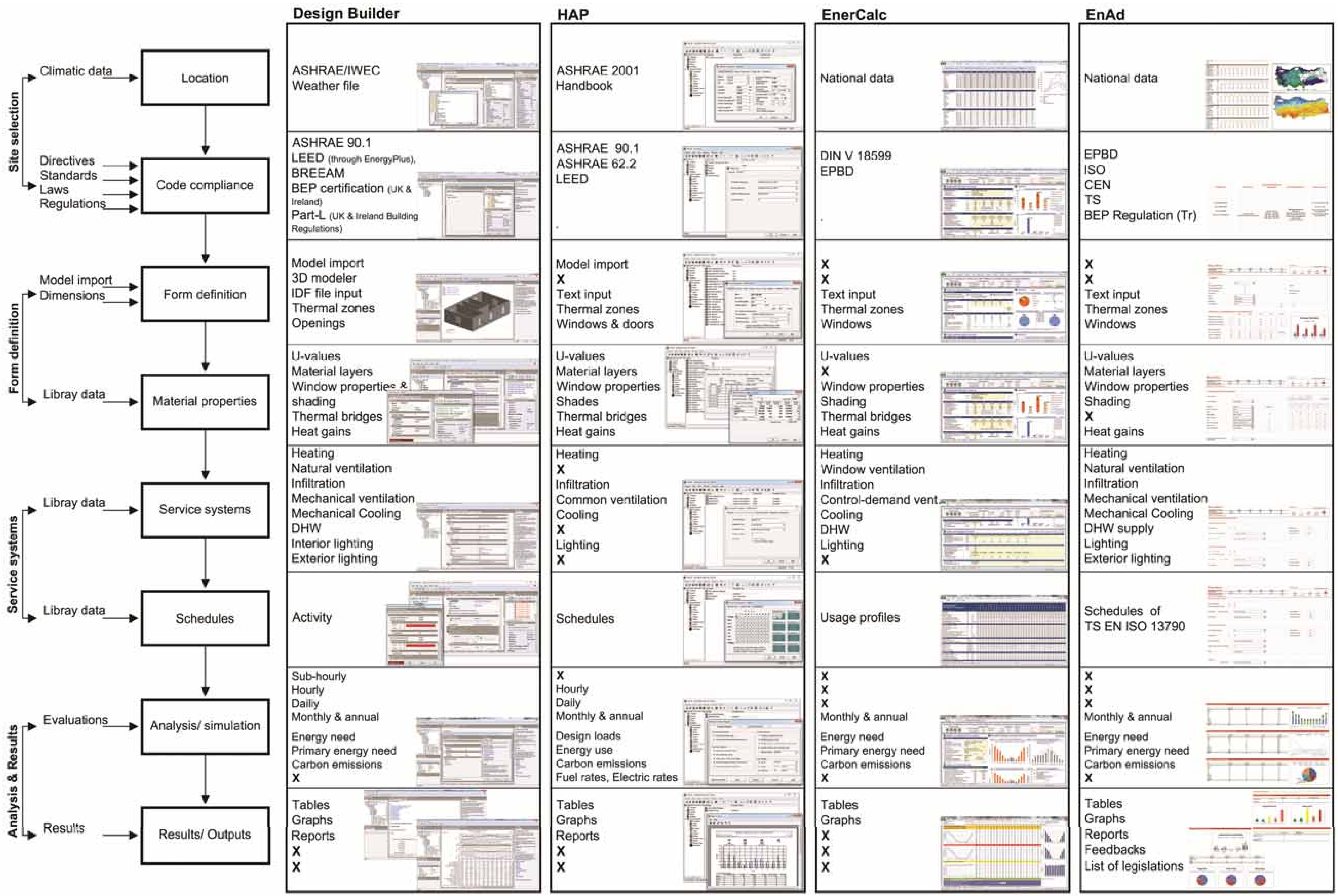


Figure 6.6 Comparison of Program Structures of the Selected Evaluation Tools

In order to compare the structures of the assessment tools more systematically, it is beneficial to group the evaluation steps under four main headings: (1) site selection, including climatic data and code compliance, (2) form definition with material properties, (3) service systems and schedules, and (4) evaluations and the results of the programs.

6.2.1 Site Selection

For location and climatic data, EnAd uses national weather data for Turkey, while IWEC weather data for selected cities is also introduced to the program to minimize differences in the case studies resulting from the use of different climatic data. HAP and Design Builder use the international weather data approved by ASHRAE, including ASHARE 2001 Handbook and ASHRAE/IWEC, whereas EnerCalc uses national weather data for Germany. All four programs claim they allow existing weather data to be modified or edited, and/or permit the introduction of new data. The international weather data used by these simulation tools claims to be editable, however the files have hourly average data for a ten-year period for each city, making it almost impossible to modify these files. Table 6.2 provides the input data required for defining the location of a building.

Table 6.2 Input data on the location of a building

	Design Builder	HAP	EnerCalc	EnAd
Climatic data	ASHRAE/IWEC (P)[1]	ASHRAE 2001 Handbook (P)	National data (E) [2]	National data (E) [3]
Code compliance	ASHRAE Part-L Building regulations	ASHRAE	DIN V 18599 EPBD	EPBD TS EN ISO 13790 Turkish BEP Regulation
Certification	LEED BREEAM The UK BEP certification	LEED	German BEP certification	Turkish BEP certification

E: Editable P: Partly editable

[1] Although international weather data used by the simulation tools claims to be editable, the files have hourly average data for a ten-year period for each city, making it almost impossible to modify these files.

[2] The program has weather data for one general and 16 climatic regions in Germany. If required, weather data can be introduced to the program for different cities and countries.

[3] The program has weather data for 81 cities in Turkey. If required, new weather data can be introduced to the program for different cities and countries.

Since EnAd and EnerCalc are developed based on national energy performance standards and regulations, their results can be used for BEP certification. Since HAP is an approved simulation software according to ASHRAE Standard 140, the outputs are accepted and may be used in LEED certification. Design Builder outputs are accepted by ASHRAE 90.1 and LEED certification through EnergyPlus, and by BREEAM.

6.2.2 Form Definition

The definition of building form and the properties of the building envelope is the most important data input step for each program. This step covers a wide range of data, starting from the introduction of the building form, zoning, construction type, shading and thermal bridges, to heat losses and heat gains. This is presented in Table 6.3, which shows the availability of each option in each program, as well as the way the data is handled by the programs, such as editable, un-editable, partly editable, optional and not applicable. Table 6.3 also shows the default values and the formula used by the programs, if available, to show the differences between the calculations and methods used by the programs.

Table 6.3 Inputs for Form Definition and Material Assignment

	Design Builder	**HAP**	**EnerCalc**	**EnAd**
Introduction of the geometry				
2D-3D model import	Both (E)	Only 3D (E)	**NA**	**NA**
Embedded CAD	✓ (E)	**NA**	**NA**	**NA**
Text-based data[1]	**NA**	✓ (E)	✓ (E)	✓ (E)
Net area in the computation	Internal dimensions of the model	Manual input (A_n)	Manual input (A_n)	Average (V_{brut}*0,32)
Net volume in the computation	Internal dimensions of the model	Calculated (A_n *h_{int})	Calculated (A_n *h_{int})	Average (V_{brut}* 0,8)
#/density of occupants	people/m^2	# of people or m^2/people	**x**	# of people
Zoning (thermal zone)	Single or multi-zone[2]	Single or multi-zone	Single or multi-zone[3]	Single zone
Construction				
Construction type	✓ (3) (E)	✓ (3) (E)	✓ (3) (O)	✓ (3) (E)
Light		Building weight (146.5 kg/m^2)	S. heat capacity (50 Wh/(m^2K)* A_f)	S. heat capacity (110,000 (J/K)* A_f)
Medium		Building weight (341.8 kg/m^2)	S. heat capacity (90 Wh/(m^2K)* A_f)	S. heat capacity (165,000 (J/K)* A_f)
Heavy		Building weight (634.7 kg/m^2)	S. heat capacity (130 Wh/(m^2K)* A_f)	S. heat capacity (260,000 (J/K)* A_f)
Material library	✓ (100+) (E) [4]	✓ (100+) (E) [4]	**x** (U-values) [5]	✓ (100+) (E) [6]
Windows	✓ (100+) (E)	✓ (100+) (E)	✓ (13) (O)	✓ (14) (E)
Window frames	✓ (7) (E)	✓ (4) (E)	✓ (8) (O)	✓ (8) (O)
Shading				
from external objects	✓ (E)	✓ (E)	✓ (O) $F_S = \min(F_h; F_o; F_f)$ [7]	✓ (O) $F_S = F_h . F_o . F_f$ [7]
Window shade	✓ (O)	✓ (E)	✓ (O)	**NA**
Thermal bridges	Default (O) [8]	✓ (E)	DIN (O)	**NA**
Heat losses			$Q_{ht} = Q_{tr} + Q_{ve} + Q_{l,loss} + Q_S$ [9]	$Q_{ht} = Q_{tr} + Q_{ve}$
Solar gains	✓ (U)	✓ (E)	✓ (U) - $Q_{S,tr} = F_F A g_{eff} I_S t$ (transparent) $g_{eff} = F_S F_w F_V g_\perp$ $Q_{S,op} = R_{se} U A (\alpha I_S - F_f h_r \Delta\theta_{er}) t$ for $\alpha I_S > F_f h_r \Delta\theta_{er}$ (heat gain) (opaque) $Q_{S,op} = R_{se} U A (F_f h_r \Delta\theta_{er} - \alpha I_S) t$ for $\alpha I_S < F_f h_r \Delta\theta_{er}$ (heat loss) (opaque) [10]	✓ (U) $Q_{sol} = (F_{sh,ob} . A_{sol} . I_{sol} - F_r . \Phi_r) t$ $A_{sol,gl} = F_{sh,gl} . g_{gl} . A_{win} . (1 - F_F)$ $A_{sol,op} = \alpha_{sol,em} . R_{se} . U_{op} . A_{op}$ $\Phi_r = R_{se} . U_{op} . A_{op} . h_r . \Delta\theta_{er}$
Internal gains	Default	ASHRAE	Default	TS, ASHRAE
Average	**NA**	**NA**	**NA**	✓ (E)
Living+Kitchen	**NA**	**NA**	**NA**	✓ (U)
Other spaces	**NA**	**NA**	**NA**	✓ (U)
Occupancy	✓ (E)	✓ (E)	✓ (E)	✓ (U)
Office equip.	✓ (E)	✓ (E)	✓ (U)	✓ (U)
Catering	✓ (E)	**NA**	**NA**	**NA**
Lighting	✓ (U)	✓ (U)	✓ (U)	✓ (U)
DHW use	**NA**	**NA**	✓ (U)	✓ (U)
HVAC system	**NA**	**NA**	✓ (U)	**NA**
Other	✓ (E)	✓ (E)	✓ (U) $Q_l = Q_{l,p} + Q_{l,L} + Q_{l,fac} + Q_{l,goods} + Q_{l,h}$ [11]	**NA** $Q_{int} = \Phi_{int,mn}\, t$ $\Phi_{int} = \Phi_{int,sen,D} + \Phi_{int,sen,M} + \Phi_{int,App,lat} + \Phi_{int,Occ,lat} + \Phi_{int,W} + \Phi_{int,lg}$ [12]

E: Editable U: Un-editable P: Partly O: Optional NA: Not Applicable

[1] Size, dimensions and number of components introduced to the given cells

[2] All rooms should be modeled with an activity assignment. Each zone is introduced as conditioned or unconditioned; occupied or unoccupied; and/or include in thermal zone calculations or not.

[3] A single zone assessment is performed for residential buildings. For non-residential buildings, after the introduction of the building dimensions, the sizes and schedule of each zone are introduced one by one.

[4] The program features a rich material library, and allows the addition of new items, both for default values and component layers.
[5] The program only provides three types of construction (light, middle and heavy construction). The U-values for surfaces (wall, floor and ceiling) are introduced by the user. There are limited types of glass and frame.
[6] The program gives special importance to the building envelope, and thus it has a very rich material list for component layers, as well as default values, and allows the introduction of new materials.
[7] EnerCalc takes minimum shading from the horizon, overhang or fins; while EnAd takes a multiplication of all factors.
[8] Thermal bridges can be taken into account if the user checks the related box. Thermal bridge calculations are handled by the program, that is, the value cannot be changed by the user.
[9] Besides heat flow due to heat transfer and ventilation, it includes heat flow due to internal heat losses and radiative heat transfer
[10] Although the formulas seem to be different, they are almost the same.
[11] Internal heat gains from occupants, lighting, electrical equipment, goods/materials, heating/cooling system. Instead of calculation, all values are taken from DIN 18599-10 usage profiles lists.
[12] Sensible and lateral gains from occupants and electrical equipment, DHW use, lighting.

As seen in Table 6.3, the introduction of the building form is handled in different ways in the programs. EnAd, EnerCalc and HAP work on text-based input, while DesignBuilder requires a solid 3D model or an EnergyPlus data input file. EnAd and EnerCalc do not accept any file imports, while HAP and DesignBuilder accept BIM models for import. Each tool makes different assumptions for the net floor area and volume included in computation. EnAd evaluates a building depending on the average net area derived from the gross volume, as described in the building standards; DesignBuilder considers the net construction area depending on internal dimensions of the model; while HAP and EnerCalc require inputting the net area and interior height manually, and compute the net volume accordingly. The conditioned net area and volume values included in the computations affect both internal gains and losses, and energy requirement values per building and per area. For example, for a building of 100 m^2 gross area and 300 m^3 gross volume, EnAd calculates a 96 m^2 net area and a 240 m^3 net volume; while Design Builder considers this building as having an 88.83 m^2 net area and a 264 m^3 net volume. When the 89 m^2 net area is introduced to HAP and EnerCalc, and the interior height as 2.8m, the tools assume a net volume of 249 m^3. Accordingly, the results are different among the programs, and as the project gets larger, so does the discrepancy.

As seen in Table 6.3, when defining the number of people in a building, the different evaluation tools require the same data, but define it in different ways, like area per person, person per area or number of people. EnAd requires only the number of people, while DesignBuilder requires the number of people per unit, and HAP accepts both the number of people per unit and the area per person. Considering the zoning of buildings, EnAd evaluates a building as one thermal zone, while the other tools allow both single- and multi-zone evaluation, considering the functional use of each zone.

Once the building form is introduced, the properties of the building envelope are determined. EnAd gives paramount importance to the detailed definition of each building component, and accordingly it features a rich material library that allows the addition of new materials. Material properties can also be introduced either using the default values found in legislation or manually by introducing material layers using the material library. Similarly, DesignBuilder and HAP both feature an editable material library, while EnerCalc has neither a library nor material layers. As shown in Table 6.3, all four programs define three types of construction, light, medium and heavy, however the default values for each type are different in each program. Construction type values can change according to each country since construction types depend strongly on local traditions. This value affects the time constant of the building, which is used to determine the length of seasons and/or hours required for the heating and cooling of a building. In this regard, the differences between construction types results in discrepancies in the evaluations, which should also be taken into account. Considering the window properties, all programs have editable options for windows and window frames, except EnerCalc, which does not allow changes in the properties.

Table 6.3 shows that all tools consider shading from external objects, while the effects from window shading and thermal bridges are disregarded in EnAd, one reason for which is that

TS 825 suggests windows without curtains and internal shade be assumed in residential buildings. Another reason is that the computations required calculating thermal bridges are excessive for making an assumption about the length and area of the building components that cause thermal bridges. In addition, there is no nationally accepted average value for the evaluation of thermal bridges.

As can be seen in Table 6.3, all programs take solar gains into account in their evaluations; however the method/formula is not known for all. Furthermore, since the programs use different climatic data, solar gain calculations differ between the programs and lead to different results. Another important source of heat in the evaluations are internal heat gains, which are also taken into account in very different ways by the individual tools. Heat gains from solar and internal heat sources are not fully controlled by the users, and thus result in differences in results. This matter should be taken into consideration when making comparisons.

6.2.3 Service Systems Used in Buildings

The third group of data required by the programs for the evaluations is related to the service systems used in the buildings, including heating, cooling, ventilation, domestic hot water, lighting etc. As in the form definition, service systems are introduced into each program in different ways. Table 6.4 summarizes the service systems and their means of introduction into each tool with the input data required by the programs, options, default values and formulas.

As can be seen in Table 6.4, all four tools require a determination of the properties of the space heating system, including the type of heater, the fuel type and its energy efficiency, as well as the heating set-point temperature, the use of a programmer or thermostatic control and primary energy conversion. EnAd, referring to the UK SAP database, features a rich library of heaters, detailing the fuel type and equipment efficiency. EnerCalc, on the other hand, provides only a limited number of standard boilers, detailing their fuel type and equipment efficiency, while DesignBuilder asks for data only on fuel type and equipment efficiency. HAP, which has been developed for the HVAC system sizing of commercial buildings, requires very detailed information about the heating system, including boiler capacity, overall efficiency, fuel type, boiler accessories, hot water flow rate, performance rating, equipment data, system sizing data inputs, etc. In all programs, the heating set-point temperature and programmer control can be selected by the user, aside from DesignBuilder which has no programmer option. Equipment efficiency, on the other hand, is the coefficient of performance (CoP) for the equipment, which can be edited by the user in all tools except EnerCalc. As mentioned in section 3.9, all four tools have their own coefficients for primary energy conversion, which are uneditable. For example, according to the national values EnAd uses primary energy conversions of 2.36 for electricity and 1 for natural gas; while EnerCalc uses 2.60 and 1.10; DesignBuilder uses 3,167 and 1,084; and HAP uses 3,56 and 1. Although the conversion coefficients for natural gas seem to be very close to each other in all programs, those for electricity are very different, which also leads to differences in the results.

Table 6.4 Inputs for Service Systems

	Design Builder	**HAP**	**EnerCalc**	**EnAd**
Space heating				
Heater type	Default (E)	Default (E)	✓ (8) (O)	✓ (75) (O)
Fuel type	✓ (7) (O)	✓ (4) (O)	**NA**	**NA**
Heating set temp.	18°C (E)	21°C (E)	20°C (E)	20°C (E)
Programmer	**NA**	✓	✓ (3) (O)	✓ (3) (O)
Equipment efficiency	1 (E)	Default (E)	Default (U)	Default (E)
Pr. En. Conv.	Default (U)	Default (U)	Default (U) $Q_{H,nd}=Q_{H,ht}-\eta_{H,gn}Q_{H,gn}$ $\eta=(1-\gamma^{a})/(1-\gamma^{a+1})$ if $\gamma\neq1$ [1] $\eta=a/(a+1)$ if $\gamma=1$	Default (E) $Q_{H,nd}=Q_{H,ht}-\eta_{H,gn}Q_{H,gn}$ $\eta=(1-\gamma^{a})/(1-\gamma^{a+1})$ if $\gamma>0$ $\eta=a/(a+1)$ if $\gamma=1$ $\eta=1/\gamma_{H}$ if $\gamma<0$
Space cooling				
Conditioner	**NA**	✓ (E)	✓ (7) (O)	✓ (3) (O)
Fuel type	✓ (7) (O)	✓ (4) (O)	**NA**	**NA**
Cooling set temp.	24°C (E) **NA**	25°C (E) Default (E)	26°C (E) **NA**	26°C (E) **NA**
Min. set point control	**NA**	**NA**	**NA**	✓ (10) (O)
Efficiency class	1 (E)	✓ (E)	Default (U)	Default (U)
CoP	Default (U)	Default (U)	Default (U)	Default (U)
Pr. En. Conv.			$Q_{C,nd}=Q_{C,gn}(1-\eta_{C,ls})$ [2]	$Q_{C,nd}=Q_{C,gn}-\eta_{C,ls}Q_{C,ht}$
DHW supply	International	**NA**	to area or person	TS
Water heater	**NA**		**NA**	✓ (7) (O)
Fuel type	✓ (7) (O)		**NA**	**NA**
Use water temp	65°C (E)		**NA**	50°C (E)
Supply water t.	10°C (E)		**NA**	10°C (E)
Daily usage	l/m² d (E)		Wh/m²d kWh/p d (U)	l/p d kWh/p d kWh/m² d (E)
CoP	1 (E)		1 (U)	Default (E)
Pr. En. Conv.	3,167 (U)		2,60 (U) $Q_{w,b} = q_{w,b} * d_{mth}/365 * d_{nutz}$ *reference [3]	2,36 (U) $Q_{w,b} = p.c.V_{w}.(\theta_{w,m}-\theta_{k})t$
Ventilation				
Natural Vent.	✓ (E)	**NA**	✓ (O)	✓ (O)
Mechanical Vent.	✓ (E)	✓ (E)	✓ (O)	✓ (E)
Infiltration	✓ (E)	✓ (E)	✓ (O) $Q_{ve} = \Sigma H_{ve} (\theta_{i}-\theta_{e}) t$ $H_{ve}=H_{ve,win}+H_{ve,mech}+H_{ve,inf}+H_{ve,U}$ $H_{ve} = p.c.V.n$	✓ (E) $Q_{ve} = \Sigma H_{ve} (\theta_{i}-\theta_{e}) t$ $H_{ve}=H_{ve,win}+H_{ve,mech}+H_{ve,inf}+H_{ve,U}$ $H_{ve} = p.c.V.n$
Interior lighting				
Luminaire type	✓ (5) (O)	✓ (3) (O)	**NA**	**NA**
Lamp type	NA	NA	✓ (13) (O)	✓ (3) (O)
Radiant fraction	✓ (E)	✓ (E)	according to lamp type (U)	according to lamp type (U)
Lighting /Power	W/m² (E)	W/m² (E)	lux $Q_{l} = p.[A_{TL}(t_{eff,day,TL}+t_{eff,night,TL})+A_{KTL}(t_{eff,day,KTL}+t_{eff,night,KTL})]$ [4]	W; W/m² (E) $W_{year}=[(52*5*P_{hi})+((52*2+1)*P_{hs})]/1000$ [5]
Exterior lighting	✓	**NA**	**NA**	✓
Schedules				
Type	Default (E)	Default (E)	Default (DIN)	Default (ISO; BEP Regulation)
Time step	24 hours (E)	24 hours (E)	24 hours (E)	24 hours (P)*

[1] Different from ISO, DIN standards accept two types of gain-loss ratio.
[2] In cooling energy need computations, DIN standards only consider heat gains and assume that there is no heat loss.
[3] DHW need is calculated depending on daily and monthly coefficients and per unit/person use profiles.
[4] It considers areas with/out daylight and with day and night usage patterns.
[5] It computes the need for artificial lighting depending on the number and power of lamps and weekdays and weekend coefficients.

In a similar way, mechanical cooling is introduced to all programs by determining the types of air conditioner, its fuel type and CoP, as well as its cooling set-point temperature and primary energy conversion coefficient. EnAd also provides ten energy efficiency classes for air-conditioners for ease of use, ranging from G to A+++, as determined in Directive 2010/30/EU[36]. The tool also provides three options for cooling: no cooling, continuous cooling and intermittent cooling, for which it is assumed to work six hours a day according to TS EN ISO 13790. EnerCalc provides several standard options for air conditioners, while DesignBuilder needs only the fuel type and CoP value. HAP requires defining plants, chillers and/or cooling towers, as well as very detailed data inputs such as cooling equipment, system sizing data, sizing specifications, safety factors, cooling tower model, condenser properties, chiller properties, minimum set point control properties, fluid temperatures, flow rates, capacity and performance rates.

Table 6.4 shows that DHW is included in the calculations of three of the tools, considering water heater, fuel type, supply water temperature and use water temperature. In order to calculate the energy requirement for DHW, daily usage should also be determined, which is handled in different ways in each program. For instance, EnAd assumes 60 lt per person per day for a single-family house, and 45 lt/pd for multi-family houses, while DesignBuilder requires inputting daily consumption as liter per unit (l/m^2d). EnerCalc determines daily energy needs for DHW according to monthly coefficients and the daily usage patterns determined in DIN 18599-10 per unit as Wh/m^2d or per person as kWh/pd. HAP, on the other hand, does not include DHW use in the evaluations, but the daily energy requirement for any system and DHW is given, and the tool computes the annual energy need accordingly. In the case studies, the daily energy requirement for DHW is introduced to the tool, which will be explained in the following sections.

As can be seen in Table 6.4, in terms of the physical calculations, although DIN standards recognize ISO standards, and at first glance appear to be similar to ISO, in fact, they differ in some of the assumptions made, and this is more obvious in the calculations of energy requirements for heating and cooling. For instance, the heating energy requirement formula is the same with that of ISO 13790; however the gain-loss ratio (γ) is calculated in a different way. In cooling energy requirement computations, DIN standards consider only heat gains and assume that there is no heat loss. This seems to be logical itself, but when compared with ISO, a discrepancy between the standards and tools becomes inevitable.

Buildings can be ventilated naturally or by mechanical means. All four tools evaluate the natural ventilation, mechanical ventilation and infiltration in buildings, however HAP, which is designed specifically to deal with commercial buildings, does not cover natural ventilation directly. According to ASHRAE standards, the tool considers only mechanical ventilation, but natural ventilation can be introduced as infiltration. EnAd provides for two types of natural ventilation: minimum ventilation (i.e. with a 0.3 ac/h airflow rate for residential buildings) and natural ventilation, for which the airflow rate is determined according to the shielding of the building considered. For infiltration, the tool determines infiltration based on the airtightness of the building envelope, for which the default values of the BEP Regulation are adopted. Design Builder requires the set point temperatures for natural and mechanical ventilation, outside air definition method (by zone or by minimum fresh air per person), outside airflow rate, schedule, minimum fresh air per person and mechanical ventilation per area. Since minimum, maximum or optimum values for these requirements are not provided by the program, such inputs can be complex for the new low-end users. HAP provides two options for mechanical ventilation, which are direct or common ventilation. There is no other requirement for direct ventilation. On the other hand, the tool requires very detailed data inputs to define common ventilation system components, including airflow control, ventilation sizing method, minimum airflow, damper leak rate, minimum and maximum CO_2 differential rates, etc. EnerCalc, on the other hand, requires the determination of ventilation type, the control type and the heat recovery efficiency of the system.

All four tools consider artificial interior lighting, while exterior lighting is only taken into account in EnAd and DesignBuilder. In all programs, the energy need for interior lighting is

[36] Directive 2010/30/EU with regard to the energy labeling of air conditioners

calculated according to the luminaire type, lamp type, the radiant fraction value for evaluation coefficients as well as lighting power, as either W/m^2 or lux. Although each tool requires different types of data, as shown in Table 6.4, the interior lighting calculations are the same for all tools.

HVAC systems work according to schedules defined by the user or by the default values of the tools. Schedules can be adjusted to desired hours of a day, months and year. EnAd has developed for the evaluation of residential and office buildings for the start up. TS EN ISO 13790 assumes the service systems of residential buildings are always in operation and so accepts some correction coefficients rather than schedules. In this respect, for residential buildings, the tool uses the coefficients defined by TS EN ISO 13790 and the BEP Regulation while it requires hourly schedules for office buildings. EnerCalc requires the definition of usage profiles for each zone, including information about the service and operating hours, lighting, indoor air, heat gains, set point temperatures for heating and cooling, specific geometries and mechanical ventilation options. HAP uses three types of schedule, which are utility rate time-of-day, fan/thermostat and fractional (occupancy, lighting, equipment, ventilation airflow, electric, etc.). Hourly profiles are scheduled for a 24-hour period, and the program allows for the setting of eight profiles, which are assigned to the design day, holidays, and the days of the 12 months in a year. DesignBuilder, on the other hand, requires defining very detailed 'activity' templates for each zone, which include occupancy, metabolic rates, DHW consumption rate, set point temperatures for heating, cooling, and natural and mechanical ventilation, minimum fresh air requirements, illuminance requirements, and electrical equipment information for gains. Use periods for each item are scheduled as hours or sub-hours for weekdays, weekends, holidays, summer design day and winter design day, and then for months and a year. Special periods can also be set, for example 'from 15th March to 1st June'.

6.2.4 Comparison of Calculation Methods used by the Programs

Once the design decisions related to the site, building form and properties of the building envelope have been made, and the service systems and their schedules have been set, all of the four programs calculate the energy requirements for the building and evaluate its energy use for various time intervals, such as sub-hourly (15 or 30 minutes), hourly, daily, monthly and annual. As can be seen in Table 6.5, all programs make evaluations on a monthly and annual basis, while DesignBuilder and HAP, the simulation tools, also perform hourly and daily evaluations. Outputs are presented in the form of tables, graphs and reports. Furthermore, EnAd provides feedback to achieve higher performances, while also showing the legislation to be covered during the design process. The major difference between the four programs can be found in their method of calculation.

The main reason for the variations in the data inputs and outputs is the different calculation methods employed by the individual programs. EnAd uses the monthly calculation method of TS EN ISO 13790, using the daily and monthly correlation coefficients determined by the BEP Regulation and TS EN ISO 13790. Similar to EnAd, EnerCalc uses the monthly calculation method of DIN EN ISO 13790, but the tool uses the daily use patterns and schedules of DIN V 18599 with monthly correlation coefficients. As explained in Chapter 3, the monthly calculation method used by EnAd and EnerCalc considers heat losses through transmission and ventilation, and solar and internal heat gains throughout the year, by using monthly average outside temperatures. For the calculation of heating and cooling energy requirements, gain and loss utilization factors are used for the heating and cooling seasons, which are determined by the gain-loss ratio calculated for each month. DesignBuilder, on the other hand, uses the heat balance model of EnergyPlus, considering heat and mass balance calculations. For heating load calculations, the tool assumes a constant external temperature and constant heating, considering heat transmission in the building through the building envelope, ventilation and infiltration, while disregarding solar and internal gains and schedules to converge heat flows in each zone. Then, the tool calculates heating loads according to the maximum number of days specified in the weather data file. For cooling, DesignBuilder includes solar and internal heat gains, transmission heat losses by transfer and natural ventilation. It uses periodic steady-state external temperatures, which are calculated according to maximum and minimum outside dry-bulb temperature and wet-bulb temperature at the time of the maximum dry-bulb temperature of the month of July for buildings in the Northern Hemisphere. HAP uses the ASHRAE-endorsed transfer function method for load calculations. For heating, the tool computes design heating loads for a single heating design condition based on winter design temperatures. In the heating load calculations the tool takes heat transmission and infiltration into account while ignoring heat gains to calculate the worst case, by which the design heating loads are determined. For cooling, HAP calculates design loads according to one design cooling day for each month, considering the internal heat gains and other heat transfers in the building.

Table 6.5 Evaluations and Results for the Selected Tools

	Design Builder	**HAP**	**EnerCalc**	**EnAd**
Calculation method	Heat balance model of EnergyPlus	ASHRAE-endorsed transfer function method	Monthly calculation method of DIN EN ISO 13790	Monthly calculation method of TS EN ISO 13790
Evaluation				
Energy requirement	kWh & kWh/m^2	kWh	kWh/m^2	kWh & kWh/m^2
Energy use	kWh & kWh/m^2	kWh	**NA**	kWh & kWh/m^2
Primary energy	kWh (just total)	kWh	kWh/m^2	kWh & kWh/m^2
Energy costs	**NA**	$ (E)	**NA**	**NA**
Sub-hourly	✓	**NA**	**NA**	**NA**
Hourly	✓	✓	**NA**	**NA**
Daily	✓	✓	**NA**	**NA**
Monthly & annual	✓	✓	✓	✓
Outputs Exports				
Graphs	✓ (jpeg)	✓ (rtf)	✓ (xlsx)	✓ (xlsx)
Tables	✓ (csv)	✓ (rtf)	✓ (xlsx)	✓ (xlsx)
Report	✓ (html)	✓ (rtf)	**NA**	✓ (xlsx)
Feedbacks & Information	**NA**	**NA**	Required thickness of insulation material Energy that can be covered by PV systems	Feedback for improvements Lists of legislation regarding each subject

EnAd and EnerCalc, both based on EN ISO 13790, consider the building as one thermal zone and evaluate the building envelope as a whole, while DesignBuilder and HAP, which are simulation tools, calculate each zone separately. In line with EN ISO 13790, EnAd and EnerCalc consider heat gains and losses to be present throughout the year, whereas DesignBuilder and HAP disregard heat gains in heating load calculations. EnAd and EnerCalc use the correlation coefficients determined in the TS and DIN standards and gain-loss utilization factors to control the results; while DesignBuilder and HAP make simulations based on the maximum number of days specified for the heating and cooling periods until the temperatures in each zone are converged.

The differences between the calculation and evaluation methods employed in the programs do not necessarily result in different assessments of energy performance in terms of grading. Since each tool has a different program structures and adopts a different calculation method, differences can be observed both in the databases, such as in the climatic data and the material library, and in the input data, such as type and quantity of input data, and the units of measurement used in the programs. Even though the quantitative values and the calculation methods differ, since they all result in an assessment for energy performance, the final assessment grades can be very alike. This will be explored through several case studies in the following sections.

6.3 Differences Observed in the Results of the Programs: A Reference Case

In order to explore the reliability and accuracy of EnAd's results, they were compared with those of DesignBuilder, HAP and EnerCalc through several case studies. Firstly, the reference case given in TS EN ISO 13790 was assessed by all four programs, and the results of each were compared to identify differences. TS EN ISO 13790 provides the thermal properties and calculation results for a single office room in Paris, which has a floor area of about 20m^2 and a ceiling height of 2.8m. The office has only one exterior wall containing a window facing west, while other walls, floor and ceiling are accepted to be adjacent to conditioned zones. The room is heated, cooled and mechanically ventilated for ten hours on weekdays. The case assumes a 20 W/m^2 internal gain for ten hours on weekdays, and solar gains according to the weather data provided by the standard. The case was evaluated according to the monthly and annual method of the standard. The general features of the test case are presented in Table 6.6, while the input data entered for each tool is given in Table 6.7.

Table 6.6 General Features of the Reference Case

Case	Single office room
Location	Paris, France
Floor area	19.80 m2
Floor height	2.8m
Exposed surface	West façade
Window/wall ratio	2.27 (7 x 3.08)
Construction type	Heavy
Internal gains	20 W/m2
Heating	08:00–18:00 weekdays
Cooling	08:00–18:00 weekdays
Natural Ventilation	x
Mechanical Ventilation	08:00–18:00 weekdays
Infiltration	x
DHW use	x
Lighting	x

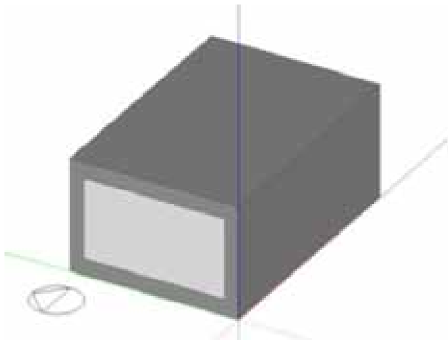


Table 6.7 Input Data for the Reference Case

		Design Builder	HAP	EnerCalc	EnAd
Location	**Climatic data**	Paris (ASHRAE/IWEC)	Paris (ASHRAE 2001 Handbook)	Paris data from TS EN ISO 13790	Paris data from TS EN ISO 13790
	Code compliance	ASHRAE	ASHRAE	DIN V 18599	TS EN ISO 13790 Turkish BEP Regulation
Form definition	**Introduction of the geometry**				
	Internal dimensions	5.5m * 3.6m * 2.8m	5.5m * 3.6m * 2.8m	5.5m * 3.6m * 2.8m	5.5m * 3.6m * 2.8m
	Net area	19.8 m^2	19.8 m^2	19.8 m^2	19.8 m^2
	Net volume	55.4 m^3	55.4 m^3	55.4 m^3	55.4 m^3
	# of occupants	-	-	**x**	-
	Zoning (thermal zone)	Single zone	Single zone	Single zone	Single zone
	Construction				
	Construction type	Heavy	Heavy	Heavy	Heavy
	Material library	Reference materials[2]	Reference materials	**x**	Reference materials
	U-value (wall)	0.493 W/m^2K	0.493 W/m^2K	0.493 W/m^2K	0.493 W/m^2K
	Windows	DG (U: 2.375; gl: 0.20)	DG (U: 2.375; gl: 0.20)	DG (U: 0.84; gl: 0.37)[1]	DG (U: 2.375; gl: 0.20)
	Window frames	No frame	No frame	No frame	No frame
	Shading				
	from external objects	No shade	No shade	No shade	No shade
	Window shade	No shade	No shade	No shade	**x**
	Thermal bridges	No thermal bridge	No thermal bridge	With thermal bridge[2]	**x**
	Solar gains	Default	Default	Default	Default
	Internal gains				
	Average internal gain	20 W/m^2	20 W/m^2	120 Wh/m^2d	20 W/m^2
	Living+Kitchen	**x**	**x**	**x**	-
	Other spaces	**x**	**x**	**x**	-
	Occupancy	-	-	-	-
	Office equip.	-	-	-	-
	Catering	-	**x**	**x**	**x**
	Lighting	-	-	-	-
	DHW use	-	**x**	-	-
	HVAC system	**x**	**x**	-	**x**
	Other	-	-	-	**x**
Service systems	**Space heating**				
	Heater type	Boiler	Boiler	Boiler	Boiler
	Fuel type	Natural gas	Natural gas	Natural gas	Natural gas
	Heating set temp.	20°C	20°C	20°C	20°C
	Setback temp.	18°C	18°C	18°C	**x**
	Programmer	**x**	-	-	-
	Equipment efficiency	0.74	0.74	0.63[3]	0.74
	Pr. En. Conv.	1.084	1	1.10	1
	Energy need	454 kWh	715 kWh	525 kWh	567 kWh
	Primary energy need	613 kWh	966 kWh	837 kWh	766 kWh
	Space cooling				
	Conditioner	Default	Chiller	Air cooled compressor. improved Electricity	Air cond. except single/double duct
	Fuel type	Electricity	Electricity	26°C	Electricity
	Cooling set temp.	26°C	26°C	28°C	26°C
	Setback temp	28°C	28°C	**x**	**x**
	Efficiency class	**x**	**x**	1.30[3]	B
	CoP	4.85	4.85	2.60	4.85
	Pr. En. Conv.	3.167	3.56	210 kWh	2.36
	Energy need	230 kWh	213 kWh	161 kWh	217 kWh
	Primary energy need	48 kWh	44 kWh		45 kWh
	DHW supply	No DHW use	**x**	No DHW use	No DHW use
	Ventilation				
	Natural Vent.	-	**x**	-	-
	Mechanical Vent.	1 ac/h (outside airflow rate)	**x**	1 ac/h	1 ac/h
	Infiltration	-	-	0.04 ac/h[4]	-
	Ventilation Requirement		2.5 L/(s.person) (D)		
	Ventilation Requirement		0.3 $L/(s.m^2)$ (D)		
	Airflow control		ASHRAE 62.1 – 2007		
	Interior lighting	No lighting	No lighting	No lighting	No lighting
	Exterior lighting	-	**x**	**x**	-
Analysis and results	**Schedules**				
	Occupancy	-	-	-	-
	Electrical equipment	08:00–18:00 (weekdays)	08:00–18:00 (weekdays)	08:00–18:00 (weekdays)	08:00–18:00 (weekdays)
	Lighting	-	-	-	-
	HVAC	08:00–18:00 (weekdays)	08:00–18:00 (weekdays)	08:00–18:00 (weekdays)	08:00–18:00 (weekdays)
	Evaluations				
	Annual energy need				
	For heating	454 kWh	715 kWh	822 kWh	567 kWh
	For cooling	230 kWh	213 kWh	406 kWh	217 kWh
	Outputs Exports	✓	✓	✓	✓

[1] The closest window type to that of the test case
[2] Thermal bridges cannot be cancelled in the program
[3] CoP cannot be changed
[4] Minimum allowable value of the program

The reference case is assessed by each tool individually using the input data given in Table 6.7. The internal dimensions are considered as a single zone with construction properties as determined in the standard. No shade or thermal bridges are taken into account. Solar gains are considered according to the climatic data, while occupants, office equipment, DHW use, lighting and their internal heat gains are all disregarded, with internal heat gains assumed to be 20 W/m^2 on average. The office is heated, cooled and mechanically ventilated for ten hours on weekdays throughout the year. The set point temperature for heating is accepted as 20°C, while that for cooling is 26°C. Although the standard gives no information about the types of heater or air conditioner and their CoP and fuel types, they were defined and used by all tools to complete the evaluation. As can be seen in Table 6.7, all these properties were introduced to each program in similar ways, although several differences were observed among the programs, particularly in climatic data.

In the calculations, the climatic data for Paris given by TS EN ISO 13790 (2008) was introduced into EnAd and EnerCalc, while DesignBuilder uses ASHRAE/IWEC and HAP uses ASHRAE 2001 Handbook weather data file for Paris; however the monthly average temperatures and solar radiation data given by TS EN ISO 13790 are different from that of ASHRAE/IWEC, which are presented in Table 6.8.

Table 6.8 Weather data for Paris used by TS EN ISO 13790 and ASHRAE/IWEC

	TS EN ISO 13790		ASHRAE/IWEC	
	Monthly average outside temperature °C	Solar radiation (west) W/m^2	Outside temperature °C	Solar radiation (west) (estimated)* W/m^2
January	3.2	20	3.9	16
February	4.8	37	4.2	28
March	6.3	85	7	44
April	7.8	82	10	66
May	13	99	14.3	84
June	15.4	117	16.8	101
July	18.3	125	19.4	103
August	17	92	19.7	98
September	14.9	68	15.7	66
October	10.1	44	11.3	42
November	5.4	21	6.4	23
December	4.2	17	4.5	12
Average	10	67.3	11.1	56.9

* Monthly average solar radiation data is not provided directly in the IWEC file, which was estimated according to the solar gains produced by DesignBuilder.

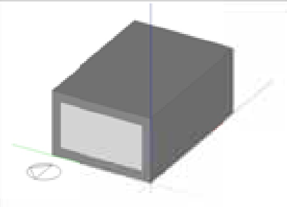
As can be seen in Table 6.8, the monthly and annual average values used by the standard and the simulation tools differ by 10% for outside temperatures, and by 15% for solar radiation data. This may lead to discrepancies in the calculations of both the solar gains due to the differences in the solar radiation data, and the energy requirement for heating and cooling due to the temperature differences, as well as the calculation method used by the programs.

Another difference in input data can be found in the definition of building form in the tools. As explained in section 6.2.2, each tool calculates the net area and volume in different ways. The values of the net area and interior height of the office were given in EnerCalc and HAP. In EnAd, since the tool works with external dimensions, as required by the standards, larger dimensions (5.7*3.8*2.9) were defined to obtain the values determined for the net area and volume. Similarly, in DesignBuilder, a 3D model was created using larger dimensions to obtain the same net area and volume.

Other differences in input data are observed in EnerCalc due to its limitations. For instance, the value for heavy construction in EnerCalc cannot be changed, being set at 130 Wh/m^{2}K, while this figure is 355000 J/m^{2}K both in the standard and in the other programs. Since the tool does not provide an option for material layers, only the U-value of the western façade is given, as 0.493 W/m^{2}K. Additionally, since the tool does not allow the window properties to be changed, a double glazed window without frame, which has the closest properties to that of the test case, was selected. Internal gains are introduced as 120 Wh/m^{2}d according to the DIN V 18599-10 use profile lists. Since there is no schedule for internal gains, it is not known whether the tool considers this value as ten hours or a whole day and/or week. Furthermore, EnerCalc assumes that there should be infiltration of at least 0.6 ac/h at 50 Pascals, according to the passive house standard, and so this lowest value is used for the test case.

The reference case was assessed by the four tools, and the monthly and annual evaluation results of the programs were obtained. The results provided in the standard were compared with those derived from the four tools. The comparison of the results for annual energy requirements for heating and cooling is presented in Table 6.9. Because of the reasons stated above, it is expected to observe differences in the evaluation results of the programs.

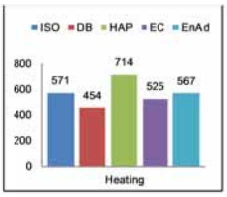
Table 6.9 Comparison of the Results for the Reference Case

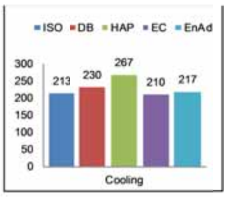


Test Case	: Worked example of TS EN ISO 13790
# of zones	: 1
Wall	: W01 (U: 0,49)
Ground	: internal floor
Roof	: internal ceiling
Window	: Wi01 (DG; U: 2,38; gl: 0,20)
WWR	: 70%

Annual energy need

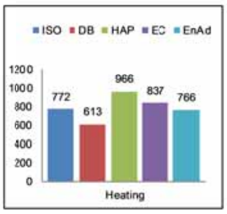
	ISO	DB	HAP	EC	EnAd
Heating	571	454	714	525	567
Cooling	213	230	267	210	217

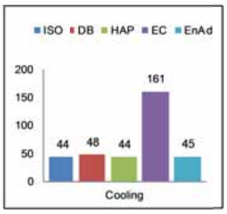




Annual primary energy need

	ISO	DB	HAP	EC	EnAd
Heating	772	613	966	837	766
Cooling	44	48	44	161	45





As seen in the annual energy requirements presented in Table 6.9, the results of the ISO standard are very close to those of EnAd and EnerCalc, the highest results are observed in HAP while the lowest ones can be seen in DesignBuilder. The discrepancies in the results for the annual energy requirements for cooling are generally very low, ranging from 2% in EnAd and EnerCalc to 8% in DesignBuilder, except from HAP (25%), while the results for heating differ by 1% in EnAd, 8% in EnerCalc, 21% in DesignBuilder, and 25% in HAP.

One reason for the discrepancies observed in the results is the differences in input data, and also the use of different climatic data caused the tools to calculate different solar gains, as well as different requirements for heating and cooling. Other different input data can be noted in the dimensions of the office considered, and since this test case is very small in size, any difference in dimensions causes discrepancies in the results. Differences that are specific to EnerCalc can be attributed to the uneditable construction type and window properties, non-cancellable thermal bridges and infiltration, and uncertainty in the schedule of internal gains.

Another reason for the discrepancies in the results can be attributed to the calculation method employed in the programs. Since the calculation methods are the same and the input data is very similar, EnAd came up with almost the same results as the ISO standard; and EnerCalc was also very close to the ISO standard for heating (8% lower) and cooling (2% higher). Although it uses the same calculation method and climatic data, the differences of EnerCalc can be explained by the program limits described above. As mentioned in Chapter 3, TS EN ISO 13790 states that there is a near 10% difference between the simple hourly method and the monthly calculation method. The standard also adds that a 5% uncertainty in input data may lead to a 30% difference in the results. Even when using the same standard, hourly and monthly calculation methods or minor differences in input data can lead to large discrepancies in the results. Coming to the other two programs, although

DesignBuilder and HAP perform hourly simulations using the same weather data file and similar calculation methods, their results are very different, both from each other and from the results of the ISO standard. They gave the highest values for cooling, whereas for heating DesignBuilder came up with the lowest value and HAP produced the highest result. These two tools make evaluations according to the worst case scenario, considering heating and cooling design days, which are created based on the degree-day hours for heating and cooling determined from the climatic data. As shown in Table 6.8, IWEC data gives higher outside temperature values for Paris than ISO, whereas the solar radiation data is estimated to be lower than that of the ISO. In this case, the results of the simulation tools would be expected to be lower in terms of heating loads and higher cooling loads. Design Builder produced such results (21% lower heating; 8% higher cooling), while HAP gave the most divergent requirement values, with 25% higher heating needs and 25% higher cooling when compared to the results of the ISO standard.

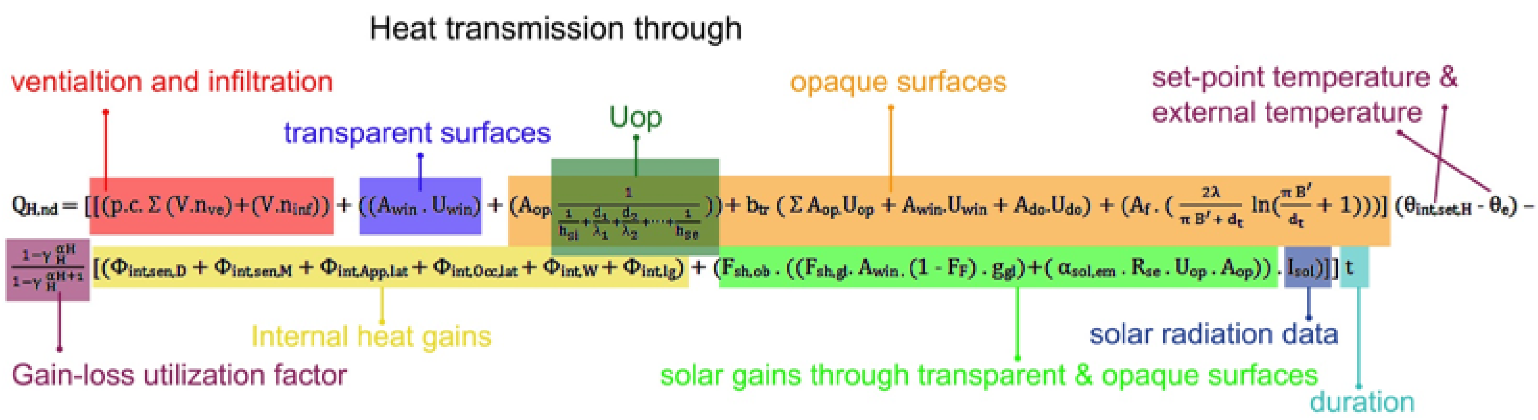
Table 6.9 also shows the results from the annual primary energy requirement calculated by the programs. The discrepancies in the results are due to the differences in the efficiency of the equipment and the primary energy conversions used by the programs. Among all, the most different results were observed in EnerCalc due to the uneditable equipment efficiency values for the heater (0.63) and air conditioner (1.35) when compared to the others, which are 0.74 and 4.85.

This reference case may be too small for the drawing of a meaningful conclusion or outside the limits of the tools selected. In order to evaluate the differences between the programs and to make comparisons in a more reliable medium, generic cases, in which the differences in input data and biases between the tools are minimized, were assessed to provide a further comparison.

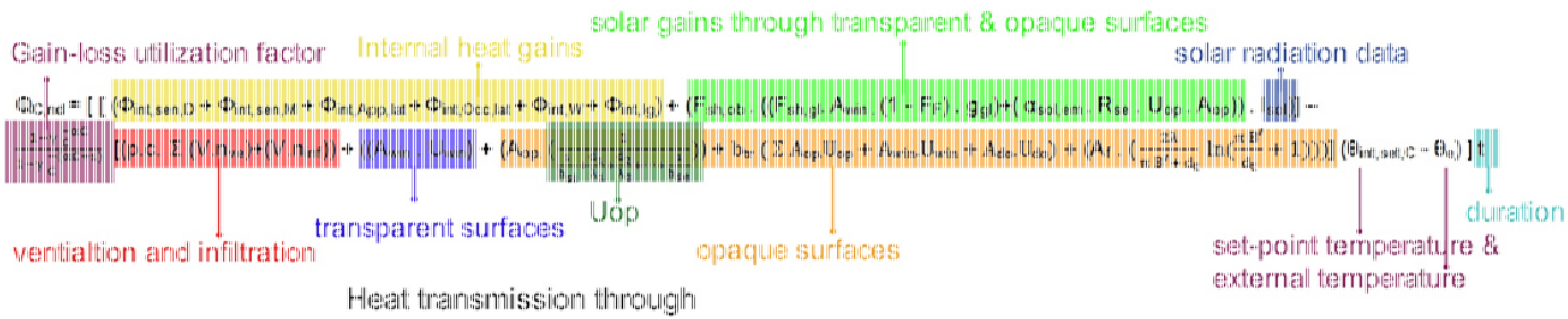
6.4 Convergence Tests through Generic Cases

The validity, reliability range, precision and use of EnAd are explored extensively through several case studies, in which the main building components affecting energy performance are studied in order to observe the validity of EnAd. In addition, EnAd is also tested with extreme ranges so as to identify its limitations (if any). The results of the case studies were compared with the results of three other performance evaluation programs in use around the world. There are two main targets in these case studies: one, the evaluation of the effect of each parameter on the energy performance of buildings, and two, the determination of the reliability and precision of EnAd when compared with the other programs.

Monthly and annual energy requirements determining the energy performance of buildings, including heating, cooling, domestic hot water (DHW) and lighting, were compared through the case studies. As explained in Chapter 3, DHW use is determined through supply and use water temperatures, daily water use per person and the number of people in a building; while energy need for lighting is based on the type, power and number of appliances used. On the other hand, the determination of energy requirements for heating and cooling requires the evaluation of many parameters related to the thermal and physical properties of a building. The formulas for the calculation of energy need for space heating and cooling were provided in Eq. 11 and 12, in Chapter 3, and are presented in the broadest way in Figure 6.7.



Energy Need for Heating



Energy Need for Cooling

Figure 6.7 Explicit Forrmulas of Energy Need for Heating and Cooling

As can be seen from the explicit formulas, the energy requirements for the heating and cooling of a building vary according to several heat transfer mechanisms, including ventilation and transmission, internal heat gains and solar gains, internal set-point temperatures and external temperatures, the gain-loss utilization factor and the duration of each month. Each factor is characterized by one or more values or functions, which are:

i. Physical properties of the building, including the net conditioned area, the volume and perimeter of the building, and the thickness of opaque surfaces like walls, floors and ceilings.
ii. Airflow rates for natural ventilation and infiltration.
iii. Window u-values and areas.
iv. U-values and areas of the opaque surfaces exposed to air, ground and unconditioned spaces.
v. Set-point temperatures for heating and cooling modes.
vi. External temperatures.
vii. Gain-loss utilization factors
viii. Internal heat gains from occupants, electrical equipment, DHW use and lighting.
ix. Solar gains through transparent and opaque surfaces.
x. Solar radiation data.
xi. Duration of each month (calculation period).

To evaluate the effect of each parameter on the heating and cooling loads, the features outlined below are examined:

i. The effect of building size (number of floors and number of apartments on each floor).
ii. The effect of exposed surfaces (such as façades, ground floors and roofs).
iii. The effect of ventilation and infiltration (considering airflow rates).
iv. The effect of U-values (for materials of different thickness, additional insulation layers and different construction types).
v. The effect of the window/wall ratio (solar gains and window types and properties).
vi. The effect of set-point temperatures (for heating and cooling modes).
vii. The effect of temperature differences between the outside and inside.

All these features were examined through generic case studies. The general features of the case studies and the data used are presented below.

6.4.1 Data and Buildings Used in the Case Studies

For the generic test cases, in order to minimize the differences between the programs and to avoid any bias during the comparisons, standard data sets were established that could be inputted into all of the programs. To ensure a controlled comparison, some features were assumed to be the same for all cases, including location, orientation, heating and cooling system types, schedules, number of residents and other values that may be subject to variation, such as internal heat gains, lighting and DHW use. On the other hand, shading from external objects, sun protection, window frames, thermal bridges and mechanical ventilation were disregarded in the evaluations. The evaluated parameters included the size of a building in terms number of floors (1, 3, 6 and 15) and the number of flats on each floor (1 or 4); U-values and material properties (uniform single layer material and layered surfaces), window types and properties (with double- and triple-glazing); window/wall ratio (WWR) (from 0% to 100%); natural ventilation and infiltration; extreme temperatures and set-point temperatures for heating and cooling modes.

The case studies are formulated in such a way that in every case study, one feature affecting the energy performance of buildings was examined by all programs. In this way, the differences resulting from these parameters were observed both on the energy performance of buildings and the results of the programs; while the dimensions of a flat, as one thermal zone, were fixed. The use of a standard flat size enables the number of residents also to remain fixed, while also allowing variations resulting from internal gains, lighting and DHW use per unit to be avoided. By keeping the flat size the same in all cases, various organizations of floors and flats in a building were able to be studied. On the other hand, open and/or closed cantilever floors and balconies were not included in the evaluations due to the inherent uncertainties and problems in their introduction to some tools.

A total of eight buildings were determined for the case studies. The first generic building is developed according to the size and features of the worked examples in TS 825 and TS EN 832, and comprises a single 100 m^2 family house. The building is rectangular in plan, having external dimensions of 12.5m*8m*3m. All façades have windows with the same WWR of 10%. The building has a flat roof and a ground floor that is in contact with the earth. All the surfaces of the building are heat losing, constructed as a uniform single 25cm layer of autoclaved aerated concrete (AAC). The house is heated, cooled and naturally ventilated throughout the year. Generic cases were developed based on this first generic building with the addition of floors and flats, and then by changing the material properties, window types and WWR of the building. The eight buildings generated for the case studies are presented in Table 6.10. To examine the effect of the size of a building on energy performance, each case, beginning from a one-story single-family house (SFH) to a 15-story multiple-family house (MFH), was assessed in order to follow systematically the discrepancies in the results for each energy parameter. The generated buildings represent four different types of buildings: a single-family house; and low-rise, mid-rise and high-rise multiple-family houses. In addition, to allow the evaluation of the effect of differences in building size, the number of flats on each floor was increased to four for the first four building types.

The location for all cases was assumed as Ankara, Turkey. In terms of weather data, since there are important differences between weather data in ASHRAE/IWEC and the national climatic data, the monthly average outside temperatures for Ankara were taken from the ASHRAE/IWEC Ankara climatic data file. As mentioned in Chapter 5, solar radiation data is not available in the ASHRAE/IWEC weather file as monthly average values, and since there is no other available value, the national data relating to monthly average solar radiation provided by TS 825 was used in the EnAd and EnerCalc programs.

For the form definition, since there is no common ground between the tools selected, the external dimensions of each building were introduced to each program individually. Each flat, 100 m^2 in area, was introduced as one thermal zone without partition walls. The number of zones in a building was determined according to the total number of flats in the building. The same features were introduced to each of the tools, including the number of floors, number of exposed surfaces and WWRs. The same material layers were introduced to each of the tools, except EnerCalc, which has no material library. The same construction type and U-values were defined, while thermal bridges and (external or window) shade disregarded. All zones/buildings were assumed to be heated by a natural gas boiler operating at 74% constant efficiency at 20°C, and cooled by an air-conditioner, electricity, energy class B (4.85 CoP) with a 26°C set point. Interior lighting was set to 7 W/m^2, as the average value for residential buildings according to ASHRAE, and the schedules were adjusted to the coefficients listed in TS EN ISO 13790. The common input data relating to location, building form, material properties, service systems and schedules is provided for all buildings in Table 6.11.

Table 6.10 Buildings Used in the Case Studies

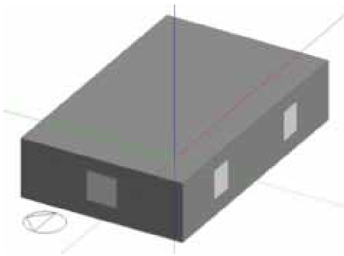
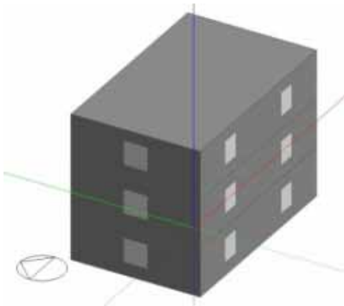
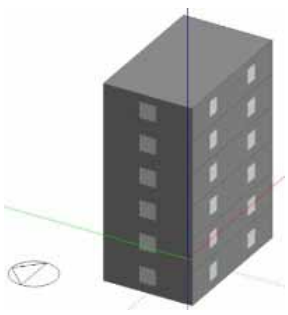
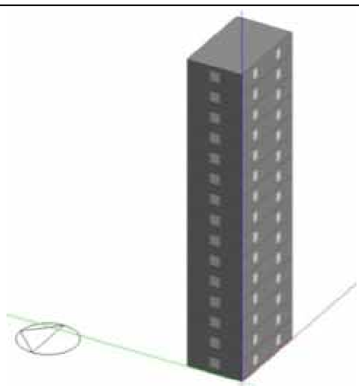
Case 01	One-story SFH	
Dimensions	12.5*8*3m	
# of people (in a flat)	4	
# of floors	1	
# of flats on each floor	1	
Exposed surfaces	All	
WWR	10%	
Materials	Uniform single layer	
Heating	On	
Cooling	On	
Natural Vent.	On (0,5 ac/h)	
Mechanical Vent.	x	
Infiltration	On (0,04 ac/h)	
DHW	45 lt/pd	
Lighting	7 W/m^2	
Case 02	Low-rise MFH	
Dimensions	12.5*8*9m	
# of people (in a flat)	4	
# of floors	3	
# of flats on each floor	1	
Exposed surfaces	All	
WWR	10%	
Materials	Uniform single layer	
Heating	On	
Cooling	On	
Natural Vent.	On (0,5 ac/h)	
Mechanical Vent.	x	
Infiltration	On (0,04 ac/h)	
DHW	45 lt/pd	
Lighting	7 W/m^2	
Case 03	Mid-rise MFH	
Dimensions	12.5*8*18m	
# of people (in a flat)	4	
# of floors	6	
# of flats on each floor	1	
Exposed surfaces	All	
WWR	10%	
Materials	Uniform single layer	
Heating	On	
Cooling	On	
Natural Vent.	On (0,5 ac/h)	
Mechanical Vent.	x	
Infiltration	On (0,04 ac/h)	
DHW	45 lt/pd	
Lighting	7 W/m^2	
Case 04	High-rise MFH	
Dimensions	12.5*8*45m	
# of people (in a flat)	4	
# of floors	15	
# of flats on each floor	1	
Exposed surfaces	All	
WWR	10%	
Materials	Uniform single layer	
Heating	On	
Cooling	On	
Natural Vent.	On (0,5 ac/h)	
Mechanical Vent.	x	
Infiltration	On (0,04 ac/h)	
DHW	45 lt/pd	
Lighting	7 W/m^2	

Table 6.10 Buildings Used in the Case Studies (continued)

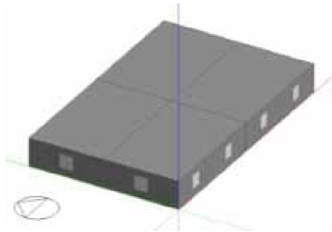
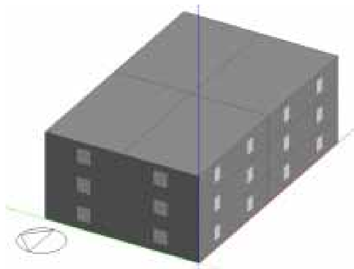
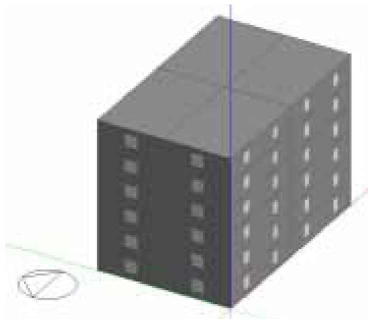
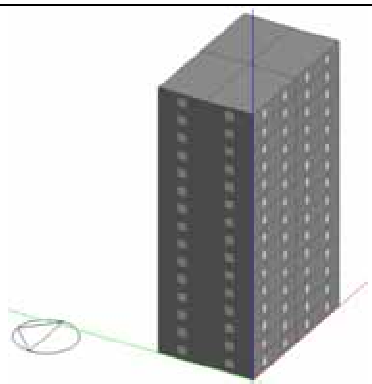
Case 05	One-story SFH	
Dimensions	25*16*3m	
# of people (in a flat)	4	
# of floors	1	
# of flats on each floor	4	
Exposed surfaces	All	
WWR	10%	
Materials	Uniform single layer	
Heating	On	
Cooling	On	
Natural Vent.	On (0,5 ac/h)	
Mechanical Vent.	x	
Infiltration	On (0,04 ac/h)	
DHW	45 lt/pd	
Lighting	7 W/m^2	
Case 06	Low-rise MFH	
Dimensions	25*16*9m	
# of people (in a flat)	4	
# of floors	3	
# of flats on each floor	4	
Exposed surfaces	All	
WWR	10%	
Materials	Uniform single layer	
Heating	On	
Cooling	On	
Natural Vent.	On (0,5 ac/h)	
Mechanical Vent.	x	
Infiltration	On (0,04 ac/h)	
DHW	45 lt/pd	
Lighting	7 W/m^2	
Case 07	Mid-rise MFH	
Dimensions	25*16*18m	
# of people (in a flat)	4	
# of floors	6	
# of flats on each floor	4	
Exposed surfaces	All	
WWR	10%	
Materials	Uniform single layer	
Heating	On	
Cooling	On	
Natural Vent.	On (0,5 ac/h)	
Mechanical Vent.	x	
Infiltration	On (0,04 ac/h)	
DHW	45 lt/pd	
Lighting	7 W/m^2	
Case 08	High-rise MFH	
Dimensions	25*16*45m	
# of people (in a flat)	4	
# of floors	15	
# of flats on each floor	4	
Exposed surfaces	All	
WWR	10%	
Materials	Uniform single layer	
Heating	On	
Cooling	On	
Natural Vent.	On (0,5 ac/h)	
Mechanical Vent.	x	
Infiltration	On (0,04 ac/h)	
DHW	45 lt/pd	
Lighting	7 W/m^2	

Table 6.11 Common Input Data Used for All Cases

Location	**City**	Ankara, Turkey
	Weather data source	
	Outside temperatures	ASHRAE/IWEC weather data
	Solar radiation data	ASHRAE/IWEC weather data and TS 825
Form definition	**Dimensions of a flat**	12.5 *8 *3m (100m^2)
	# of flats on each floor	1 or 4
	# of floors	1, 3, 6 or 15
	# of people	4 persons for each flat
	Orientation	Long façade facing with south
	Zoning (thermal zone)	Single zone for each apartment/flat
	Construction	
	Construction type	Light/Medium/Heavy construction
	Material library	Uniform material/ moderately insulated layered surface
	Windows	Double- and Triple-glazing
	Window frames	No frame
	Shading	
	Shading from external objects	No external shading
	Window shading (Sun protection)	No window shading
	Thermal bridges	No thermal bridges
	Solar gains	Included according to solar radiation data
	Internal gains	Included according to the defaults of each program
Service systems	**Space heating**	
	Heater type	Combustion boiler
	Fuel type	Natural gas
	Heating set-point temperature	20 °C
	Programmer	x
	Equipment efficiency	0.74
	Space cooling	
	Conditioner	Non-duct type air-conditioner
	Fuel type	Electricity
	Cooling set-point temperature	26 °C
	Efficiency class	B
	CoP	4.85
	DHW supply	
	Water heater	Stand-alone water heater
	Fuel type	Electricity
	Use water temperature	50
	Supply water temperature	10
	Daily usage	45 lt/person.day
	Equipment efficiency	1
	Ventilation	No ventilation*
	Natural Ventilation	0.5 ac/h*
	Mechanical Ventilation	No
	Infiltration	0.6 ac/h*
	Interior lighting	
	Luminaire type	Free hanging
	Lamp type	Incandescent
	Radiant fraction	0.5
	Lighting /Power	7 W/m^2
	Exterior lighting	Not included
Evaluations & results	**Schedules**	
	Use profiles	Constant heating, cooling and ventilation
		Daily use pattern for DHW
		Lighting per unit
	Evaluations and Results	
	Monthly & annual energy need for;	
	Heating	kWh/m^2a
	Cooling	kWh/m^2a
	DHW	kWh/m^2a
	Lighting	kWh/m^2a

* This option is included in some cases, not for all.

Since an exterior lighting option is not provided by all tools, and is not required for BEP certification, this category was disregarded in the assessments. EnerCalc uses an electrical heater as default for DHW supply, and for this reason the water heater was accepted as electrical stand-alone in all case studies.

For the comparisons, three types of material lists were used. The first material list consists of a uniform single layer of AAC with a high U-value and the same material thickness for all surfaces of the building; the second list includes a uniform single layer of brick material with higher U-values and different material thicknesses; and the third material list considers insulated versions of the first and second material lists, creating two- or three-layered moderately insulated surfaces. The material library used in the comparisons is presented in Table 6.12, showing material properties and sketches.

Table 6.12 Material Layers and Properties of Building Envelope Used in the Comparisons

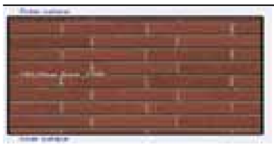
		Thickness cm	Thermal conductivity λ (W/mK)	Density p (kg/m3)	Specific heat capacity c (J/(kgK))	U-value
Material List 01						
W01 Exterior Wall; **G01 Ground Floor**; **R01 Flat Roof** ; Uniform Single Layer Material						
	AAC	25	0.29	800	1000	**0.97**
Material List 02						
W02 Exterior Wall; **G02 Ground Floor**; **R02 Flat Roof** ; Uniform Single Layer Material						
	Brick (1200 density)	9	0.5	1200	1000	**2.89**
Material List 03						
W03 Exterior Wall; **G03 Ground Floor**; **R03 Flat Roof** ; Uniform Single Layer Material						
	Brick (1200 density)	18	0.5	1200	1000	**1.30**
Material List 04						
W04 Exterior Wall; **G04 Ground Floor**; **R04 Flat Roof** ; Uniform Single Layer Material						
	Brick (1200 density)	50	0.5	1200	1000	**0.86**

Table 6.12 Material Layers and Properties of Building Envelope Used in the Comparisons (continued)

Material List 05

W05 Exterior Wall; **G05 Ground Floor**; **R05 Flat Roof** ; insulated surfaces

	Thickness cm	Thermal conductivity λ (W/mK)	Density p (kg/m3)	Specific heat capacity c (J/(kgK))	U-value
AAC	25	0.29	800	1000	
Thermal insulation, EPS	4	0.04	10	1450	
Average	**29**				**0.49**

Material List 06

W06 Exterior Wall; **G06 Ground Floor**; **R06 Flat Roof** ; insulated surfaces

AAC	10	0.29	800	1000	
Thermal insulation, EPS	4	0.04	10	1450	
AAC	25	0.29	800	1000	
Average	**39**				**0.42**

Material List 07

W07 Exterior Wall; **G07 Ground Floor**; **R07 Flat Roof** ; insulated surfaces

Thermal insulation, EPS	8.2	0.04	10	1450	
Brick (1200 density)	9	0.5	1200	1000	
Average	**17.2**				**0.42**

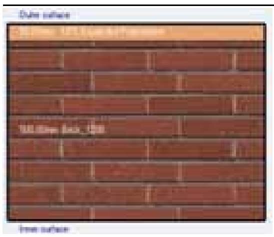
Material List 08

W08 Exterior Wall; **G08 Ground Floor**; **R08 Flat Roof** ; insulated surfaces

Thermal insulation, EPS	7.5	0.04	10	1450	
Brick (1200 density)	18	0.5	1200	1000	
Average	**25.5**				**0.42**

Material List 09

W09 Exterior Wall; **G09 Ground Floor**; **R09 Flat Roof** ; insulated surfaces



Thermal insulation, EPS	5	0.04	10	1450	
Brick (1200 density)	50	0.5	1200	1000	
Average	**55**				**0.42**

Besides the material lists, different types of windows were used in the case studies. The windows used and their thermal properties are presented in Table 6.13.

Table 6.13 Properties of Windows Used in the Convergence Tests

Window code	Window type	U-value - λ (W/mK)	Solar transmission - gl
Wi01	Double glazing	2.03	0.78
Wi02	Triple glazing	0.84	0.37

As mentioned in section 6.2, each program uses different evaluation methods, and thus requires different input data. When defining the properties of the building and their input data, the aim was to minimize the differences between the programs in order to minimize bias in the results. The input data entered into the programs was tabulated and presented in Table 6.14. This data table, prepared for the first case, shows the inputs for four data packages, which are location, form definition, service systems, and schedules and evaluation options. This data table also reveals the similarities and differences in inputs required for each program, and indicates whether an item is editable, partly editable or default of the program. Furthermore, the equivalent units of data are shown in this data table. The blank cells, that is, the non-applicable items, and the default values accepted by the programs represent potential for possible differences in the results, including the minimum and/or maximum allowable values of a program, the default window properties and the non-cancellable infiltration. Since there are more than 100 case studies for comparison, one data table of the first generic case is provided in Table 6.14 as a sample. In order to conduct case studies in a controlled medium, the location, service systems and schedules were kept the same for all cases, while only building size, WWR and material properties were changed in turn.

Table 6.14 Input Data for Single Family House with Uniform Single Layer Material

		DesignBuilder	HAP	EnerCalc	EnAd
Location	**Climatic data**				
	Outside temperatures	Esenboğa (ASHRAE/IWEC)	Ankara (ASHRAE 2001 Handbook)	Esenboğa (ASHRAE/IWEC)	Esenboğa (ASHRAE/IWEC)
	Solar gains	Esenboğa (ASHRAE/IWEC)	Ankara (ASHRAE 2001 Handbook)	TS 825	TS 825[1]
	Code compliance	ASHRAE	ASHRAE	DIN V 18599	BEP documents of Turkey
Form definition	**Introduction of the geometry**				
	External dimensions	12.5m * 8m * 3m	12.5m * 8m * 3m	12.5m * 8m * 3m	12.5m * 8m * 3m
	Net area	90 m^2	90 m^2	90 m^2	96 m^2
	Net volume	252 m^3	252 m^3	252 m^3	240 m^3
	# of floors	1	1	1	1
	# of exposed surfaces	All (6 surfaces)	All (6 surfaces)	All (6 surfaces)	All (6 surfaces)
	Window/wall ratio	10%	10%	10%	10%
	Density of people	0.045 people/m^2	4 people	**x**	4 people
	Zoning (thermal zone)	Single zone	Single zone	Single zone	Single zone
	Construction				
	Construction type	Medium	Medium	Medium	Medium
	Material library	Uniform material (AAC 25cm)	Uniform material	**x**	Uniform material
	U-values	W01: 0.97; G01: 0.97; R01: 0.97[2]	W01: 0.97; G01: 0.97; R01: 0.97	W01: 0.97; G01: 0.97; R01: 0.97	W01: 0.97; G01: 0.97; R01: 0.97
	Windows	Wi01: DG (U: 2.03; gl: 0.78)	Wi01: DG (U: 2.03; gl: 0.78)	Wi01: DG (U: 2.03; gl: 0.78)[3]	Wi01: DG (U: 2.03; gl: 0.78)
	Frames	No frame	No frame	No frame	No frame
	Shading				
	from external objects	No shading	No shading	No shading	No shading
	Window shading	No shading	No shading	No shading	**x**
	Thermal bridges	No thermal bridge	No thermal bridge	With thermal bridges (0.01)	**x**
	Solar gains	Default	Default	Default	Default
	Internal gains				7 W/m^2
	Average	**x**	**x**	**x**	-
	Living+Kitchen	**x**	**x**	**x**	-
	Other spaces	**x**	**x**	**x**	-
	Occupancy	Default (unknown)	Default (Sen:71.8; Lat:60.1 W/p)	55 Wh/m^2d	-
	Office equipment	1 W/m^2	1 W/m^2	14 Wh/m^2d	-
	Catering	-	**x**	**x**	**x**
	Lighting	Default (unknown)	Default (unknown)	Default (unknown)	-
	DHW use	-	**x**	-	-
	HVAC system	**x**	**x**	-	**x**
	Other	-	-	-	**x**
Service systems	**Space heating**				
	Heater type	Boiler	Boiler	Boiler	Boiler
	Fuel type	Natural gas	Natural gas	Natural gas	Natural gas
	Heating set temp.	20°C	20°C	20°C	20°C
	Setback temp.	18°C	18°C	18°C	**x**
	Programmer	**x**	-	-	-
	Efficiency	0.74	0.74	0.74 (D)	0.74
	Pr. En. Conv.	1.084 (D)	1 (D)	1.10 (D)	1
	Space cooling				
	Conditioner	Default	Chiller	Air cooled compressor, improved	Air cond., non-duct type
	Fuel type	Electricity	Electricity	Electricity (D)	Electricity
	Cooling set temp.	26°C	26°C	26°C	26°C
	Setback temp	28°C	28°C	28°C	**x**
	Efficiency class	**x**	**x**	**x**	B
	CoP	4.85	4.85	2.07 (D)	4.85
	Pr. En. Conv.	3.167 (D)	3.56 (D)	2.60 (D)	2.36 (D)
	DHW supply		**x** (Miscellaneous energy)		
	Water heater	Default		Default	Electric heater
	Fuel type	Electricity		Electricity	Electricity
	Use water temp	50°C		Default (unknown)	50°C
	Supply water t.	10°C		Default (unknown)	10°C
	Daily usage	1.8 l/m^2 d	8.37 kWh/d (manual input)	1.4 kWh/p.d (O)	45 l/p.d
	Efficiency	1	1	1	1
	Pr. En. Conv.	3.167 (D)	3.56 (D)	2.60 (D)	2.36 (D)
	Ventilation	No ventilation [a,b]	No ventilation [a,b]	No ventilation [b]	No ventilation [a,b]
	Natural Vent.	0.5 ac/h [c,d]	0.5 ac/h (manual input as infiltration) [c,d]	0.5 ac/h [c,d]	0.5 ac/h [c,d]
	Mechanical Vent.	-	-	-	-
	Infiltration	0.6 ac/h (n_{50}) [b,d]	0.04 ac/h [b]	0.6 ac/h (n_{50})[4] [b,d]	0.6 ac/h (n_{50}) [b,d]
	Interior lighting				
	Luminaire type	Suspended	Free hanging	**x**	**x**
	Lamp type	**x**	**x**	Incandescent	Incandescent
	Radiant fraction	0.5	**x**	Default (unknown)	0.5
	Ballast multiplier	**x**	1 (min. allowable value)	**x**	**x**
	Lighting /Power	7 W/m^2	7 W/m^2	75 lx	620 W (floor area * 7 W/m^2)
	Exterior lighting	-	**x**	**x**	-
Evaluations and results	**Schedules**				
	Occupancy	Schedule 1 (24h)[5]	Schedule 1 (24h)	Default (24h)	Schedule 1 (24h)
	Electrical equipment	On[6]	On	Default (unknown)	Default
	Lighting	Schedule 2 (8h daily)[7]	Schedule 2 (8h daily)	Default (unknown)	Schedule 2 (8h daily)
	Heating	On[6]	On	Default (24 h)[8]	On
	Cooling	On[6]	On	Default (24h)	On
	Evaluations and results				
	Evaluations	Hourly evaluation	Hourly evaluation	Monthly evaluation	Monthly evaluation
	Annual energy need for				
	Heating	Wh/m^2	kWh/m^2	kWh/m^2	kWh/m^2
	Cooling	Wh/m^2	kWh/m^2	kWh/m^2	kWh/m^2
	Lighting	Wh/m^2	kWh/m^2	kWh/m^2	kWh/m^2
	DHW	Wh/m^2	kWh/m^2	kWh/m^2	kWh/m^2

D: Default

[a,b,c,d] Conditions regarding the inclusion of infiltration and natural ventilation, which are explained in the following.

[1] Monthly average outside temperatures are obtained from ASHARE/IWEC Ankara climatic data file, whereas solar radiation data is not available as monthly average values.

[2] Material Layers; Walls - W01 consists of 25cm AAC with U-value of 0.97 W/m^2K; Ground floor - G01: 25cm AAC, U-value: 0.97 W/m^2K; Roof - R01: 25cm AAC, U-value: 0.97 W/m^2K. Detailed information is provided in Table 6.9 above.

[3] Since EnerCalc has uneditable window properties, this window type of the program was accepted as the same for many cases and the programs.

[4] Minimum allowable value of the program.

[5] For occupancy; Schedule 1; until 08.00 1; until 18.00 0.25; until 24.00 1 (16 hours daily).

[6] For electrical equipment, heating and cooling; Schedule is always On; until 24 1.

[7] For lighting; Schedule 2; until 06.00 0.15; until 08.00 0.8; until 18.00 0.2; until 22.00 0.8; until 24.00 0.3 (total; 8 hours daily).

[8] The program assumes 17 hours standard and 7 hours reduced heating daily.

In schedules, ‘1’ means On, and ‘0’ means Off, while others like 0.50 mean the percentage of use.

As can be seen in Table 6.14, all programs use different climatic data for Ankara: EnAd and EnerCalc use monthly average values of ASHRAE/IWEC weather data, while DesignBuilder and HAP use hourly values of ASHRAE/IWEC and the ASHRAE 2001 Handbook respectively. Since DesignBuilder and HAP use different types of files for weather data, it could not be possible to introduce the same weather file to the two programs. Regarding solar radiation data, EnAd and EnerCalc use the values provided in TS 825; while DesignBuilder and HAP use their own weather data files. The building was introduced to each program separately using external dimensions; however each program makes different assumptions when calculating the net area and volume. In the first single zone case and the other cases, the same construction type, material properties and window type were defined in EnAd, DesignBuilder and HAP. As mentioned above, EnerCalc allows only limited editing of the program defaults, including the value of construction type and window properties, while no material layers can be introduced. In EnerCalc, medium construction was selected, and a double-glazed window, which is available in EnerCalc, was used in all programs. Thermal bridges, shading from external objects and window shades were not considered, however thermal bridges were not allowed to be disregarded in EnerCalc.

The most significant difference between the programs is related to internal heat gains, for which each program has its own defaults in terms of heat gains from occupancy, equipment, lighting and DHW use. For solar gains, each program also has its own defaults in the calculations, and uses different climatic data. The building was assumed to be heated continuously with a standard natural gas boiler at 20°C, and cooled continuously using a non-duct type air-conditioner at 26°C. The building is assumed to have four occupants, from which DHW is defined. In the Turkish BEP Regulation, DHW use is accepted as 60 lt per person per day for single-family houses and residences, and 45 lt for multi-family houses and apartment blocks. Based on a value of 45 lt/pd, DHW use was accepted as 180 lt per day for a four-person family in each flat in all cases. Accordingly, daily DHW use value of 1.8 lt/m^{2}d for a 100 m2 flat was introduced to DesignBuilder. EnerCalc, according to DIN standards, considers two types of DHW use as 1.4 kWh/pd or 44 Wh/m^{2}d. Among these two options, the former for “per person” was selected to be used in all cases. Since HAP was developed for the system sizing of HVAC for commercial buildings, it does not consider energy need for DHW supply in its energy analyses; however if the user knows the energy consumption for a system, a miscellaneous energy option with a schedule can be introduced to the program, and the annual energy need and consumption can be calculated accordingly. Based on Equation 27 provided in section 3.7, the energy need for DHW use of 180 lt/d for four persons was calculated as 8.37 kWh/day, and this value was entered into HAP for all cases. The building was assumed to be ventilated naturally and has infiltration with a 0.6 ac/h airflow rate at 50 Pascal, which is the lowest value accepted in EnerCalc. Since HAP does not consider natural ventilation, it was introduced as infiltration in the program by providing an airflow rate for natural ventilation. The building was assumed to have interior lighting with a power of 7 W/m^2, as determined by ASHRAE and accepted in the Turkish BEP Regulation, while no exterior lighting was considered. Since all these programs use different calculation methods and require the input of different data, differences can be expected in the evaluation results of the programs. Available climatic data, variations in climatic data, net areas and volumes, types of construction, solar gains, internal gains and schedules may all lead to different results.

6.4.2 Evaluation of Case Studies

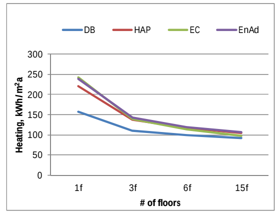
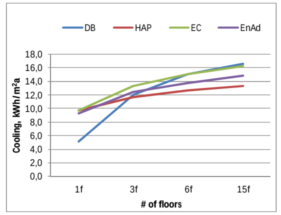
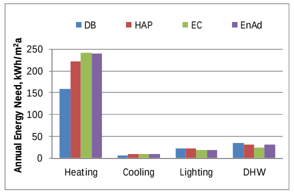
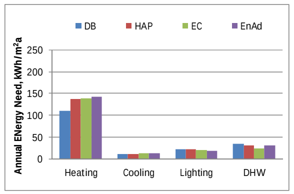
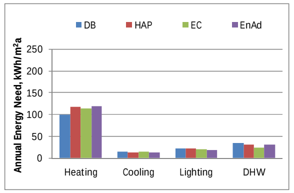
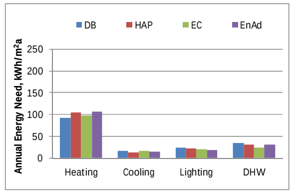
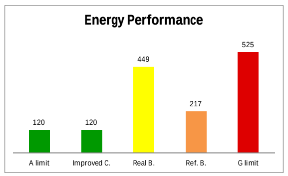
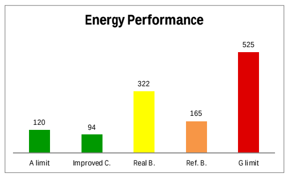
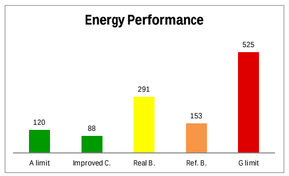
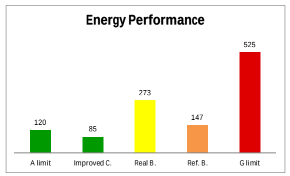
Several case studies were conducted in order to compare the results of EnAd with the three existing highly recognized programs in order to evaluate the accuracy and reliability of the program developed as part of this study. Features affecting energy performance were examined through eight different building configurations, and analyzed in seven sets: building size, exposed surfaces, ventilation and infiltration, U-value, WWR, set-point temperatures and temperature differences between the outside and inside spaces. The evaluation results for each case derived from DesignBuilder, HAP, EnerCalc and EnAd are presented, along with building sketches and line and bar graphs, in the following sections.

Each case was evaluated through the four evaluation programs to determine the annual energy requirements for heating, cooling, DHW and interior lighting in a building. Regarding monthly and annual evaluation of the case studies, three types of results were obtained from the programs: energy requirement, primary energy requirement and end energy consumption. As explained in Chapter 3, once the energy requirement for a service system has been determined, the primary energy requirement and end energy consumption can be found based on the properties of the system selected, taking into account system efficiency and conversion coefficients for primary energy and end consumption. All programs calculate energy requirements for the four service systems (heating, cooling, DHW and lighting), whereas the primary energy requirement and end consumption results are not made available in all programs. Furthermore, each program has its own default conversion coefficients for primary energy requirements and end consumption. When energy requirements are converted into primary energy requirements and end energy consumption with different coefficients, the results become more complicated to compare, and in this regard it is more reliable to compare only the energy requirements. For this reason, it was decided to use only the annual energy requirements for each service system in the comparisons of the case studies.

6.4.2.1 Effect of Building Size (Area and Volume)

Building size has a significant impact on the energy performance of buildings. As can be seen from the formula presented in Figure 6.7, there is a direct relation between building size and energy requirements for heating and cooling – as building size increases, so does the energy requirements for heating and cooling. In order to evaluate the effect of building size on the heating and cooling loads of buildings, eight different buildings, which have the same properties aside from number of floors and number of flats, were studied. All of the buildings are detached and oriented in a south-north direction. To prevent differences between the programs resulting from multi-layered material properties, a uniform single layer material, 25 cm AAC with a U-value of 0.97 W/m^2K, which provides medium weight construction, was assumed for all surfaces. All façades have windows with 10% WWR. Each flat has a 100 m^2 gross floor area and 90 m^2 net floor area, while the story height is 3 m and ceiling height is 2.8 m, creating a 300 m^3 gross and 252 m^3 net volume. All spaces are conditioned, and all surfaces of the building (façades, ground floor and roof) lose heat. The number of floors for the case studies was selected as one-story, representing a single family house; a 3-story building, representing low-rise multi-family housing; a 6-story building, representing mid-rise multi-family housing; and a 15-story building, representing high-rise multi-family housing. All four buildings have one flat on each floor, while for the second group the number of flats was increased to four for the evaluation of differences in the results due to increases in the area and volume. These eight buildings were analyzed using the four programs, and the evaluation results were derived as annual energy requirement per unit. For the sake of simplicity, all values in the tables are given in kWh per unit annually as kWh/m^2a, as presented in Tables 6.15 and 6.16.

Table 6.15 Evaluation Results for the Effect of Building Size

	Effect of # of stories	Effect of # of stories	Effect of # of stories	Effect of # of stories	Convergence
	Case 01	Case 02	Case 03	Case 04	
Material : AAC 25cm (U=0.97) WWR : 10% Windows : Wi01 # of flats : 1					
Effect of building size (area & volume)	One-story SFH with one flat on each floor	3-story MFH with one flat on each floor	6-story MFH with one flat on each floor	15-story MFH with one flat on each floor	 
Energy Need	DB HAP EC EnAd	DB HAP EC EnAd	DB HAP EC EnAd	DB HAP EC EnAd	
Heating	158 221 242 239	111 137 139 143	99 117 114 120	93 105 98 106	
Cooling	5.2 9.7 9.7 9.3	12.0 11.7 13.3 12.4	15.1 12.7 15.1 13.8	16.6 13.3 16.3 14.8	
Lighting	22.5 21.3 19.1 19.3	22.5 21.3 19.5 19.3	22.5 21.3 19.5 19.3	23.3 21.3 19.5 19.3	
DHW	34.6 30.6 23.0 31.8	34.6 30.6 23.0 31.8	34.6 30.6 23.0 31.8	34.6 30.6 23.0 31.8	
Bar graphs Energy Need vs. Case	 	 	 	 	
Performance Class Energy Performance Evaluation by EnAd (only available in EnAd)	F  	D  	C  	C  	

As can be seen in Table 6.15, the first case has high heating loads and very low cooling loads. As the number of floors increases, the energy requirement for heating decreases for each unit, while energy for cooling shows a slight increase. All of the programs show a similar tendency as number of floors increases. EnAd, EnerCalc and HAP give closer results both for heating and cooling loads, while DesignBuilder shows a lower band in the results.

Each program produced the same results for lighting and DHW for all conditions, for which the discrepancy between the results of the programs is very low. Since lighting is introduced on a per unit basis, DHW use is determined per person and/or per unit in the programs, and flat size and number of occupants in each flat are kept constant as well, the results of the energy requirements for interior lighting and DHW per unit do not change as the number of floors increases. The reason for differences in lighting and DHW can be explained by the differences in the net area considered by the programs, and also the different methods employed in the programs.

Since ground floors and flat roofs are heat losing surfaces, when the number of floors is increased, the proportion of heat loss area to conditioned area and volume becomes lower. In this context, the first case, which has the highest compactness ratio (1.08), produced the highest results for heating, while this ratio was calculated as 0.63 for the 3-story building, 0.52 for the 6-story building and 0.45 for the 15-story building in Cases 02, 03 and 04 respectively. After three stories, the compactness ratio becomes moderate and changes slower for each floor, and closer results are obtained since the heat loss area per unit becomes smaller as the number of stories increases. Compactness ratio (c) is the proportion of the thermal envelope area to the conditioned volume (A_E/V_C). Here, the thermal envelope area includes the heat losing surfaces that are exposed to the air, ground or an unconditioned space, including façades (walls and windows), (ground) floor and ceiling/roof. The results of Cases 01–04 show that lighting and DHW do not change with the number of floors, while heating and cooling requirements can change significantly with the number of floors and/or the compactness ratio of the building. Although they produced differences in the results, the four programs showed similar tendencies as the number of floors increased. Table 6.15 also shows the energy performance of the buildings, as provided by EnAd, which is a feature that is not available in the other programs. The performance classes show that despite having the same features, as the number of floors is increased, the energy performance of buildings improves. Case 01 has an energy class of F, while the 3-story building has an energy class of D, and 6- and 15-story buildings are in class C. It should be noted here that energy performance classes are defined according to the energy consumption of buildings, and thus the values indicated on the energy performance graphs are not the same as the energy requirement values in the tables.

In order to explore the effect of changes in the area and volume of the buildings, the number of flats on each floor was increased to four, meaning a 400 m^2 floor area for Cases 05-08. This caused increases in ground floor area and roof area, and decreases in the area of the façade from Cases 01–04. Cases 05–08, with four flats are four times larger than those of Cases 01–04 with one flat, while keeping all other properties the same, including building height, material properties, window type, WWR, service systems and schedules. The results of the evaluations are presented in Table 6.16.

Table 6.16 Evaluation Results for the Effect of Building Size

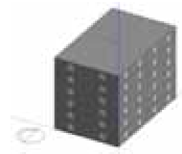
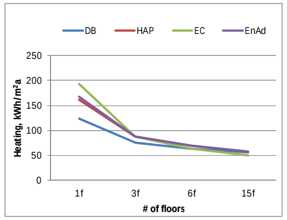
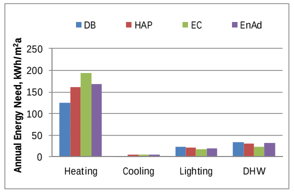
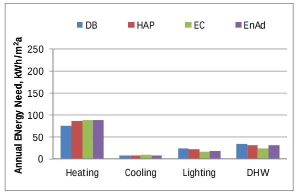
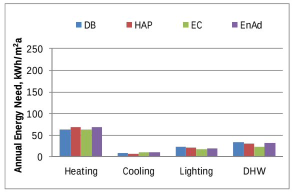
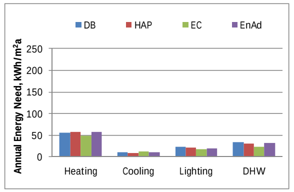
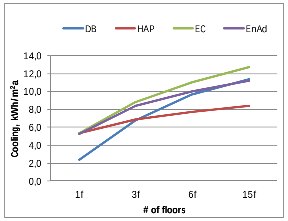
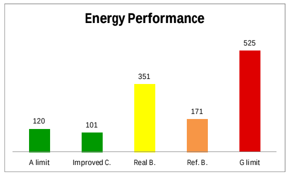
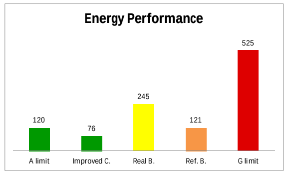
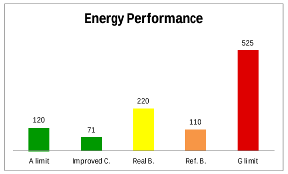
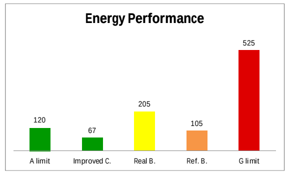
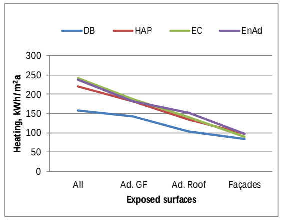
	Effect of # of stories & flats	Effect of # of stories & flats	Effect of # of stories & flats	Effect of # of stories & flats	
	Case 05	Case 06	Case 07	Case 08	
Material : AAC 25cm (U=0.97) WWR : 10% Windows : Wi01 # of flats : 4					
Effect of building size (area & volume)	One-story SFH with 4 flats on each floor	3-story MFH with 4 flats on each floor	6-story MFH with 4 flats on each floor	15-story MFH with 4 flats on each floor	
Energy Need	DB HAP EC EnAd	DB HAP EC EnAd	DB HAP EC EnAd	DB HAP EC EnAd	
Heating	124 162 193 168	76 87 88 88	63 69 64 69	56 58 49 57	
Cooling	2.4 5.4 5.4 5.3	6.8 6.9 8.8 8.4	9.7 7.7 11.0 10.0	11.4 8.4 12.7 11.2	
Lighting	23.3 21.3 17.4 19.3	23.3 21.3 17.4 19.3	23.3 21.3 17.4 19.3	23.3 21.3 17.4 19.3	
DHW	34.6 30.6 23.0 31.8	34.6 30.6 23.0 31.8	34.6 30.6 23.0 31.8	34.6 30.6 23.0 31.8	
Bar graphs Energy Need vs. Case					
Performance Class Energy Performance Evaluation by EnAd (only available in EnAd)	D 	C 	B 	B 	

Table 6.16 shows that buildings with four flats on each floor have lower compactness ratios and need lower heating and cooling when compared to buildings with one flat on each floor. Close results were obtained by the four programs both for heating and cooling requirements, aside for the one-story building. In order to explore the reason(s) for these differences, both on the energy performance of the buildings and between the evaluation results of the programs, the effect of exposed surfaces were examined.

6.4.2.2 Effect of Exposed Surfaces (Walls, Floors and Roof)

The formulas for the calculation of heating and cooling requirements (Figure 6.7) indicate heat loss through the opaque surfaces in a building, which are the walls, ground floor and roof. Since the building thermal envelope consists of many opaque surfaces, heat loss through opaque surfaces plays a determining role in the energy requirements of buildings. In order to evaluate the effect of different surfaces on heating and cooling loads, the ground floor and roof of the buildings were assumed as internal surfaces, that is, not subject to heat loss, for Cases 09–32. For the case studies, the first eight buildings, with one and four flats on each floor, were assessed with the same characteristics, being evaluated for three conditions: the first assumes the ground floor is adiabatic, the second assumes the roof is adiabatic; and the third assumes both the ground floor and the roof are adiabatic. Cases in which all the surfaces are exposed are also included for comparison, and are presented in Tables 6.17–24.

Table 6.17 Evaluation Results for the Effect of Exposed Surfaces for One-Story Building

	Case 01	Case 09	Case 10	Case 11	Convergence
Material : AAC 25cm (U=0.97) WWR : 10% Windows : Wi01 # of flats : 1					
Effect of exposed surfaces	All surfaces are exposed	Façades and roof are exposed Adiabatic Ground floor	Façades and ground floor are exposed Adiabatic Roof	Only façades are exposed	

Energy Need	DB	HAP	EC	EnAd	DB	HAP	EC	EnAd	DB	HAP	EC	EnAd	DB	HAP	EC	EnAd
Heating	158	221	242	239	143	182	188	182	103	134	141	152	83	98	89	97
Cooling	5.2	9.7	9.7	9.3	21.4	11.0	10.2	10.8	2.1	11.5	14.0	12.0	20.7	14.0	17.1	15.6
Lighting	22.5	21.3	19.1	19.3	23.3	21.3	19.1	19.3	23.3	21.3	19.1	19.3	22.5	21.3	19.1	19.3
DHW	34.6	30.6	23.0	31.8	34.6	30.6	23.0	31.8	34.6	30.6	23.0	31.8	34.6	30.6	23.0	31.8

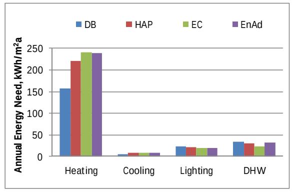
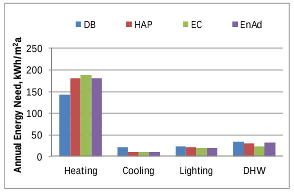
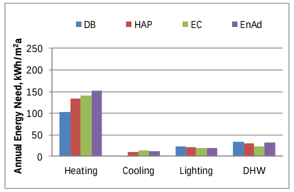
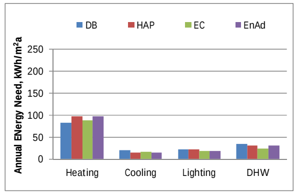
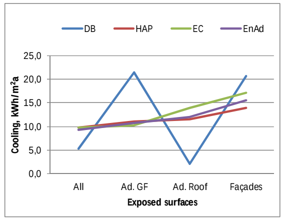
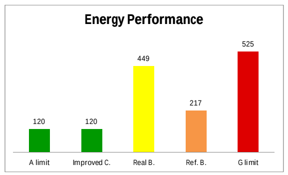
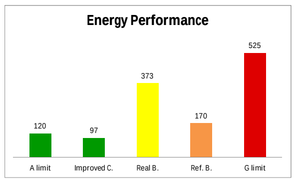
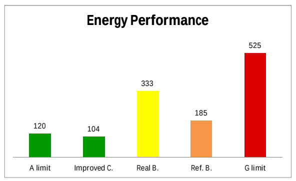
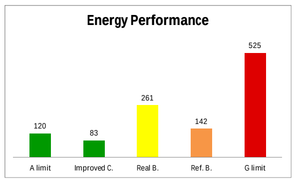
	Case 01	Case 09	Case 10	Case 11	Convergence
Bar graphs Energy Need vs. Case					
Performance Class	F	E	D	C	
Energy Performance Evaluation by EnAd (only available in EnAd)					

Table 6.18 Evaluation Results for the Effect of Exposed Surfaces for 3-Story Building

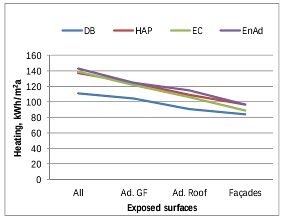
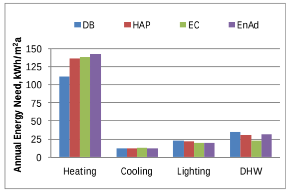
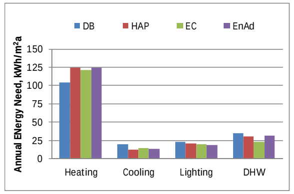
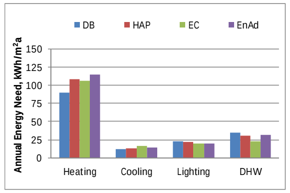
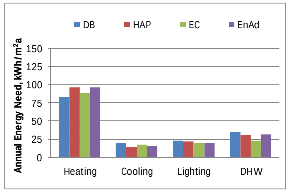
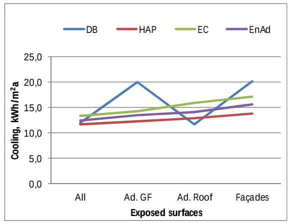
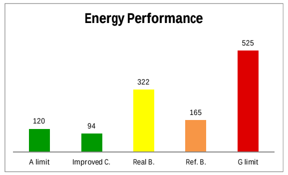
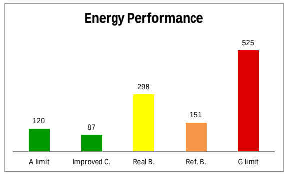
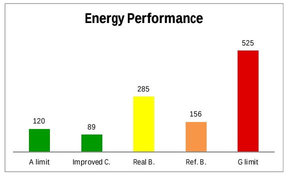
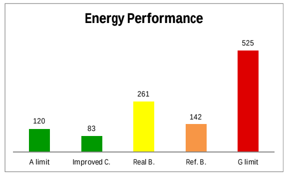
	Case 02	Case 12	Case 13	Case 14	Convergence
Material : AAC 25cm (U=0.97) WWR : 10% Windows : Wi01 # of flats : 1					
Effect of exposed surfaces	All surfaces are exposed	Façades and roof are exposed Adiabatic Ground floor	Façades and ground floor are exposed Adiabatic Roof	Only façades are exposed	
Energy Need	DB / HAP / EC / EnAd	DB / HAP / EC / EnAd	DB / HAP / EC / EnAd	DB / HAP / EC / EnAd	
Heating	111 / 137 / 139 / 143	104 / 125 / 121 / 125	90 / 109 / 106 / 115	84 / 97 / 89 / 97	
Cooling	12.0 / 11.7 / 13.3 / 12.4	20.0 / 12.3 / 14.3 / 13.4	11.7 / 12.9 / 16.0 / 14.1	20.1 / 13.8 / 17.2 / 15.6	
Lighting	22.5 / 21.3 / 19.5 / 19.3	23.3 / 21.3 / 19.5 / 19.3	23.3 / 21.3 / 19.5 / 19.3	22.5 / 21.3 / 19.5 / 19.3	
DHW	34.6 / 30.6 / 23.0 / 31.8	34.6 / 30.6 / 23.0 / 31.8	34.6 / 30.6 / 23.0 / 31.8	34.6 / 30.6 / 23.0 / 31.8	
Bar graphs Energy Need vs. Case			6 		
Performance Class Energy Performance Evaluation by EnAd (only available in EnAd)	D 	C 	C 	C 	

Table 6.19 Evaluation Results for the Effect of Exposed Surfaces for 6-Story Building

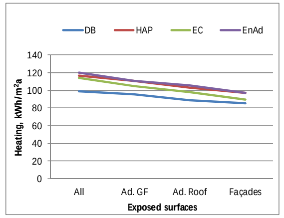
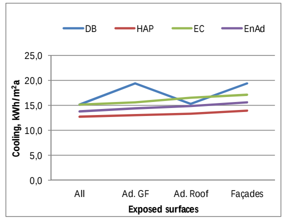
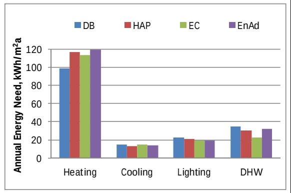
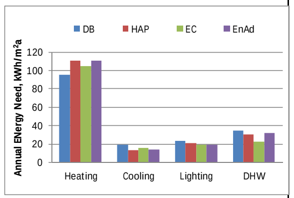
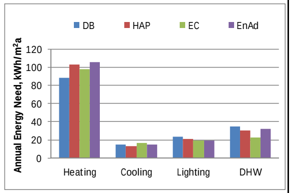
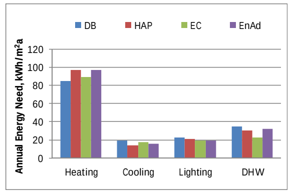
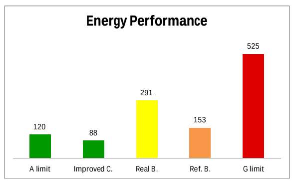
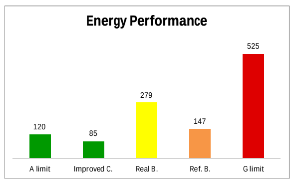
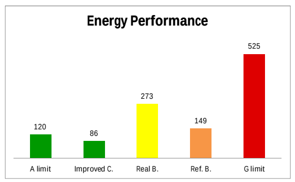
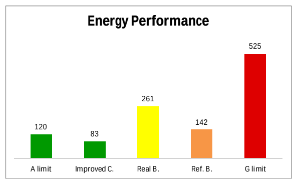
	Case 03	Case 15	Case 16	Case 17	Convergence
Material : AAC 25cm (U=0.97) WWR : 10% Windows : Wi01 # of flats : 1					
Effect of exposed surfaces	All surfaces are exposed	Façades and roof are exposed Adiabatic Ground floor	Façades and ground floor are exposed Adiabatic Roof	Only façades are exposed	 
Energy Need	DB / HAP / EC / EnAd	DB / HAP / EC / EnAd	DB / HAP / EC / EnAd	DB / HAP / EC / EnAd	
Heating	99 / 117 / 114 / 120	96 / 111 / 105 / 111	88 / 103 / 98 / 106	85 / 97 / 89 / 97	
Cooling	15.1 / 12.7 / 15.1 / 13.8	19.3 / 13.1 / 15.6 / 14.4	15.3 / 13.4 / 16.5 / 14.8	19.5 / 14.0 / 17.2 / 15.6	
Lighting	22.5 / 21.3 / 19.5 / 19.3	23.3 / 21.3 / 19.5 / 19.3	23.3 / 21.3 / 19.5 / 19.3	22.5 / 21.3 / 19.5 / 19.3	
DHW	34.6 / 30.6 / 23.0 / 31.8	34.6 / 30.6 / 23.0 / 31.8	34.6 / 30.6 / 23.0 / 31.8	34.6 / 30.6 / 23.0 / 31.8	
Bar graphs Energy Need vs. Case					
Performance Class Energy Performance Evaluation by EnAd (only available in EnAd)	C 	C 	C 	C 	

Table 6.20 Evaluation Results for the Effect of Exposed Surfaces for 15-Story Building

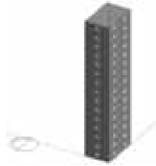
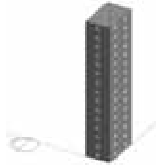
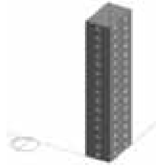
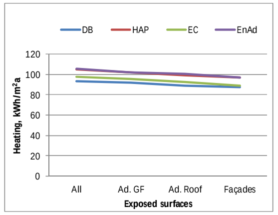
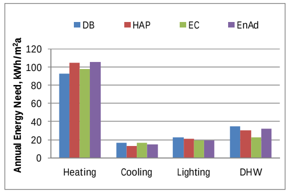
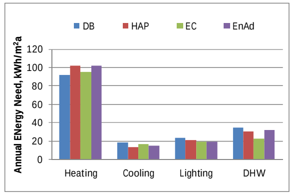
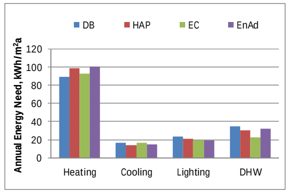
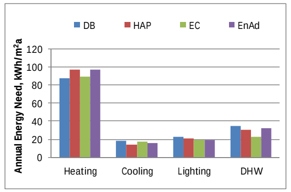
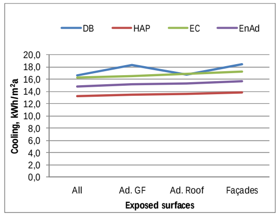
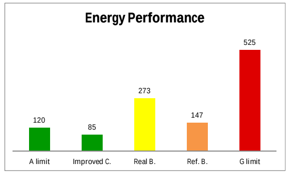
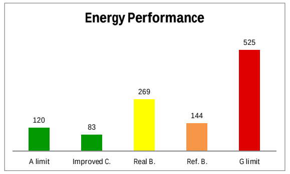
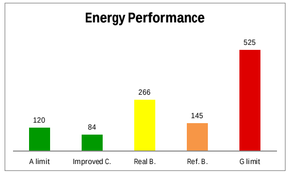
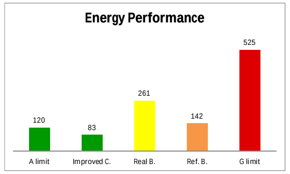
	Case 04	Case 18	Case 19	Case 20	Convergence
Material : AAC 25cm (U=0.97) WWR : 10% Windows : Wi01 # of flats : 1					
Effect of exposed surfaces	All surfaces are exposed	Façades and roof are exposed Adiabatic Ground floor	Façades and ground floor are exposed Adiabatic Roof	Only façades are exposed	
Energy Need	DB / HAP / EC / EnAd	DB / HAP / EC / EnAd	DB / HAP / EC / EnAd	DB / HAP / EC / EnAd	
Heating	93 / 105 / 98 / 106	92 / 102 / 96 / 102	89 / 99 / 93 / 100	87 / 97 / 89 / 97	
Cooling	16.6 / 13.3 / 16.3 / 14.8	18.3 / 13.5 / 16.5 / 15.1	16.7 / 13.6 / 16.9 / 15.3	18.4 / 13.8 / 17.2 / 15.6	
Lighting	22.5 / 21.3 / 19.5 / 19.3	23.3 / 21.3 / 19.5 / 19.3	23.3 / 21.3 / 19.5 / 19.3	22.5 / 21.3 / 19.5 / 19.3	
DHW	34.6 / 30.6 / 23.0 / 31.8	34.6 / 30.6 / 23.0 / 31.8	34.6 / 30.6 / 23.0 / 31.8	34.6 / 30.6 / 23.0 / 31.8	
Bar graphs Energy Need vs. Case					
Performance Class Energy Performance Evaluation by EnAd (only available in EnAd)	C 	C 	C 	C 	

Table 6.21 Evaluation Results for the Effect of Exposed Surfaces for One-Story Building

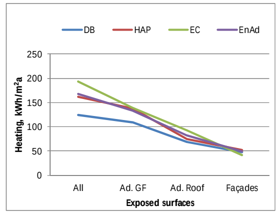
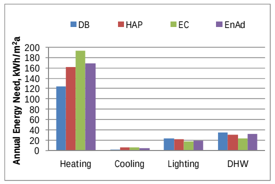
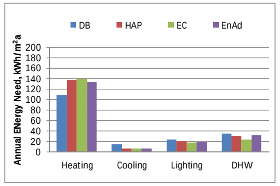
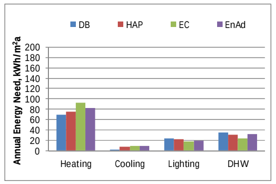
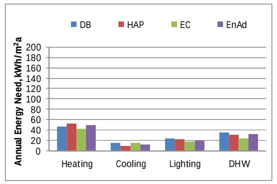
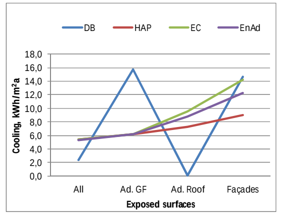
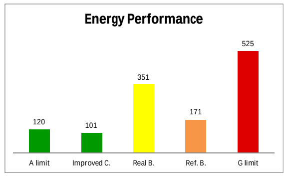
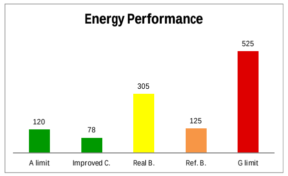
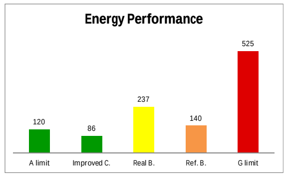
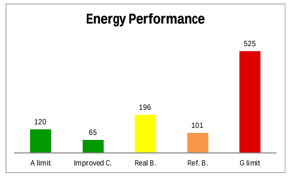
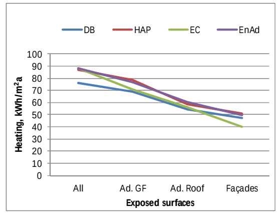
	Case 05	Case 21	Case 22	Case 23	Convergence
Material : AAC 25cm (U=0.97) WWR : 10% Windows : Wi01 # of flats : 4					
Effect of exposed surfaces	All surfaces are exposed	Façades and roof are exposed Adiabatic Ground floor	Façades and ground floor are exposed Adiabatic Roof	Only façades are exposed	
Energy Need	DB HAP EC EnAd	DB HAP EC EnAd	DB HAP EC EnAd	DB HAP EC EnAd	
Heating	124 162 193 168	109 137 139 134	69 75 93 82	47 52 42 50	
Cooling	2.4 5.4 5.4 5.3	15.7 6.2 6.2 6.2	0.1 7.3 9.5 8.8	14.7 9.0 14.2 12.3	
Lighting	23.3 21.3 17.4 19.3	23.3 21.3 17.4 19.3	23.3 21.3 17.4 19.3	23.3 21.3 17.4 19.3	
DHW	34.6 30.6 23.0 31.8	34.6 30.6 23.0 31.8	34.6 30.6 23.0 31.8	34.6 30.6 23.0 31.8	
Bar graphs Energy Need vs. Case					
Performance Class Energy Performance Evaluation by EnAd (only available in EnAd)	D  	D  	B  	B  	

Table 6.22 Evaluation Results for the Effect of Exposed Surfaces for 3-Story Building

	Case 06	Case 24	Case 25	Case 26	Convergence
Material : AAC 25cm (U=0.97) WWR : 10% Windows : Wi01 # of flats : 4					
Effect of exposed surfaces	All surfaces are exposed	Façades and roof are exposed Adiabatic Ground floor	Façades and ground floor are exposed Adiabatic Roof	Only façades are exposed	

Energy Need	Case 06 DB	Case 06 HAP	Case 06 EC	Case 06 EnAd	Case 24 DB	Case 24 HAP	Case 24 EC	Case 24 EnAd	Case 25 DB	Case 25 HAP	Case 25 EC	Case 25 EnAd	Case 26 DB	Case 26 HAP	Case 26 EC	Case 26 EnAd
Heating	76	87	88	88	69	79	71	77	54	59	56	60	47	51	40	50
Cooling	6.8	6.9	8.8	8.4	14.2	7.4	10.0	9.2	6.2	8.2	12.2	10.8	14.4	8.8	14.2	12.3
Lighting	23.3	21.3	17.4	19.3	23.3	21.3	17.4	19.3	23.3	21.3	17.4	19.3	23.3	21.3	17.4	19.3
DHW	34.6	30.6	23.0	31.8	34.6	30.6	23.0	31.8	34.6	30.6	23.0	31.8	34.6	30.6	23.0	31.8

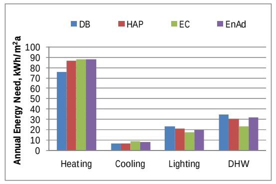
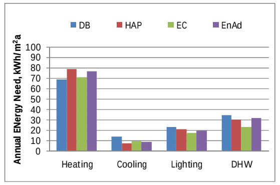
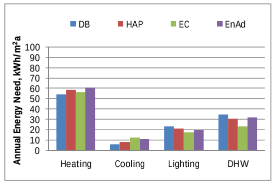
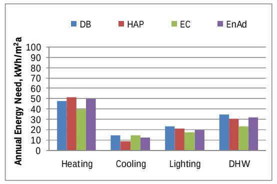
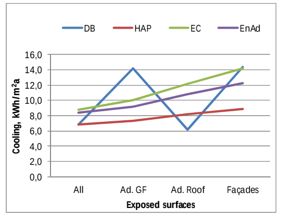
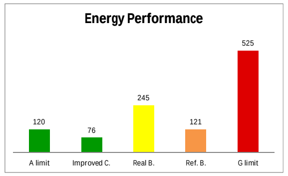
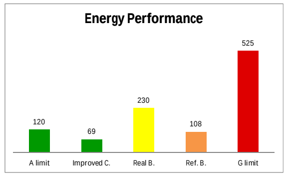
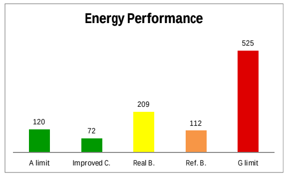
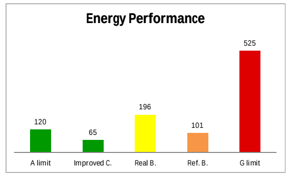
	Case 06	Case 24	Case 25	Case 26	Convergence
Bar graphs Energy Need vs. Case					
Performance Class Energy Performance Evaluation by EnAd (only available in EnAd)	C 	B 	B 	B 	

Table 6.23 Evaluation Results for the Effect of Exposed Surfaces for 6-Story Building

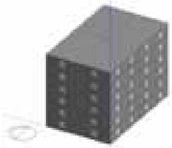
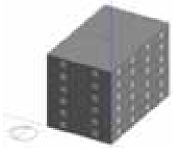
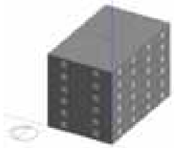
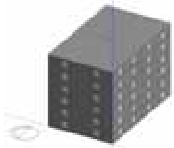
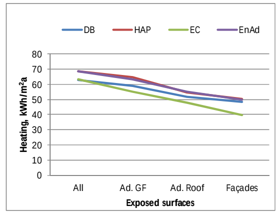
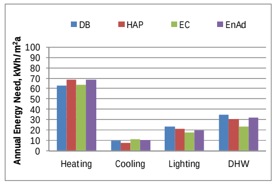
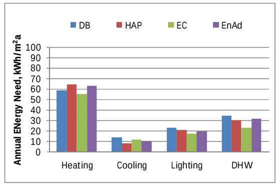
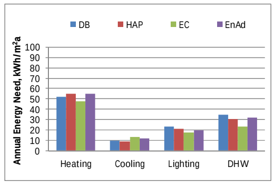
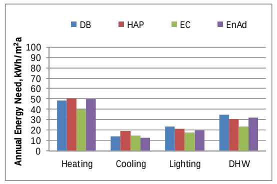
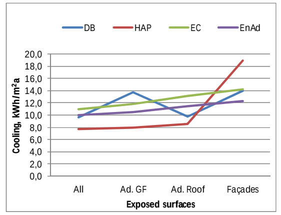
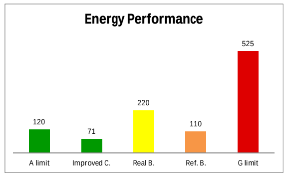
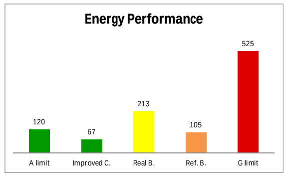
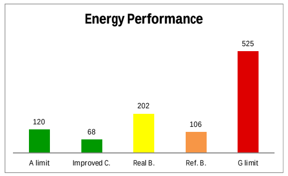
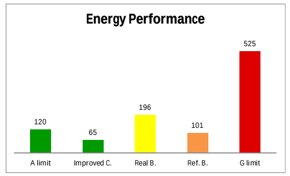
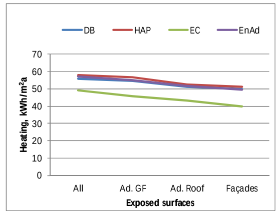
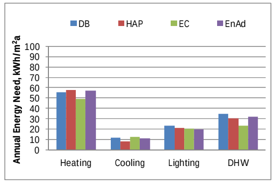
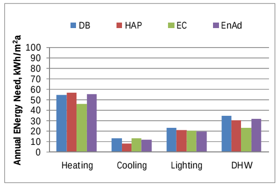
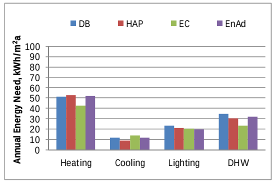
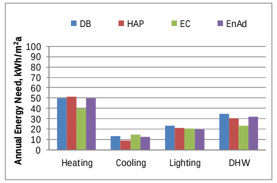
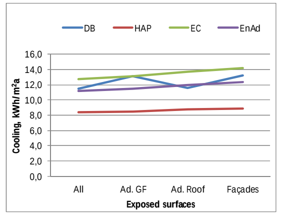
	Case 07	Case 27	Case 28	Case 29	Convergence
Material : AAC 25cm (U=0.97) WWR : 10% Windows : Wi01 # of flats : 4					
Effect of exposed surfaces	All surfaces are exposed	Façades and roof are exposed Adiabatic Ground floor	Façades and ground floor are exposed Adiabatic Roof	Only façades are exposed	
Energy Need	DB / HAP / EC / EnAd	DB / HAP / EC / EnAd	DB / HAP / EC / EnAd	DB / HAP / EC / EnAd	
Heating	63 / 69 / 64 / 69	59 / 65 / 55 / 63	52 / 55 / 48 / 55	48 / 50 / 40 / 50	
Cooling	9.7 / 7.7 / 11.0 / 10.0	13.7 / 8.0 / 11.8 / 10.5	9.8 / 8.5 / 13.1 / 11.5	14.0 / 19.0 / 14.2 / 12.3	
Lighting	23.3 / 21.3 / 17.4 / 19.3	23.3 / 21.3 / 17.4 / 19.3	23.3 / 21.3 / 17.4 / 19.3	23.3 / 21.3 / 17.4 / 19.3	
DHW	34.6 / 30.6 / 23.0 / 31.8	34.6 / 30.6 / 23.0 / 31.8	34.6 / 30.6 / 23.0 / 31.8	34.6 / 30.6 / 23.0 / 31.8	
Bar graphs Energy Need vs. Case					
Performance Class	B	B	B	B	
Energy Performance Evaluation by EnAd (only available in EnAd)					

Table 6.24 Evaluation Results for the Effect of Exposed Surfaces for 15-Story Building

<table>
<tr><th></th><th colspan="4">Case 08</th><th colspan="4">Case 30</th><th colspan="4">Case 31</th><th colspan="4">Case 32</th><th>Convergence</th></tr>
<tr><td>Material : AAC 25cm (U=0.97)
WWR : 10%
Windows : Wi01
# of flats : 4</td><td colspan="4"></td><td colspan="4"></td><td colspan="4"></td><td colspan="4"></td><td></td></tr>
<tr><td>Effect of exposed surfaces</td><td colspan="4">All surfaces are exposed</td><td colspan="4">Façades and roof are exposed
Adiabatic Ground floor</td><td colspan="4">Façades and ground floor are exposed
Adiabatic Roof</td><td colspan="4">Only façades are exposed</td><td rowspan="6">
</td></tr>
<tr><td>Energy Need</td><td>DB</td><td>HAP</td><td>EC</td><td>EnAd</td><td>DB</td><td>HAP</td><td>EC</td><td>EnAd</td><td>DB</td><td>HAP</td><td>EC</td><td>EnAd</td><td>DB</td><td>HAP</td><td>EC</td><td>EnAd</td></tr>
<tr><td>Heating</td><td>56</td><td>58</td><td>49</td><td>57</td><td>54</td><td>56</td><td>46</td><td>55</td><td>51</td><td>53</td><td>43</td><td>52</td><td>50</td><td>51</td><td>40</td><td>50</td></tr>
<tr><td>Cooling</td><td>11.4</td><td>8.4</td><td>12.7</td><td>11.2</td><td>13.1</td><td>8.5</td><td>13.1</td><td>11.5</td><td>11.6</td><td>8.8</td><td>13.7</td><td>12.0</td><td>13.2</td><td>8.9</td><td>14.2</td><td>12.3</td></tr>
<tr><td>Lighting</td><td>23.3</td><td>21.3</td><td>17.4</td><td>19.3</td><td>23.3</td><td>21.3</td><td>17.4</td><td>19.3</td><td>23.3</td><td>21.3</td><td>17.4</td><td>19.3</td><td>23.3</td><td>21.3</td><td>17.4</td><td>19.3</td></tr>
<tr><td>DHW</td><td>34.6</td><td>30.6</td><td>23.0</td><td>31.8</td><td>34.6</td><td>30.6</td><td>23.0</td><td>31.8</td><td>34.6</td><td>30.6</td><td>23.0</td><td>31.8</td><td>34.6</td><td>30.6</td><td>23.0</td><td>31.8</td></tr>
<tr><td>Bar graphs
Energy Need vs. Case</td><td colspan="4">
</td><td colspan="4">
</td><td colspan="4">
</td><td colspan="4">
</td><td>
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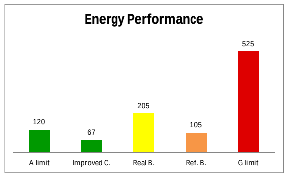
Energy Performance Evaluation by EnAd (only available in EnAd)</td><td colspan="4">B

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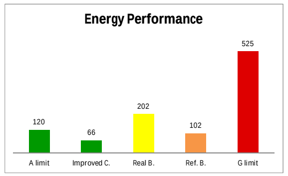
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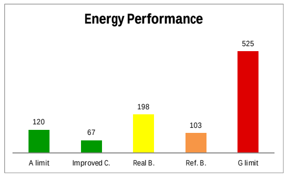
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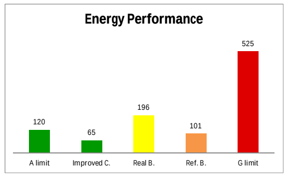

</td><td></td></tr>
</table>

As can be seen in Tables 6.17–24, when the number of exposed surfaces was reduced by assuming the floor and ceiling as internal surfaces, the heating requirements of the buildings diminished and cooling requirements increased. As in the previous cases, as the number of floors increases, discrepancy in the results decreased and closer results were obtained from the four programs. Smaller differences in the results were observed for heating requirements, while greater discrepancies were noted in cooling requirements. This may be due to the use of similar approaches for heating, while being dissimilar for cooling calculations. Furthermore, the most diverse results were recorded for one-story buildings with one and four flats on each floor. Since the heat loss areas are larger than the conditioned area, having the highest compactness ratio, very high heating loads were observed for these buildings. When the ground floor and roof were assumed as internal floors, a convergence was observed in the results of the programs. When only the façades were assumed to be exposed, the results of DesignBuilder for one-story buildings converged with the others. This shows that DesignBuilder uses a different model for the evaluation of the ground floor and roof than the other three programs, and so produced the most diverse results for cooling requirements with changes in the number of exposed surfaces.

As Zhong and Braun (2005) stated, a ground floor in contact with the earth is responsible for 30–50% of the total heat loss in well-built residential buildings. For the heat transmission of the ground floor, the ASHRAE Handbook 2001 assumes heat losses occur through the perimeter of the building, and provides edge insulation coefficients that take into consideration soil properties and climatic conditions. The reason for the lower results from DesignBuilder can be considered as related to such an assumption.

Tables 6.17–20 also show that in Cases 11, 14, 17 and 20, with one flat on each floor and with an internal floor and ceiling, almost the same results were obtained for both heating and cooling requirements from all four tools. The same is true for Cases 23, 26, 29 and 32 with an internal floor and ceiling, and with four flats on each floor. It can be concluded that if only the façades are subject to heat loss, the results do not differ with a change in the number of floors in a building. This verifies that the effect of an exposed ground floor and a flat roof is distributed to each unit, and as the number of floors increases, the distribution of the ground-roof effect decreases relatively. As can be seen from the energy performance classes of the buildings, the ground-roof effect is more dominant in one-story buildings. When ground and roof were assumed as internal surfaces, energy performance classes of one-story buildings increased from F to C for the building with one flat per floor, and from D to B for the building with four flats per floor. In 3-story buildings only one class change was observed, while in 6- and 15-story buildings, slight decreases were observed, although not enough to change the performance classes of the buildings.

6.4.2.3 Effect of Ventilation and Infiltration

The second type of heat loss in a building occurs via ventilation and infiltration. In order to evaluate the effect of ventilation and infiltration on the heating and cooling requirements of a building, the following cases were studied for the four conditions. These assume the inclusion of infiltration and natural ventilation in turn, as shown in Table 6.25. The first condition, named Condition A, considers that there is no infiltration and no ventilation; the second, Condition B, includes only infiltration, while no ventilation is considered; the third, Condition C, assumes only natural ventilation; and the fourth, Condition D, accepts both infiltration and natural ventilation exist together. These four basic conditions are explored for the four cases with 1-, 3-, 6- and 15-Story. The residential buildings are assumed to be located on a site with moderate shielding, and the airflow rate for natural ventilation is assumed to be 0.5 ac/h, as defined in TS EN ISO 13790. Considering infiltration, the minimum allowable value of EnerCalc, 0.6 ac/h, is used for all programs, which is the same value for buildings with moderate shielding according to TS EN ISO 13790. Since infiltration and ventilation are optional in EnerCalc and cannot be cancelled, this program can only be run for Condition D.

Table 6.25 Four Conditions Studied for the Inclusion of Ventilation and Infiltration

Condition	Comparison steps	Case runs
A	no ventilation; no infiltration	DB, HAP, EnAd
B	no ventilation; 0,6 ac/h (n_{50}) infiltration	DB, HAP, EnAd
C	0,5 ac/h natural ventilation; no infiltration	DB, HAP, EnAd
D	0,5 ac/h natural ventilation; 0,6 ac/h (n_{50}) infiltration	DB, HAP, EnerCalc, EnAd

Table 6.26 Evaluation Results for the Effect of Ventilation and Infiltration for One-Story Building

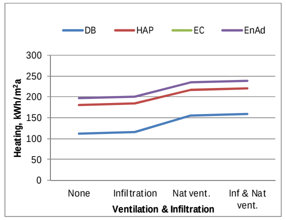
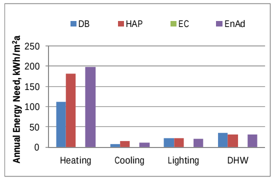
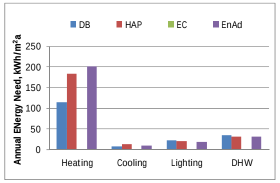
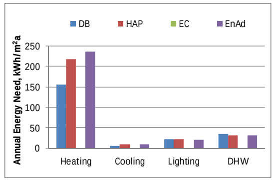
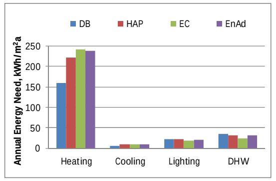
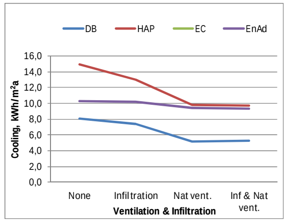
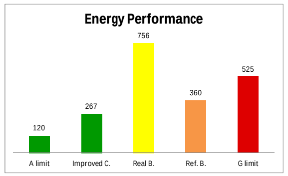
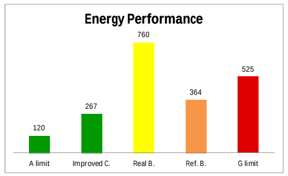
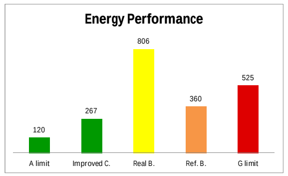
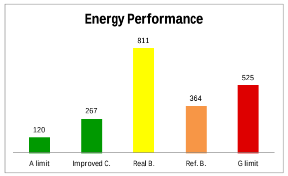
	Case 33				Case 34				Case 35				Case 01				Convergence
Material : AAC 25cm (U=0.97) WWR : 10% Windows : Wi01 # of flats : 1																	
Effect of ventilation and infiltration	No infiltration				With infiltration				With natural ventilation				With infiltration & natural ventilation				
Energy Need	DB	HAP	EC	EnAd	DB	HAP	EC	EnAd	DB	HAP	EC	EnAd	DB	HAP	EC	EnAd	
Heating	112	181		198	115	184		201	155	218		235	158	221	242	239	
Cooling	8.0	14.9		10.3	7.4	13.0		10.2	5.2	9.8		9.4	5.2	9.7	9.7	9.3	
Lighting	22.5	21.3		19.3	22.5	21.3		19.3	22.5	21.3		19.3	22.5	21.3	19.1	19.3	
DHW	34.6	30.6		31.8	34.6	30.6		31.8	34.6	30.6		31.8	34.6	30.6	23.0	31.8	
Bar graphs Energy Need vs. Case																	
Performance Class Energy Performance Evaluation by EnAd (only available in EnAd)	G 				G 				G 				G 				

Table 6.27 Evaluation Results for the Effect of Ventilation and Infiltration for a 3-Story Building

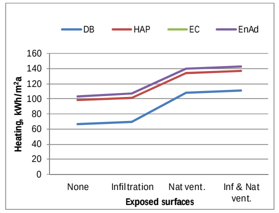
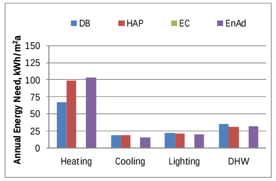
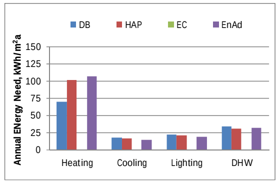
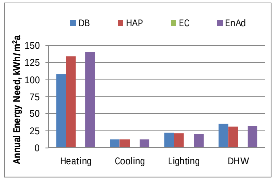
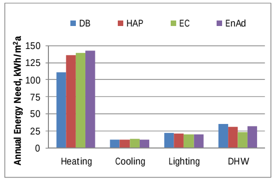
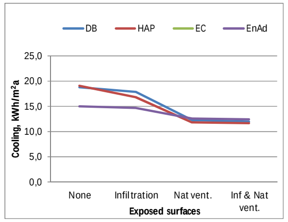
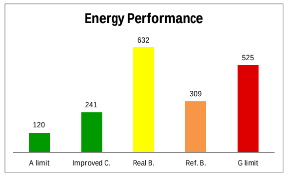
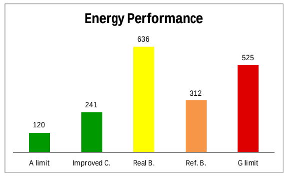
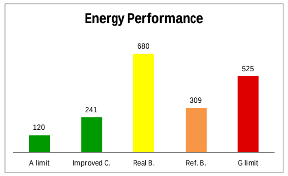
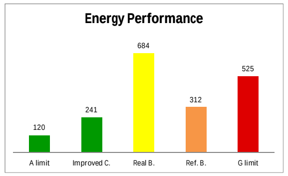
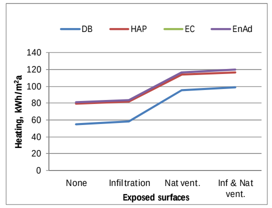
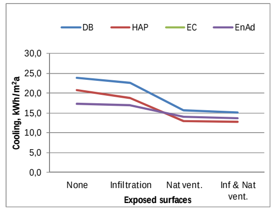
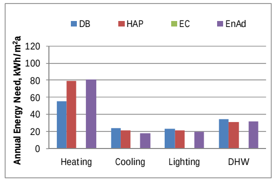
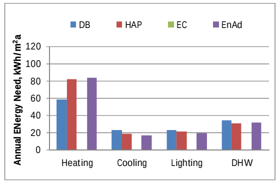
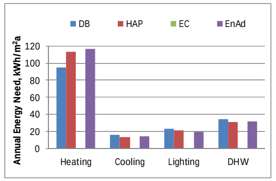
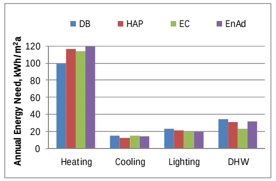
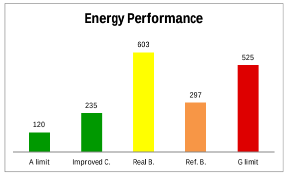
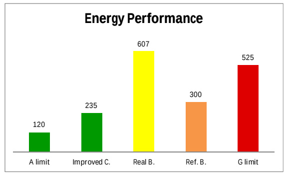
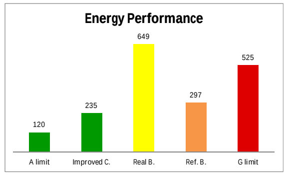
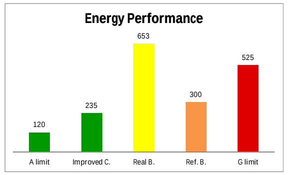
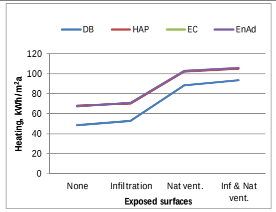
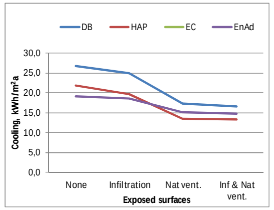
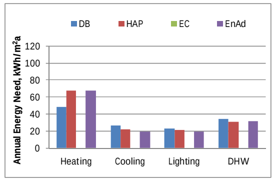
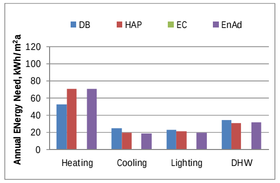
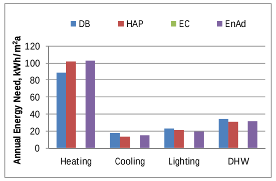
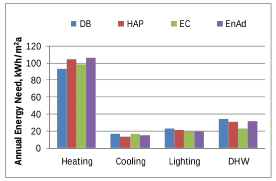
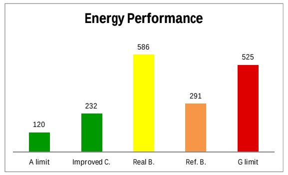
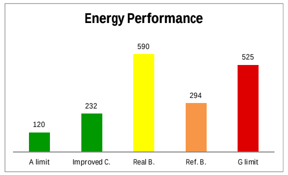
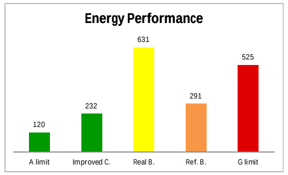
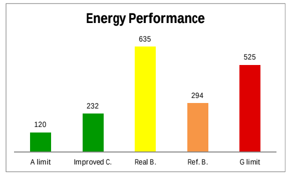
	Case 36				Case 37				Case 38				Case 02				Convergence
Material : AAC 25cm (U=0.97) WWR : 10% Windows : Wi01 # of flats : 1																	
Effect of ventilation and infiltration	No infiltration				With infiltration				With natural ventilation				With infiltration & natural ventilation				
Energy Need	DB	HAP	EC	EnAd	DB	HAP	EC	EnAd	DB	HAP	EC	EnAd	DB	HAP	EC	EnAd	
Heating	67	98		104	70	101		107	108	134		140	111	137	139	143	
Cooling	18.9	19.1		15.0	17.9	16.9		14.7	12.3	11.8		12.5	12.0	11.7	13.3	12.4	
Lighting	22.5	21.3		19.3	22.5	21.3		19.3	22.5	21.3		19.3	22.5	21.3	19.5	19.3	
DHW	34.6	30.6		31.8	34.6	30.6		31.8	34.6	30.6		31.8	34.6	30.6	23.0	31.8	
Bar graphs Energy Need vs. Case																	
Performance Class Energy Performance Evaluation by EnAd (only available in EnAd)	G 				G 				G 				G 				

Table 6.28 Evaluation Results for the Effect of Ventilation and Infiltration for a 6-Story Building

	Case 39	Case 40	Case 41	Case 03	Convergence
Material : AAC 25cm (U=0.97) WWR : 10% Windows : Wi01 # of flats : 1					
Effect of ventilation and infiltration	No infiltration	With infiltration	With natural ventilation	With infiltration & natural ventilation	 
Bar graphs Energy Need vs. Case					
Performance Class Energy Performance Evaluation by EnAd (only available in EnAd)	G 	G 	G 	G 	

Energy Need	Case 39 DB	Case 39 HAP	Case 39 EC	Case 39 EnAd	Case 40 DB	Case 40 HAP	Case 40 EC	Case 40 EnAd	Case 41 DB	Case 41 HAP	Case 41 EC	Case 41 EnAd	Case 03 DB	Case 03 HAP	Case 03 EC	Case 03 EnAd
Heating	55	79		81	58	82		84	95	114		117	99	117	114	120
Cooling	23.9	20.8		17.3	22.6	18.8		16.9	15.6	12.9		14.0	15.1	12.7	15.1	13.8
Lighting	22.5	21.3		19.3	22.5	21.3		19.3	22.5	21.3		19.3	22.5	21.3	19.5	19.3
DHW	34.6	30.6		31.8	34.6	30.6		31.8	34.6	30.6		31.8	34.6	30.6	23.0	31.8

Table 6.29 Evaluation Results for the Effect of Ventilation and Infiltration for 15-Story Building

	Case 42	Case 43	Case 44	Case 04	Convergence
Material : AAC 25cm (U=0.97) WWR : 10% Windows : Wi01 # of flats : 1					
Effect of ventilation and infiltration	No infiltration	With infiltration	With natural ventilation	With infiltration & natural ventilation	 
Bar graphs Energy Need vs. Case					
Performance Class Energy Performance Evaluation by EnAd (only available in EnAd)	G 	G 	G 	G 	

Energy Need	Case 42 DB	Case 42 HAP	Case 42 EC	Case 42 EnAd	Case 43 DB	Case 43 HAP	Case 43 EC	Case 43 EnAd	Case 44 DB	Case 44 HAP	Case 44 EC	Case 44 EnAd	Case 04 DB	Case 04 HAP	Case 04 EC	Case 04 EnAd
Heating	48	68		68	53	70		71	89	102		103	93	105	98	106
Cooling	26.8	21.9		19.1	25.0	19.6		18.6	17.3	13.6		15.1	16.6	13.3	16.3	14.8
Lighting	22.5	21.3		19.3	22.5	21.3		19.3	22.5	21.3		19.3	22.5	21.3	19.5	19.3
DHW	34.6	30.6		31.8	34.6	30.6		31.8	34.6	30.6		31.8	34.6	30.6	23.0	31.8

As can be seen in Table 6.26, when there was no ventilation or infiltration under Condition A, a high heating and low cooling requirement was recorded for a one-story building. With the existence of infiltration under Condition B, a slight increase in heating and a minor decrease in cooling were observed. The results for heating in all programs increased by about 3 kWh/m^2a, and decreased by 0.2-2 kWh/m^2a for cooling. For Condition C, with the addition of natural ventilation, higher increases were observed for heating requirements, while minor changes were recorded for cooling requirements when compared to Condition B. When compared to Condition A, the heating requirements increased between 37-43 kWh/m^2a in the programs, while the cooling requirements diminished 2-5 kWh/m^2a. For Condition D considering both natural ventilation and infiltration, heating and cooling requirements changed by sum of the changes witnessed in Conditions B and C. The inclusion of natural ventilation and infiltration made no difference to the results for lighting or DHW.

As number of floors increases, similar tendencies and changes in the results were recorded. The lowest heating needs were observed under Condition A, considering no infiltration and no ventilation, which requires the highest energy for cooling. Under Condition B, the inclusion of infiltration had minor effect on heating and cooling demand, accounting for less than 1%, while natural ventilation led to increases in heating requirements (17%) and a reduction in cooling requirements (8%) for Condition C. Under Condition D, heating and cooling requirements were changed by the sum of the effects of Condition B with infiltration and Condition C with natural ventilation. Since natural ventilation and infiltration are based on the conditioned volume, and airflow rates and the volume of each flat remain the same, no differences were recorded as the number of floors increases in the buildings.

Considering the results, the lowest values for heating and the highest for cooling were observed in the DesignBuilder program for all cases; while EnAd, EnerCalc and HAP produced very similar results to each other. When the number of flats was increased, closer results were recorded by the four programs. It can be seen that inclusion of natural ventilation and infiltration made only minor discrepancies between the results of the programs. Since infiltration and natural ventilation cannot be cancelled in EnerCalc, to include the results of EnerCalc in the comparison, the following cases were run only for Condition D, including infiltration and natural ventilation in all programs.

6.4.2.4 Effect of U-values

One of the most significant parameters in the energy performance of buildings is the U-value of the opaque and transparent surfaces. As stated by Ballarini and Corrado (2012), since the U-value (thermal conductivity) of the surfaces is a determining factor in heat loss depending on outside temperature differences, it is highly significant in the energy performance of a building. The effect of U-values on the heating and cooling requirements of a building was evaluated in three ways in this study: The first assumes the addition of layers; the second assumes an increase in material thickness; and the third considers the type of construction. For the first group, a uniform single layer of material, 25 cm AAC, was used. Next, 4 cm of insulation (EPS) was added, and then a second layer of AAC, 10 cm thick, was added. For the second group, a brick material was used of different thicknesses, as 9 cm, 18 cm and 50 cm, representing light-, medium- and heavy-weight construction types. For the third group, three brick surfaces of different thicknesses were added insulation to have the same thermal conductivity of 0.42 W/m^2K to allow the evaluation of light, medium and heavy construction types in a different way. Detailed information on the properties of these materials is provided in the material lists in Table 6.12. The evaluation results are presented in Tables 6.30–32.

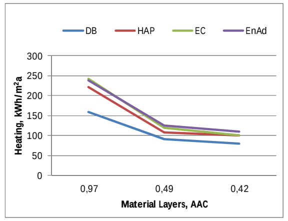
Table 6.30 Evaluation Results for the Effect of U-value for One-Story Building

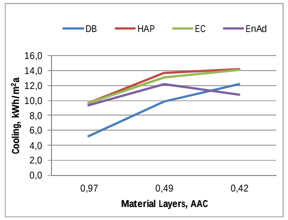
<table>
<tr><th></th><th>Case 01</th><th>Case 45</th><th>Case 46</th><th>Convergence</th></tr>
<tr><td>WWR : 10%
Windows : Wi01
# of flats : 1</td><td></td><td></td><td></td><td></td></tr>
<tr><td>Materials

Energy Need
Heating
Cooling
Lighting
DHW</td>
<td>AAC 25 cm
U = 0.97 W/m^{2}K

DB HAP EC EnAd
158 221 242 239
5.2 9.7 9.7 9.3
22.5 21.3 19.1 19.3
34.6 30.6 23.0 31.8</td>
<td>AAC 25 cm + 4 cm insulation
U = 0.49 W/m^{2}K

DB HAP EC EnAd
91 108 119 125
9.9 13.7 13.1 12.2
22.5 21.3 19.1 19.3
34.6 30.6 23.0 31.8</td>
<td>AAC 25cm + Ins 4cm + AAC 10cm
U = 0.42 W/m^{2}K

DB HAP EC EnAd
79 100 101 110
12.2 14.2 14.1 10.8
22.5 21.3 19.1 19.3
34.6 30.6 23.0 31.8</td>
<td>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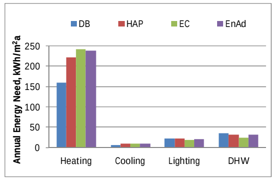
<tr><td>Bar graphs
Energy Need vs. Case</td>
<td>
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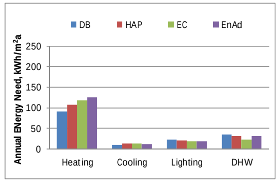
<td>
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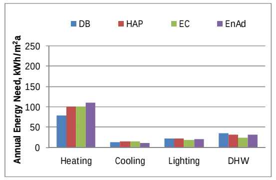
<td>
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Energy Performance Evaluation by EnAd (only available in EnAd)</td>
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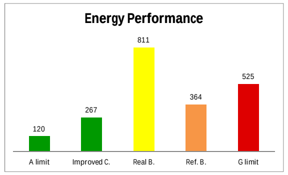
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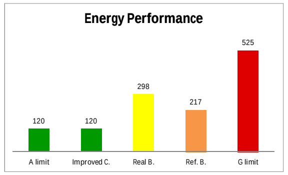
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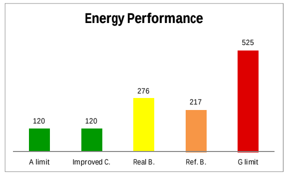
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Table 6.31 Evaluation Results for the Effect of U-value for One-Story Building

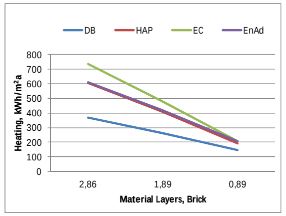
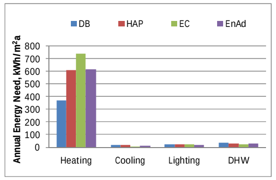
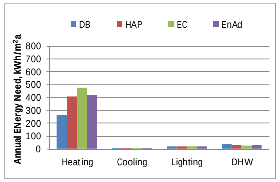
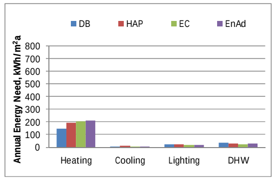
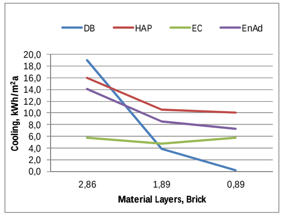
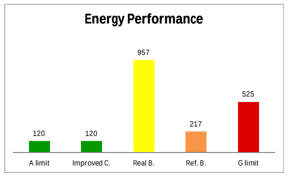
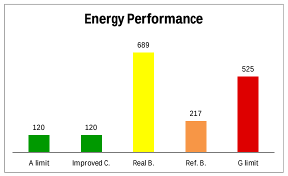
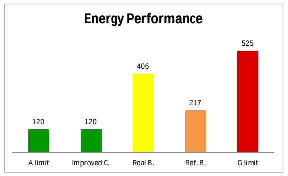
	Case 47				Case 48				Case 49				Convergence
WWR : 10% Windows : Wi01 # of flats : 1													
Materials	Brick 9 cm U = 2.86 W/m²K				Brick 18 cm U = 1.89 W/m²K				Brick 50 cm U = 0.86 W/m²K				
Energy Need	DB	HAP	EC	EnAd	DB	HAP	EC	EnAd	DB	HAP	EC	EnAd	
Heating	369	607	735	612	261	406	479	417	147	193	208	208	
Cooling	19.0	16.0	5.8	14.0	3.9	10.5	4.7	8.6	0.2	10.1	5.8	7.3	
Lighting	22.5	21.3	19.1	19.3	22.5	21.3	19.1	19.3	22.5	21.3	19.1	19.3	
DHW	34.6	30.6	23.0	31.8	34.6	30.6	23.0	31.8	34.6	30.6	23.0	31.8	
Bar graphs Energy Need vs. Case													
Performance Class Energy Performance Evaluation by EnAd (only available in EnAd)	G  				G  				E  				

Table 6.32 Evaluation Results for the Effect of U-value for One-Story Building

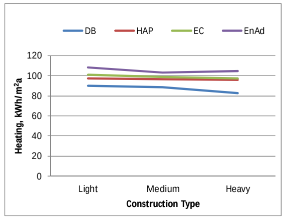
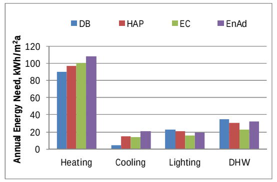
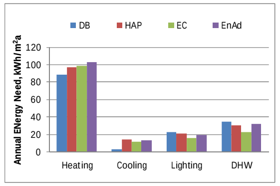
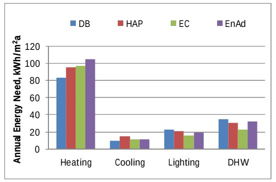
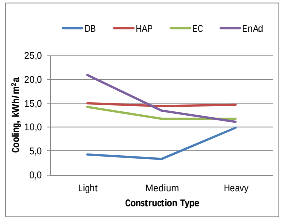
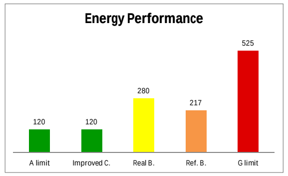
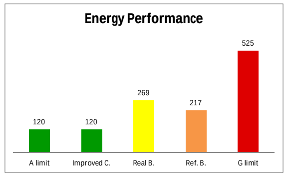
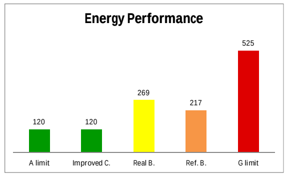
	Case 50	Case 51	Case 52	Convergence
WWR : 10% Windows : Wi01 # of flats : 1				
Materials	Brick 9 cm + insulation 8.2 cm U = 0.42 W/m²K	Brick 18 cm + insulation 7.5 cm U = 0.42 W/m²K	Brick 50 cm + insulation 5 cm U = 0.42 W/m²K	
Energy Need	DB / HAP / EC / EnAd	DB / HAP / EC / EnAd	DB / HAP / EC / EnAd	
Heating	90 / 97 / 101 / 108	89 / 97 / 98 / 103	83 / 95 / 97 / 105	
Cooling	4.4 / 15.0 / 14.2 / 20.9	3.3 / 14.4 / 11.7 / 13.5	9.9 / 14.6 / 11.7 / 11.2	
Lighting	22.5 / 21.3 / 19.1 / 19.3	22.5 / 21.3 / 19.1 / 19.3	22.5 / 21.3 / 19.1 / 19.3	
DHW	34.6 / 30.6 / 23.0 / 31.8	34.6 / 30.6 / 23.0 / 31.8	34.6 / 30.6 / 23.0 / 31.8	
Bar graphs Energy Need vs. Case				
Performance Class Energy Performance Evaluation by EnAd (only available in EnAd)	C 	C 	C 	

Table 6.33 Evaluation Results for the Effect of U-value for a 3-Story Building

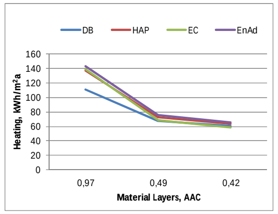
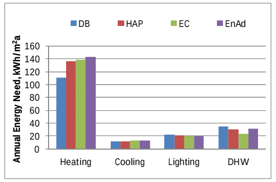
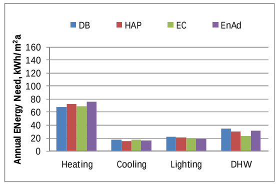
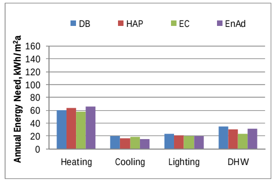
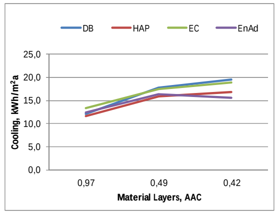
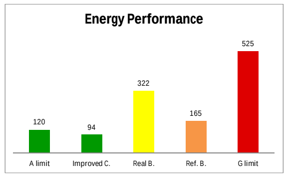
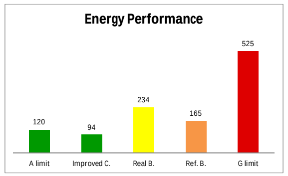
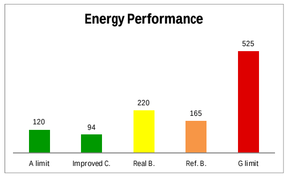
	Case 02	Case 53	Case 54	Convergence
WWR : 10% Windows : Wi01 # of flats : 1				
Materials Energy Need Heating Cooling Lighting DHW	AAC 25 cm U = 0.97 W/m^{2}K DB HAP EC EnAd 111 137 139 143 12.0 11.7 13.3 12.4 22.5 21.3 19.5 19.3 34.6 30.6 23.0 31.8	AAC 25 cm + 4 cm insulation U = 0.49 W/m^{2}K DB HAP EC EnAd 68 73 69 76 17.7 15.9 17.5 16.4 22.5 21.3 19.5 19.3 34.6 30.6 23.0 31.8	AAC 25cm + Ins 4cm + AAC 10cm U = 0.42 W/m^{2}K DB HAP EC EnAd 60 64 58 66 19.6 16.9 18.8 15.6 22.5 21.3 19.5 19.3 34.6 30.6 23.0 31.8	
Bar graphs Energy Need vs. Case				
Performance Class Energy Performance Evaluation by EnAd (only available in EnAd)	D 	B 	B 	

Table 6.34 Evaluation Results for the Effect of U-value for a 3-Story Building

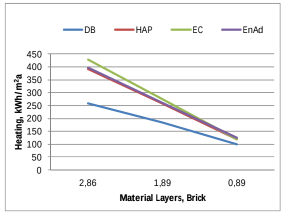
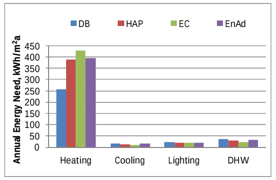
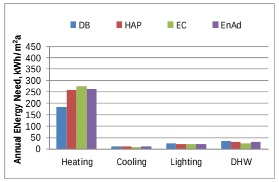
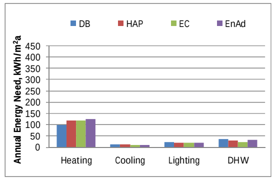
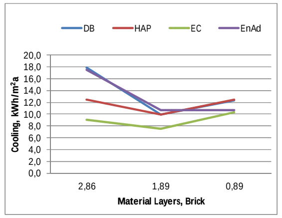
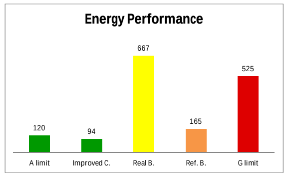
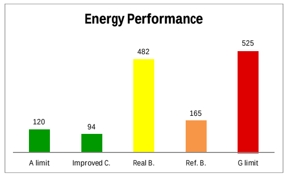
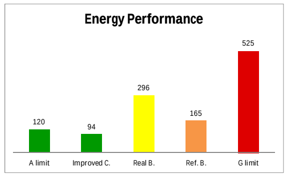
	Case 55	Case 56	Case 57	Convergence
WWR : 10% Windows : Wi01 # of flats : 1				
Materials	Brick 9 cm U = 2.86 W/m^{2}K	Brick 18 cm U = 1.89 W/m^{2}K	Brick 50 cm U = 0.86 W/m^{2}K	
Energy Need	DB / HAP / EC / EnAd	DB / HAP / EC / EnAd	DB / HAP / EC / EnAd	
Heating	258 / 390 / 428 / 396	184 / 259 / 276 / 262	100 / 120 / 119 / 125	
Cooling	17.9 / 12.4 / 9.0 / 17.5	10.0 / 10.0 / 7.5 / 10.6	12.3 / 12.5 / 10.3 / 10.7	
Lighting	22.5 / 21.3 / 19.5 / 19.3	22.5 / 21.3 / 19.5 / 19.3	22.5 / 21.3 / 19.5 / 19.3	
DHW	34.6 / 30.6 / 23.0 / 31.8	34.6 / 30.6 / 23.0 / 31.8	34.6 / 30.6 / 23.0 / 31.8	
Bar graphs Energy Need vs. Case				
Performance Class Energy Performance Evaluation by EnAd (only available in EnAd)	G 	F 	C 	

Table 6.35 Evaluation Results for the Effect of U-value for a 3-Story Building

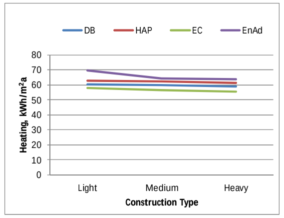
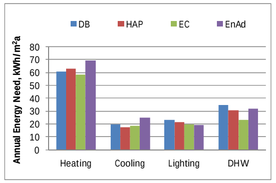
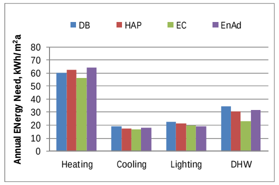
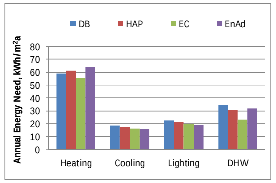
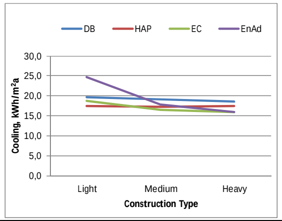
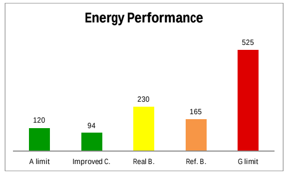
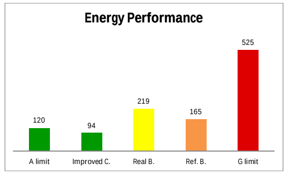
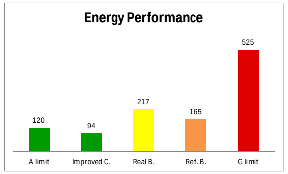
	Case 58	Case 59	Case 60	Convergence
WWR : 10% Windows : Wi01 # of flats : 1				
Materials	Brick 9 cm + insulation 8.2 cm U = 0.42 W/m^{2}K	Brick 18 cm + insulation 7.5 cm U = 0.42 W/m^{2}K	Brick 50 cm + insulation 5 cm U = 0.42 W/m^{2}K	
Energy Need	DB HAP EC EnAd	DB HAP EC EnAd	DB HAP EC EnAd	
Heating	61 63 58 69	60 62 56 64	59 61 56 64	
Cooling	19.8 17.5 18.8 24.7	19.2 17.2 16.6 17.8	18.6 17.5 16.0 15.9	
Lighting	22.5 21.3 19.5 19.3	22.5 21.3 19.5 19.3	22.5 21.3 19.5 19.3	
DHW	34.6 30.6 23.0 31.8	34.6 30.6 23.0 31.8	34.6 30.6 23.0 31.8	
Bar graphs Energy Need vs. Case				
Performance Class Energy Performance Evaluation by EnAd (only available in EnAd)	B 	B 	B 	

Table 6.36 Evaluation Results for the Effect of U-value for a 6-Story Building

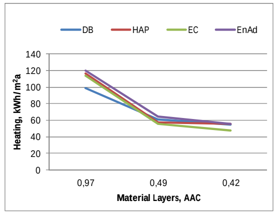
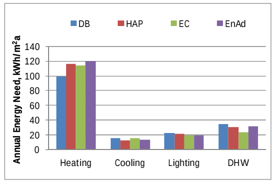
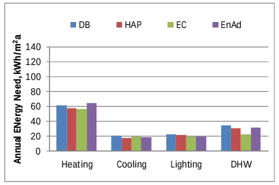
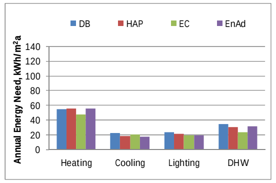
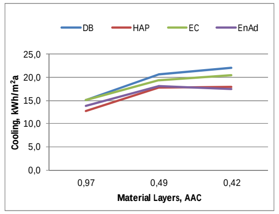
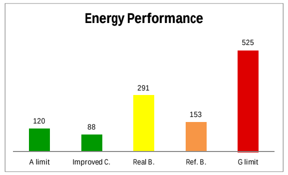
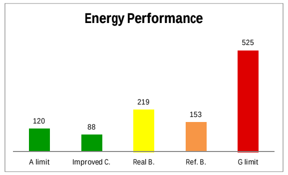
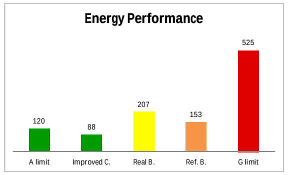
	Case 03	Case 61	Case 62	Convergence
WWR : 10% Windows : Wi01 # of flats : 1				
Materials	AAC 25 cm U = 0.97 W/m^{2}K	AAC 25 cm + 4 cm insulation U = 0.49 W/m^{2}K	AAC 25cm + Ins 4cm + AAC 10cm U = 0.42 W/m^{2}K	
Energy Need	DB / HAP / EC / EnAd	DB / HAP / EC / EnAd	DB / HAP / EC / EnAd	
Heating	99 / 117 / 114 / 120	61 / 57 / 56 / 64	55 / 56 / 48 / 55	
Cooling	15.1 / 12.7 / 15.1 / 13.8	20.6 / 17.7 / 19.4 / 18.0	22.0 / 17.9 / 20.5 / 17.4	
Lighting	22.5 / 21.3 / 19.5 / 19.3	22.5 / 21.3 / 19.5 / 19.3	22.5 / 21.3 / 19.5 / 19.3	
DHW	34.6 / 30.6 / 23.0 / 31.8	34.6 / 30.6 / 23.0 / 31.8	34.6 / 30.6 / 23.0 / 31.8	
Bar graphs Energy Need vs. Case				
Performance Class Energy Performance Evaluation by EnAd (only available in EnAd)	C 	B 	B 	

Table 6.37 Evaluation Results for the Effect of U-value for a 6-Story Building

<table>
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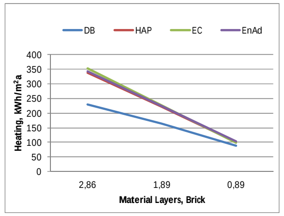
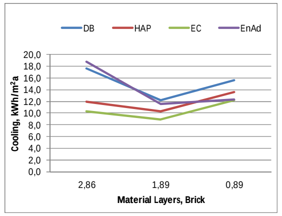
<tr><td>WWR : 10%
Windows : Wi01
# of flats : 1</td><td></td><td></td><td></td><td></td></tr>
<tr><td>Materials

Energy Need
Heating
Cooling
Lighting
DHW</td>
<td>Brick 9 cm
U = 2.86 W/m²K

DB HAP EC EnAd
229 337 352 342
17.6 11.9 10.3 18.8
22.5 21.3 19.5 19.3
34.6 30.6 23.0 31.8</td>
<td>Brick 18 cm
U = 1.89 W/m²K

DB HAP EC EnAd
163 222 226 224
12.3 10.3 8.9 11.5
22.5 21.3 19.5 19.3
34.6 30.6 23.0 31.8</td>
<td>Brick 50 cm
U = 0.86 W/m²K

DB HAP EC EnAd
89 102 97 104
15.5 13.6 12.2 12.3
22.5 21.3 19.5 19.3
34.6 30.6 23.0 31.8</td>
<td rowspan="2">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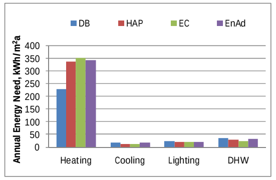
<tr><td>Bar graphs
Energy Need vs. Case</td>
<td>
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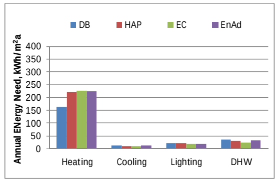
<td>
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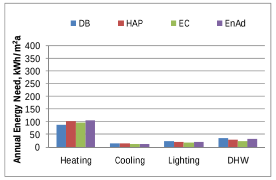
<td>
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<tr><td>Performance Class

Energy Performance Evaluation by EnAd (only available in EnAd)</td>
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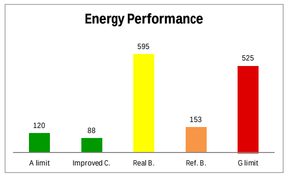
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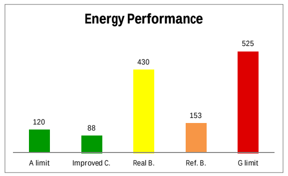
<td>F

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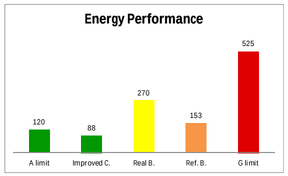
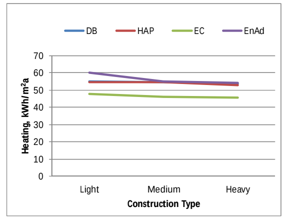
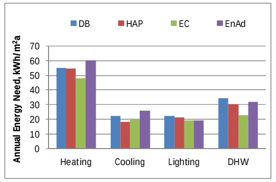
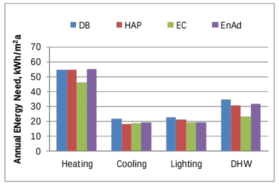
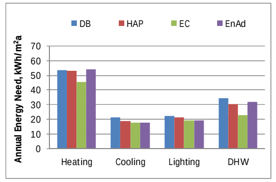
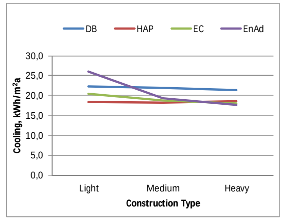
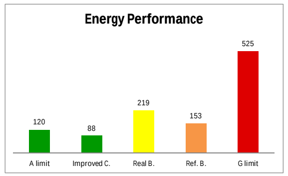
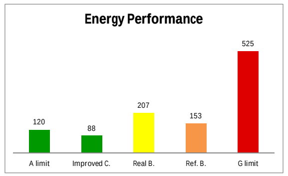
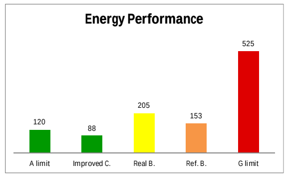
<td>C

</td>
<td></td></tr>
</table>

Table 6.38 Evaluation Results for the Effect of U-value for a 6-Story Building

	Case 66	Case 67	Case 68	Convergence
WWR : 10% Windows : Wi01 # of flats : 1				
Materials	Brick 9 cm + insulation 8.2 cm U = 0.42 W/m^{2}K	Brick 18 cm + insulation 7.5 cm U = 0.42 W/m^{2}K	Brick 50 cm + insulation 5 cm U = 0.42 W/m^{2}K	
Bar graphs Energy Need vs. Case				
Performance Class Energy Performance Evaluation by EnAd (only available in EnAd)	B 	B 	B 	

Energy Need	Case 66 DB	Case 66 HAP	Case 66 EC	Case 66 EnAd	Case 67 DB	Case 67 HAP	Case 67 EC	Case 67 EnAd	Case 68 DB	Case 68 HAP	Case 68 EC	Case 68 EnAd
Heating	55	55	48	60	54	54	46	55	54	53	46	54
Cooling	22.3	18.5	20.5	26.0	21.9	18.2	18.7	19.3	21.4	18.6	18.0	17.6
Lighting	22.5	21.3	19.5	19.3	22.5	21.3	19.5	19.3	22.5	21.3	19.5	19.3
DHW	34.6	30.6	23.0	31.8	34.6	30.6	23.0	31.8	34.6	30.6	23.0	31.8

Table 6.39 Evaluation Results for the Effect of U-value for a 15-Story Building

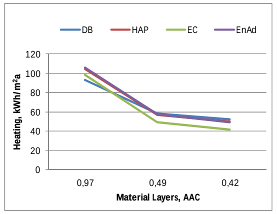
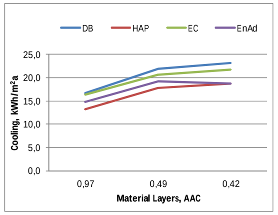
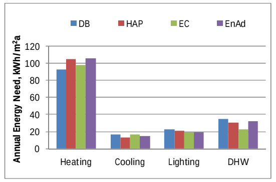
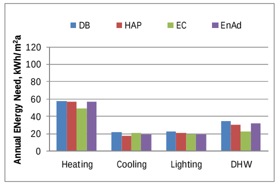
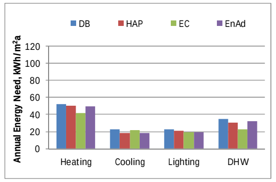
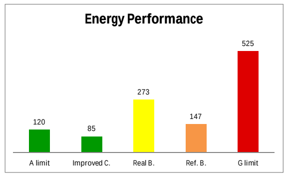
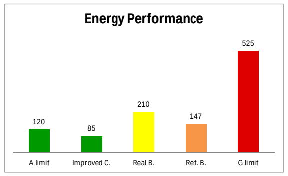
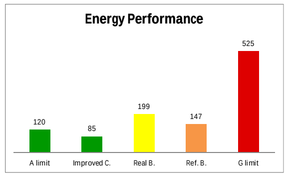
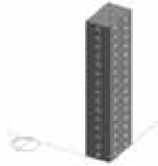
	Case 04				Case 69				Case 70				Convergence
WWR : 10% Windows : Wi01 # of flats : 1													
Materials	AAC 25 cm U = 0.97 W/m^{2}K				AAC 25 cm + 4 cm insulation U = 0.49 W/m^{2}K				AAC 25cm + Ins 4cm + AAC 10cm U = 0.42 W/m^{2}K				 
Energy Need	DB	HAP	EC	EnAd	DB	HAP	EC	EnAd	DB	HAP	EC	EnAd	
Heating	93	105	98	106	58	57	49	57	52	50	42	49	
Cooling	16.6	13.3	16.3	14.8	21.9	17.7	20.6	19.2	23.1	18.6	21.7	18.7	
Lighting	22.5	21.3	19.5	19.3	22.5	21.3	19.5	19.3	22.5	21.3	19.5	19.3	
DHW	34.6	30.6	23.0	31.8	34.6	30.6	23.0	31.8	34.6	30.6	23.0	31.8	
Bar graphs Energy Need vs. Case													
Performance Class Energy Performance Evaluation by EnAd (only available in EnAd)	C 				B 				B 				

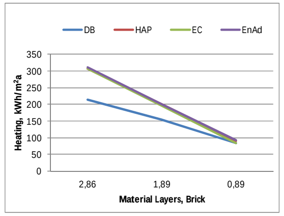
Table 6.40 Evaluation Results for the Effect of U-value for a 15-Story Building

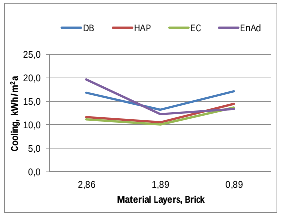
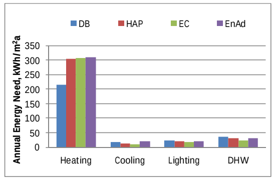
<table>
<tr><th></th><th>Case 71</th><th>Case 72</th><th>Case 73</th><th>Convergence</th></tr>
<tr><td>WWR : 10%
Windows : Wi01
# of flats : 1</td><td></td><td></td><td></td><td></td></tr>
<tr><td>Materials

Energy Need
Heating
Cooling
Lighting
DHW</td>
<td>Brick 9 cm
U = 2.86 W/m²K

DB HAP EC EnAd
214 306 307 310
16.8 11.6 11.2 19.6
22.5 21.3 19.5 19.3
34.6 30.6 23.0 31.8</td>
<td>Brick 18 cm
U = 1.89 W/m²K

DB HAP EC EnAd
153 201 196 201
13.1 10.5 10.0 12.2
22.5 21.3 19.5 19.3
34.6 30.6 23.0 31.8</td>
<td>Brick 50 cm
U = 0.86 W/m²K

DB HAP EC EnAd
84 92 85 92
17.1 14.4 13.6 13.4
22.5 21.3 19.5 19.3
34.6 30.6 23.0 31.8</td>
<td rowspan="2">


</td></tr>
<tr><td>Bar graphs
Energy Need vs. Case</td>
<td>
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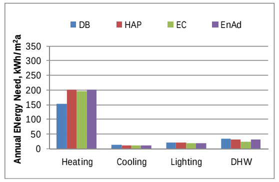
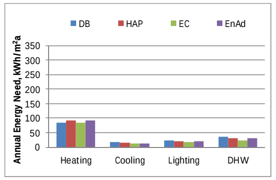
<td>
</td>
<td>
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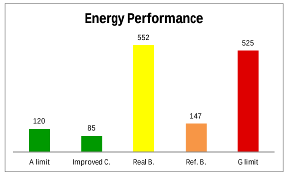
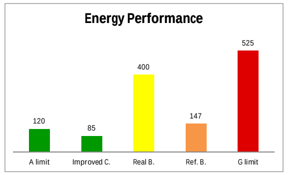
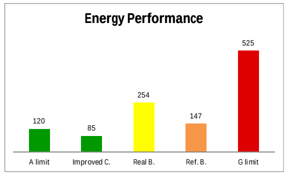
<tr><td>Performance Class

Energy Performance
Evaluation by EnAd
(only available in EnAd)</td>
<td>G

</td>
<td>E

</td>
<td>C

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<td></td></tr>
</table>

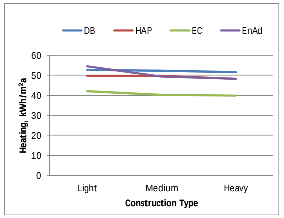
Table 6.41 Evaluation Results for the Effect of U-value for a 15-Story Building

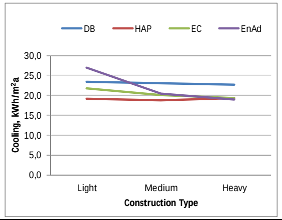
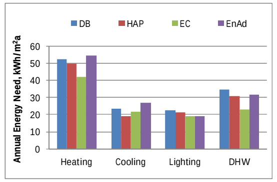
<table>
<tr><td></td><td>Case 74</td><td>Case 75</td><td>Case 76</td><td>Convergence</td></tr>
<tr><td>WWR : 10%
Windows : Wi01
# of flats : 1</td><td></td><td></td><td></td><td></td></tr>
<tr><td>Materials

Energy Need
Heating
Cooling
Lighting
DHW</td>
<td>Brick 9 cm + insulation 8.2 cm
U = 0.42 W/m²K

DB HAP EC EnAd
52 50 42 55
23.4 19.1 21.7 26.9
22.5 21.3 19.5 19.3
34.6 30.6 23.0 31.8</td>
<td>Brick 18 cm + insulation 7.5 cm
U = 0.42 W/m²K

DB HAP EC EnAd
52 50 40 49
23.1 18.8 20.1 20.4
22.5 21.3 19.5 19.3
34.6 30.6 23.0 31.8</td>
<td>Brick 50 cm + insulation 5 cm
U = 0.42 W/m²K

DB HAP EC EnAd
51 48 40 48
22.6 19.2 19.3 18.8
22.5 21.3 19.5 19.3
34.6 30.6 23.0 31.8</td>
<td rowspan="2">


</td></tr>
<tr><td>Bar graphs
Energy Need vs. Case</td>
<td>
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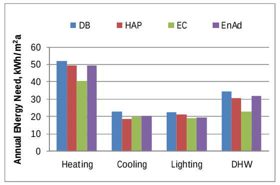
<td>
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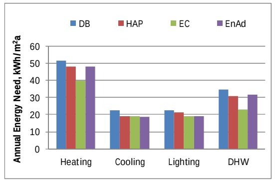
<td>
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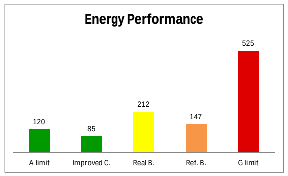
<tr><td>Performance Class

Energy Performance
Evaluation by EnAd
(only available in EnAd)</td>
<td>B

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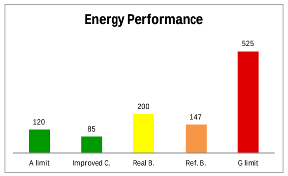
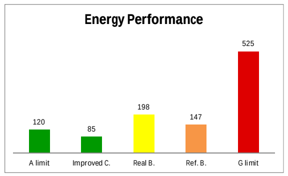

</td>
<td>B

</td>
<td></td></tr>
</table>

As can be seen in Table 6.30, when a 4 cm insulation material was added to a 25 cm AAC material, the thermal conductivity of the surfaces decreased by half, 0.49 W/m^2K, which led to a rapid decrease in heating requirements and an increase in cooling requirements. When a further 10 cm AAC layer was added to all surfaces, the U-value was reduced to 0.42 W/m^2K, which resulted in a slight decrease in heating requirements and the highest values observed for cooling requirements. When the number of floors was increased from 1 to 15, similar tendencies were observed. As the U-value was decreased and the number of floors was increased, a convergence was observed in the results of the programs. DesignBuilder continued to present a lower band for heating and a higher level for cooling requirements.

When the material was changed to brick, the highest U-value was obtained for 9 cm surfaces, at 2.86 W/m^2K. For such a light-weight construction with a very high U-value, the highest energy requirement for heating was recorded by all programs; and the highest discrepancies in the results were observed for the highest U-value both for heating and cooling loads. As the number of floors increases, the programs provide closer results. For 18 cm and 50 cm brick materials, lower U-values were obtained, at 1.89 and 0.86 W/m^2K respectively. When the lower U-values were used for all surfaces, the heating loads decreased significantly, both for 18 cm and 50 cm brick surfaces. On the other hand, when the material was changed from 9 cm to 18 cm, the cooling requirements showed a rapid decrease in all programs. For 50 cm brick surfaces, cooling requirements decreased for the one-story building, while increasing the cooling requirements for 3-, 6- and 15-story buildings. When the higher U-value was used for the surfaces, the higher heat losses were obtained; and high heat losses are multiplied with greater temperature differences between the outside and the inside temperatures, resulting in higher heating loads and lower cooling loads. Discrepancies in the results may be attributed to the energy models used by the programs for the evaluation of heat transmission.

Although all the properties are the same for all conditions, since each program uses different energy models in its evaluations, the most extraordinary differences in the results were observed for increasing U-values, which were less for heating but higher for cooling. Goldstein et al. (2010) investigated heat transfer in buildings in twenty-one titles with several sub-titles, showing the variety and complexity of the subject. The four programs used in this study use different heat transfer methods and different evaluation methods, and take into account different features of a building. EnAd, developed based on TS EN ISO 13790, for instance, considers the wall thickness, material thicknesses, construction type and thermal conductivity of the surfaces and the perimeter of the building in its evaluation of U-values and heat losses in a building. The construction type also helps in defining the thermal capacity of the building, and accordingly the time constant, determining the period of time in hours for heating and cooling (Carlos and Nepomuceno, 2012). DesignBuilder, using EnergyPlus, considers walls only in terms of thermal mass, while geometrically assuming the walls are extremely thin (EnergyPlus helpdesk, 2013).

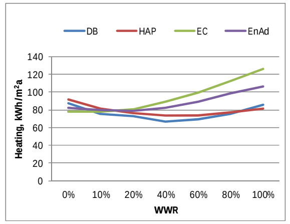
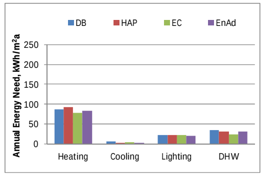
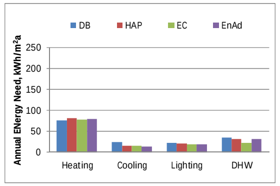
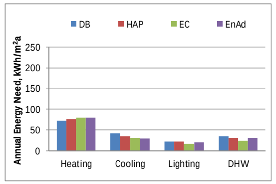
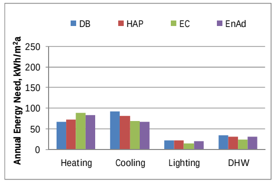
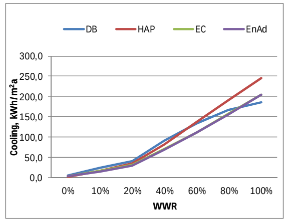
As Hui (2009) points out, the main difference between the calculation methods is the way radiative heat gains are converted into space heating and cooling loads. This is directly related with the conduction of heat through transparent and opaque surfaces like walls, floors, roofs and windows. As mentioned before, HAP employs a transfer function method, and EnerCalc and EnAd use the monthly calculation method contained in EN ISO 13790. These are based on more analytical calculations, and their results are directly affected by any change in U-values of the surfaces affecting heat transfer. DesignBuilder, on the other hand, uses two heat balance models; air heat balance and surface heat balance, considering both interior and exterior surface convection and iterative processes in its evaluations, and performing analyses until a convergence is obtained in the results (EnergyPlus Engineering Reference, 2012). It also considers the simultaneous calculation of radiation and convection processes at each time step (Crawley et. al., 2001). Further differences in the results may be related with the capabilities of the programs, most of which rely on a set of predefined system configurations for HVAC systems (Trcka and Hensen, 2010).

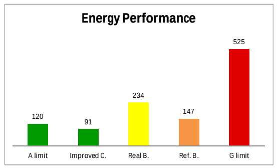
For the third group, an insulation material was added to all brick surfaces to give the same U-value of 0.42 W/m^{2}K while having three types of construction, which are light, medium and heavy. For these three types of construction, the highest discrepancy in the results was recorded for light construction, while a convergence was observed for medium and heavy construction in EnAd, HAP and DesignBuilder, which gave very close results for heating, while EnerCalc produced a lower limit due to the lack of a material library, and the consideration only of construction type and U-value. As expected, the most diverse results were obtained for the cooling of the one-story building. As stated by Ballarini and Corrado (2012), the use of thermal insulation decreases heat losses and increases cooling loads; and so the lowest heating loads and the highest cooling loads were observed for cases using insulated surfaces.

6.4.2.5 Effect of Window/Wall Ratio (WWR)

Another important parameter affecting the energy performance of a building is the window/wall ratio (WWR). Souza (2013) points out the significance of window properties in the energy performance optimization process by considering the U-value and solar transmission of the window. The heating and cooling requirement calculations of EN ISO 13790 also show a direct relation with window properties. The calculations consider the U-value of windows in terms of their heat losses, solar transmittance for solar gains, and their light transmission for daylight conditions. In order to evaluate the effect of the WWR on heating and cooling loads, the WWRs of the buildings were changed from fully opaque (0% WWR) to fully transparent (100%). For the fully opaque conditions, it was aimed to observe the effect of internal gains, while for other WWRs the effects of solar gains and heat losses through windows were aimed to be examined. In order to minimize discrepancies in the results due to material differences, insulated AAC surfaces, creating lowest discrepancy in the results, as shown in Tables 6.31–6.40, were used. For the comparison of heat losses and solar gains through windows, two types of windows were used, one being a double-glazing window with a high U-value (2.03) and solar transmission (0.78); and the other a high performance type of window with triple-glazing and with a low U-value (0.84) and low solar transmission (0.37), which are two of the available window types in EnerCalc. Since the program does not permit any changes in window types, the available types were accepted and also introduced into the other programs in order to avoid any bias in the inputs. The evaluation results are presented in Tables 6.42–57.

Table 6.42 Evaluation Results for the Effect of WWR for One-Story Building

<table>
<tr><th></th><th colspan="4">Case 77</th><th colspan="4">Case 78</th><th colspan="4">Case 79</th><th colspan="4">Case 80</th><th>Convergence</th></tr>
<tr><td>Material : AAC 35cm + insulation (U=0.42)
Windows : Wi01
# of flats : 1</td><td colspan="4"></td><td colspan="4"></td><td colspan="4"></td><td colspan="4"></td><td></td></tr>
<tr><td>WWR</td><td colspan="4">0%</td><td colspan="4">10%</td><td colspan="4">20%</td><td colspan="4">40%</td><td rowspan="6">
</td></tr>
<tr><td>Energy Need</td><td>DB</td><td>HAP</td><td>EC</td><td>EnAd</td><td>DB</td><td>HAP</td><td>EC</td><td>EnAd</td><td>DB</td><td>HAP</td><td>EC</td><td>EnAd</td><td>DB</td><td>HAP</td><td>EC</td><td>EnAd</td></tr>
<tr><td>Heating</td><td>87</td><td>91</td><td>78</td><td>83</td><td>75</td><td>81</td><td>78</td><td>79</td><td>73</td><td>76</td><td>81</td><td>79</td><td>66</td><td>73</td><td>89</td><td>82</td></tr>
<tr><td>Cooling</td><td>5.2</td><td>2.0</td><td>3.9</td><td>2.7</td><td>24.4</td><td>15.7</td><td>15.7</td><td>13.7</td><td>40.9</td><td>35.1</td><td>31.3</td><td>29.5</td><td>91.6</td><td>81.2</td><td>69.5</td><td>67.7</td></tr>
<tr><td>Lighting</td><td>22.5</td><td>21.3</td><td>21.6</td><td>19.3</td><td>22.5</td><td>21.3</td><td>19.1</td><td>19.3</td><td>22.5</td><td>21.3</td><td>16.7</td><td>19.3</td><td>22.5</td><td>21.3</td><td>15.6</td><td>19.3</td></tr>
<tr><td>DHW</td><td>34.6</td><td>30.6</td><td>23.0</td><td>31.8</td><td>34.6</td><td>30.6</td><td>23.0</td><td>31.8</td><td>34.6</td><td>30.6</td><td>23.0</td><td>31.8</td><td>34.6</td><td>30.6</td><td>23.0</td><td>31.8</td></tr>
<tr><td>Bar graphs
Energy Need vs. Case</td><td colspan="4">
</td><td colspan="4">
</td><td colspan="4">
</td><td colspan="4">
</td><td>
</td></tr>
<tr><td>Performance Class

Energy Performance Evaluation by EnAd (only available in EnAd)</td><td colspan="4">B

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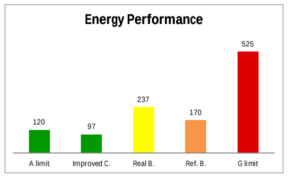
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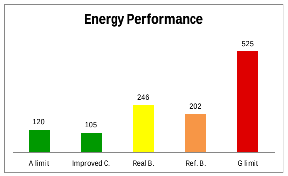
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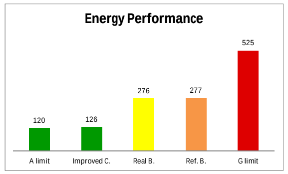
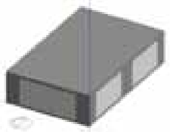
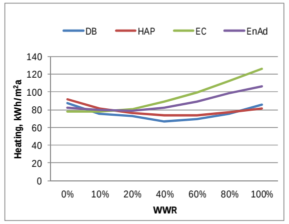

</td><td></td></tr>
</table>

Table 6.43 Evaluation Results for the Effect of WWR for One-Story Building

	Case 81	Case 82	Case 83	Convergence
Material : AAC 35cm + insulation (U=0.42) Windows : Wi01 # of flats : 1				
WWR	60%	80%	100%	

Energy Need	DB	HAP	EC	EnAd	DB	HAP	EC	EnAd	DB	HAP	EC	EnAd
Heating	69	74	100	89	76	77	112	98	86	81	126	106
Cooling	132.6	136.4	112.0	110.7	166.6	190.4	158.0	156.4	185.8	244.8	204.6	205.2
Lighting	22.5	21.3	15.5	19.3	22.5	21.3	15.5	19.3	22.5	21.3	15.5	19.3
DHW	34.6	30.6	23.0	31.8	34.6	30.6	23.0	31.8	34.6	30.6	23.0	31.8

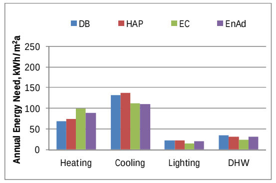
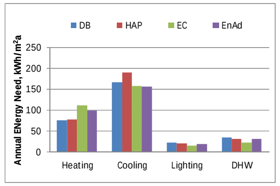
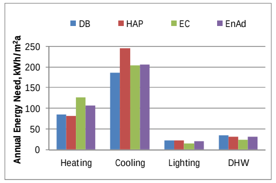
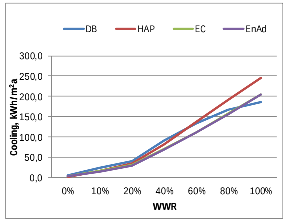
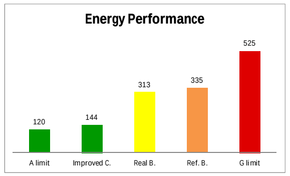
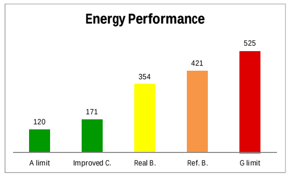
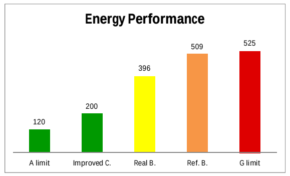
	Case 81	Case 82	Case 83	Convergence
Bar graphs Energy Need vs. Case				
Performance Class Energy Performance Evaluation by EnAd (only available in EnAd)	D 	D 	E 	

Table 6.44 Evaluation Results for the Effect of WWR for One-Story Building

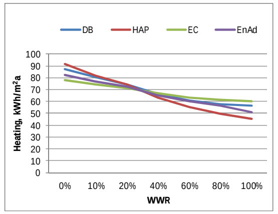
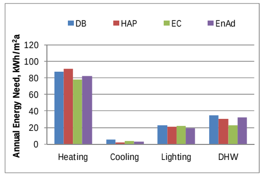
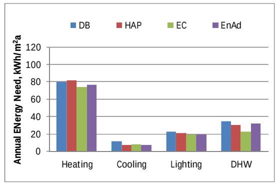
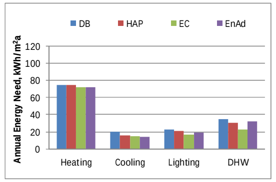
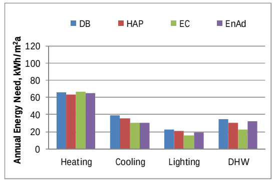
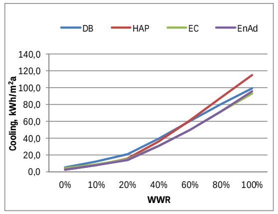
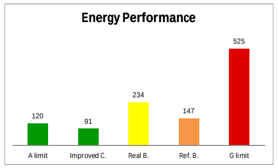
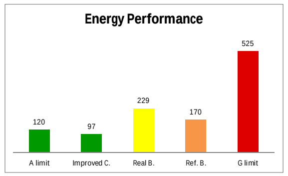
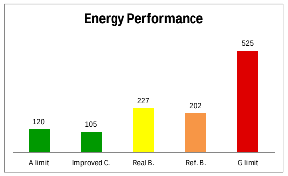
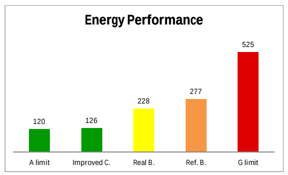
	Case 84				Case 85				Case 86				Case 87				Convergence
Material : AAC 35cm + insulation (U=0.42) Windows : Wi02 # of flats : 1																	
WWR	0%				10%				20%				40%				
Energy Need	DB	HAP	EC	EnAd	DB	HAP	EC	EnAd	DB	HAP	EC	EnAd	DB	HAP	EC	EnAd	
Heating	87	91	78	83	80	82	74	77	75	74	72	72	66	63	67	65	
Cooling	5.2	2.0	3.9	2.7	12.0	7.6	8.6	7.4	20.4	15.5	14.9	13.8	39.1	35.6	30.4	30.2	
Lighting	22.5	21.3	21.6	19.3	22.5	21.3	19.1	19.3	22.5	21.3	16.7	19.3	22.5	21.3	15.6	19.3	
DHW	34.6	30.6	23.0	31.8	34.6	30.6	23.0	31.8	34.6	30.6	23.0	31.8	34.6	30.6	23.0	31.8	
Bar graphs Energy Need vs. Case																	
Performance Class	B				B				B				B				
Energy Performance Evaluation by EnAd (only available in EnAd)																	

Table 6.45 Evaluation Results for the Effect of WWR for One-Story Building

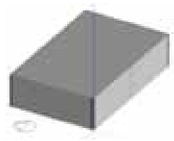
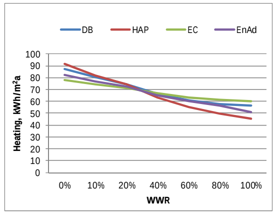
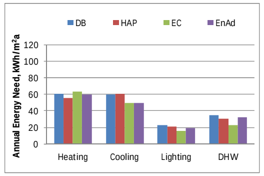
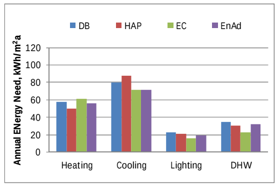
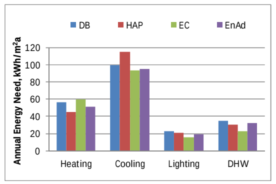
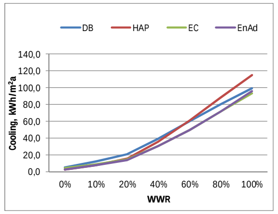
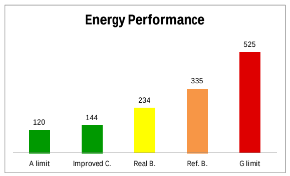
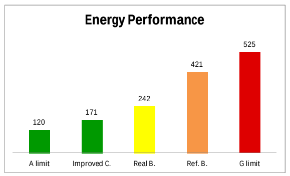
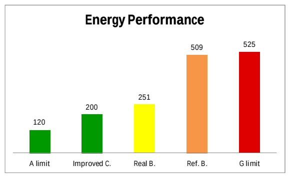
	Case 88				Case 89				Case 90				Convergence
Material : AAC 35cm + insulation (U=0.42) Windows : Wi02 # of flats : 1													
WWR	60%				80%				100%				
Energy Need	DB	HAP	EC	EnAd	DB	HAP	EC	EnAd	DB	HAP	EC	EnAd	
Heating	61	55	63	60	58	50	61	56	56	45	60	51	
Cooling	59.6	61.0	49.7	49.8	79.8	87.5	71.1	71.4	99.2	115.0	93.4	95.5	
Lighting	22.5	21.3	15.5	19.3	22.5	21.3	15.5	19.3	22.5	21.3	15.5	19.3	
DHW	34.6	30.6	23.0	31.8	34.6	30.6	23.0	31.8	34.6	30.6	23.0	31.8	
Bar graphs Energy Need vs. Case													
Performance Class	B				C				C				
Energy Performance Evaluation by EnAd (only available in EnAd)													

Table 6.46 Evaluation Results for the Effect of WWR for a 3-Story Building

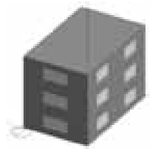
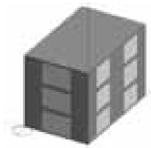
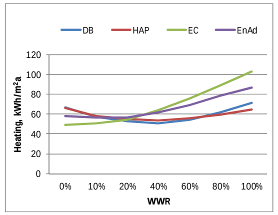
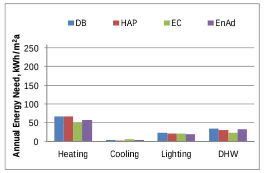
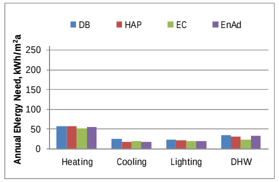
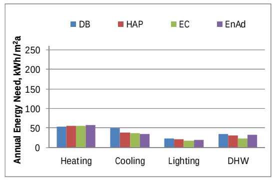
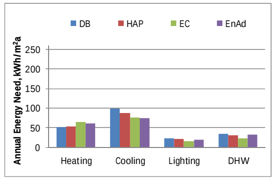
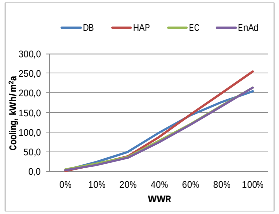
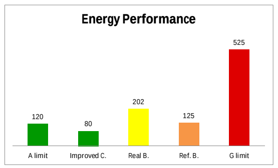
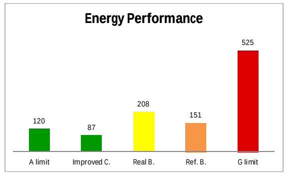
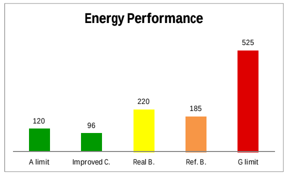
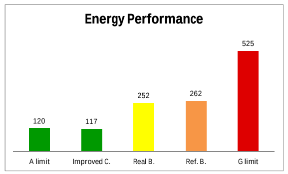
	Case 91	Case 92	Case 93	Case 94	Convergence
Material : AAC 35cm + insulation (U=0.42) Windows : Wi01 # of flats : 3					
WWR	0%	10%	20%	40%	
Energy Need Heating Cooling Lighting DHW	DB / HAP / EC / EnAd 67 / 66 / 49 / 58 4.1 / 2.3 / 5.8 / 4.1 22.5 / 21.3 / 21.6 / 19.3 34.6 / 30.6 / 23.0 / 31.8	DB / HAP / EC / EnAd 57 / 58 / 51 / 56 24.7 / 17.7 / 19.7 / 17.2 22.5 / 21.3 / 19.5 / 19.3 34.6 / 30.6 / 23.0 / 31.8	DB / HAP / EC / EnAd 53 / 55 / 55 / 57 49.6 / 38.8 / 37.0 / 34.6 22.5 / 21.3 / 16.7 / 19.3 34.6 / 30.6 / 23.0 / 31.8	DB / HAP / EC / EnAd 51 / 54 / 64 / 62 99.1 / 87.8 / 76.9 / 74.7 22.5 / 21.3 / 15.6 / 19.3 34.6 / 30.6 / 23.0 / 31.8	
Bar graphs Energy Need vs. Case					
Performance Class Energy Performance Evaluation by EnAd (only available in EnAd)	B 	B 	B 	C 	

Table 6.47 Evaluation Results for the Effect of WWR for a 3-Story Building

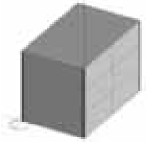
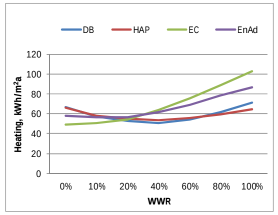
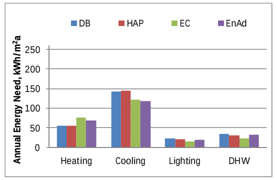
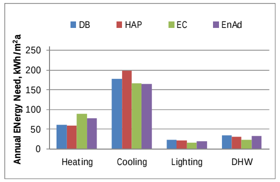
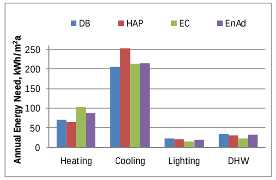
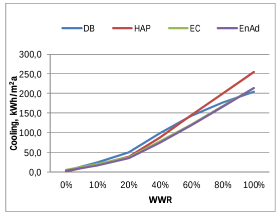
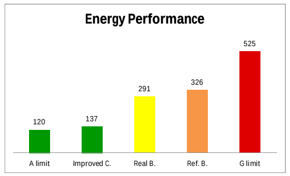
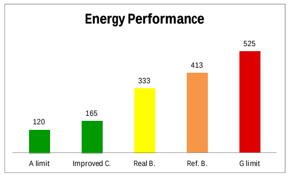
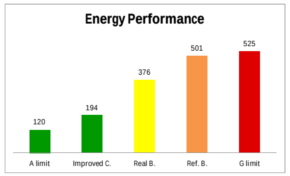
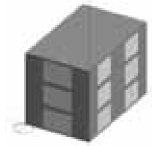
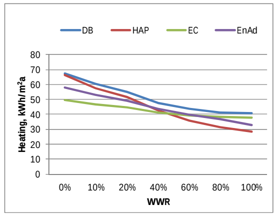
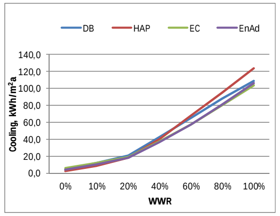
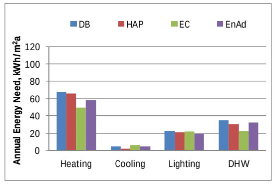
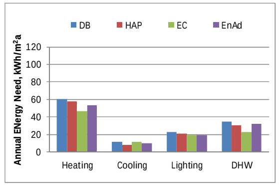
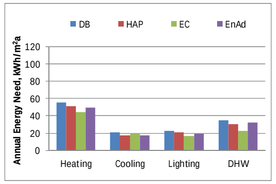
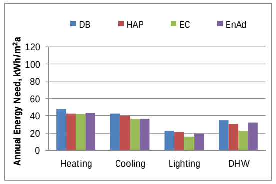
	Case 95				Case 96				Case 97				Convergence
Material : AAC 35cm + insulation (U=0.42) Windows : Wi01 # of flats : 3													
WWR	60%				80%				100%				
Energy Need	DB	HAP	EC	EnAd	DB	HAP	EC	EnAd	DB	HAP	EC	EnAd	
Heating	55	56	76	69	62	59	89	79	71	64	103	87	
Cooling	142.2	144.8	120.9	118.7	177.2	199.0	166.7	165.1	204.7	253.9	213.7	214.4	
Lighting	22.5	21.3	15.5	19.3	22.5	21.3	15.5	19.3	22.5	21.3	15.5	19.3	
DHW	34.6	30.6	23.0	31.8	34.6	30.6	23.0	31.8	34.6	30.6	23.0	31.8	
Bar graphs Energy Need vs. Case	 				 				 				
Performance Class Energy Performance Evaluation by EnAd (only available in EnAd)	C  				D  				E  				

Table 6.48 Evaluation Results for the Effect of WWR for a 3-Story Building

<table>
<tr><td></td><td>Case 98</td><td>Case 99</td><td>Case 100</td><td>Case 101</td><td>Convergence</td></tr>
<tr><td>Material : AAC 35cm + insulation (U=0.42)
Windows : Wi02
# of flats : 3</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>WWR</td><td>0%</td><td>10%</td><td>20%</td><td>40%</td><td rowspan="6">


</td></tr>
<tr><td>Energy Need</td><td>DB HAP EC EnAd</td><td>DB HAP EC EnAd</td><td>DB HAP EC EnAd</td><td>DB HAP EC EnAd</td></tr>
<tr><td>Heating</td><td>67 66 49 58</td><td>60 58 47 53</td><td>55 51 45 49</td><td>48 43 41 44</td></tr>
<tr><td>Cooling</td><td>4.1 2.3 5.8 4.1</td><td>11.5 8.6 11.9 10.0</td><td>21.1 17.7 19.0 17.6</td><td>42.4 39.8 36.8 36.3</td></tr>
<tr><td>Lighting</td><td>22.5 21.3 21.6 19.3</td><td>22.5 21.3 19.5 19.3</td><td>22.5 21.3 16.7 19.3</td><td>22.5 21.3 15.6 19.3</td></tr>
<tr><td>DHW</td><td>34.6 30.6 23.0 31.8</td><td>34.6 30.6 23.0 31.8</td><td>34.6 30.6 23.0 31.8</td><td>34.6 30.6 23.0 31.8</td></tr>
<tr><td>Bar graphs
Energy Need vs. Case</td><td>
</td><td>
</td><td>
</td><td>
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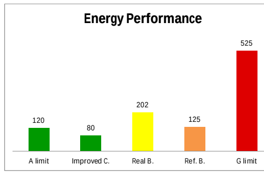
<tr><td>Performance Class

Energy Performance Evaluation by EnAd (only available in EnAd)</td><td>B

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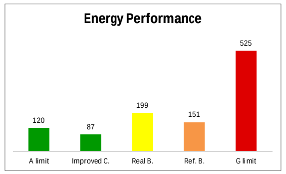
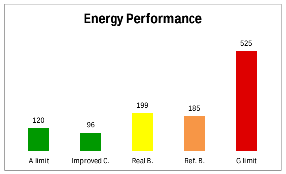
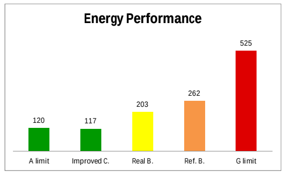

</td><td>B

</td><td>B

</td><td></td></tr>
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Table 6.49 Evaluation Results for the Effect of WWR for a 3-Story Building

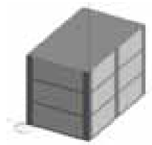
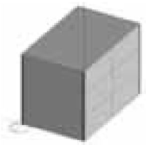
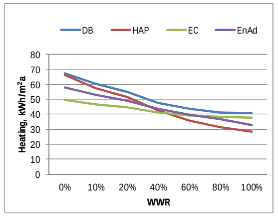
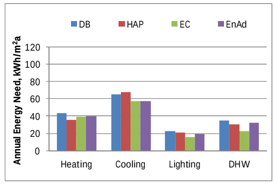
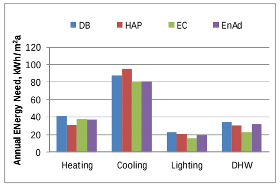
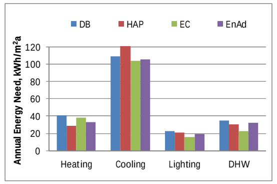
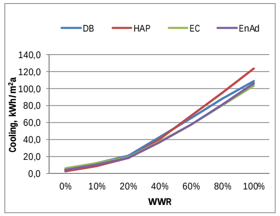
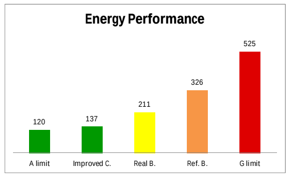
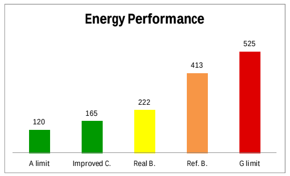
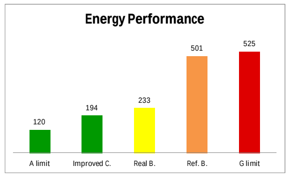
	Case 102				Case 103				Case 104				Convergence
Material : AAC 35cm + insulation (U=0.42) Windows : Wi02 # of flats : 3													
WWR	60%				80%				100%				
Energy Need	DB	HAP	EC	EnAd	DB	HAP	EC	EnAd	DB	HAP	EC	EnAd	
Heating	44	36	39	40	41	31	38	37	41	28	38	33	
Cooling	65.3	67.8	57.6	57.5	87.7	95.0	80.2	80.4	108.7	123.4	103.5	106.0	
Lighting	22.5	21.3	15.5	19.3	22.5	21.3	15.5	19.3	22.5	21.3	15.5	19.3	
DHW	34.6	30.6	23.0	31.8	34.6	30.6	23.0	31.8	34.6	30.6	23.0	31.8	
Bar graphs Energy Need vs. Case													
Performance Class Energy Performance Evaluation by EnAd (only available in EnAd)	B 				B 				B 				

Table 6.50 Evaluation Results for the Effect of WWR for a 6-Story Building

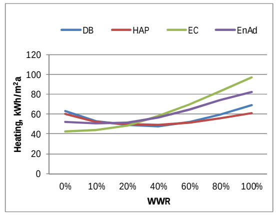
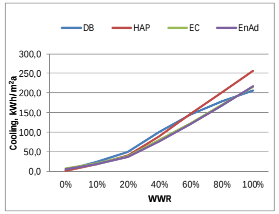
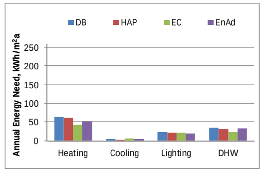
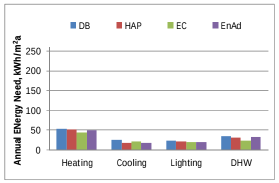
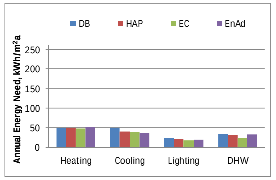
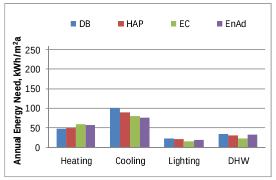
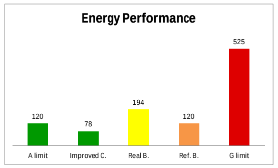
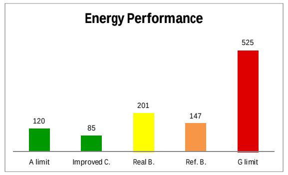
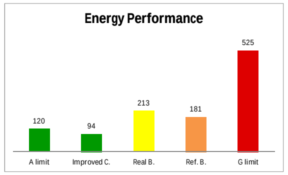
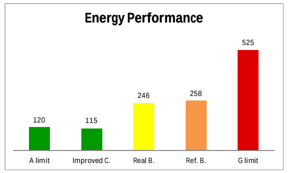
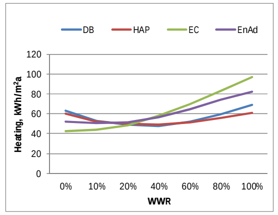
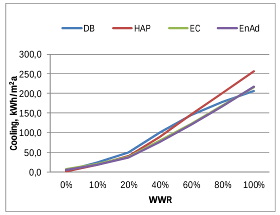
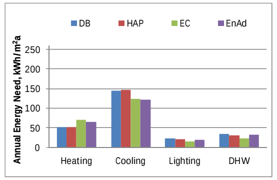
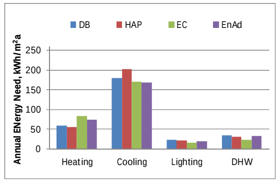
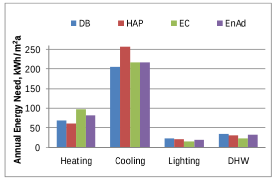
	Case 105	Case 106	Case 107	Case 108	Convergence
Material : AAC 35cm + insulation (U=0.42) Windows : Wi01 # of flats : 6					
WWR	0%	10%	20%	40%	 
Energy Need	DB / HAP / EC / EnAd	DB / HAP / EC / EnAd	DB / HAP / EC / EnAd	DB / HAP / EC / EnAd	
Heating	63 / 60 / 43 / 52	53 / 52 / 44 / 51	49 / 50 / 48 / 51	47 / 49 / 58 / 57	
Cooling	3.7 / 2.4 / 6.5 / 4.6	24.7 / 18.4 / 21.0 / 18.4	50.2 / 39.9 / 38.7 / 36.1	100.4 / 89.3 / 79.0 / 76.7	
Lighting	22.5 / 21.3 / 21.6 / 19.3	22.5 / 21.3 / 19.5 / 19.3	22.5 / 21.3 / 16.7 / 19.3	22.5 / 21.3 / 15.6 / 19.3	
DHW	34.6 / 30.6 / 23.0 / 31.8	34.6 / 30.6 / 23.0 / 31.8	34.6 / 30.6 / 23.0 / 31.8	34.6 / 30.6 / 23.0 / 31.8	
Bar graphs Energy Need vs. Case					
Performance Class Energy Performance Evaluation by EnAd (only available in EnAd)	B 	B 	B 	C 	

Table 6.51 Evaluation Results for the Effect of WWR for a 6-Story Building

<table>
<tr><th></th><th colspan="4">Case 109</th><th colspan="4">Case 110</th><th colspan="4">Case 111</th><th>Convergence</th></tr>
<tr><td>Material : AAC 35cm + insulation (U=0.42)
Windows : Wi01
# of flats : 6</td><td colspan="4"></td><td colspan="4"></td><td colspan="4"></td><td></td></tr>
<tr><td>WWR</td><td colspan="4">60%</td><td colspan="4">80%</td><td colspan="4">100%</td><td rowspan="7">


</td></tr>
<tr><td>Energy Need</td><td>DB</td><td>HAP</td><td>EC</td><td>EnAd</td><td>DB</td><td>HAP</td><td>EC</td><td>EnAd</td><td>DB</td><td>HAP</td><td>EC</td><td>EnAd</td></tr>
<tr><td>Heating</td><td>52</td><td>52</td><td>70</td><td>64</td><td>59</td><td>56</td><td>83</td><td>74</td><td>69</td><td>61</td><td>97</td><td>82</td></tr>
<tr><td>Cooling</td><td>143.9</td><td>146.4</td><td>123.2</td><td>121.0</td><td>179.0</td><td>201.4</td><td>169.1</td><td>167.5</td><td>206.4</td><td>256.8</td><td>216.2</td><td>216.9</td></tr>
<tr><td>Lighting</td><td>22.5</td><td>21.3</td><td>15.5</td><td>19.3</td><td>22.5</td><td>21.3</td><td>15.5</td><td>19.3</td><td>22.5</td><td>21.3</td><td>15.5</td><td>19.3</td></tr>
<tr><td>DHW</td><td>34.6</td><td>30.6</td><td>23.0</td><td>31.8</td><td>34.6</td><td>30.6</td><td>23.0</td><td>31.8</td><td>34.6</td><td>30.6</td><td>23.0</td><td>31.8</td></tr>
<tr><td>Bar graphs
Energy Need vs. Case</td><td colspan="4">
</td><td colspan="4">
</td><td colspan="4">
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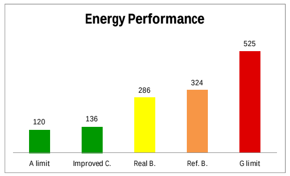
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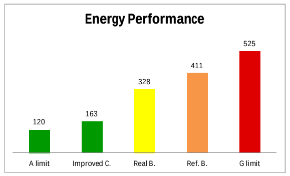
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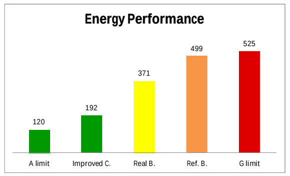
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Table 6.52 Evaluation Results for the Effect of WWR for a 6-Story Building

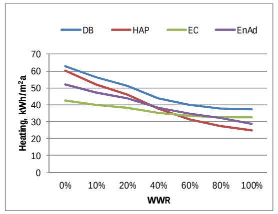
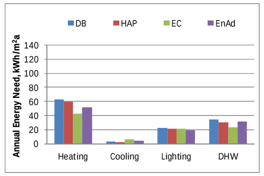
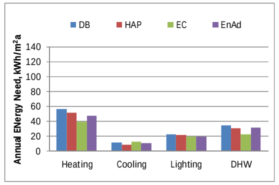
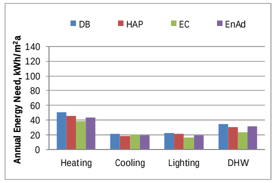
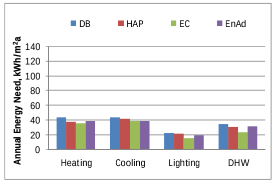
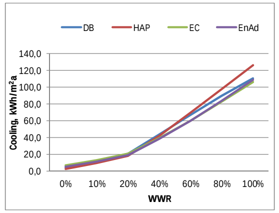
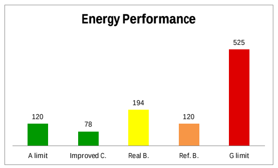
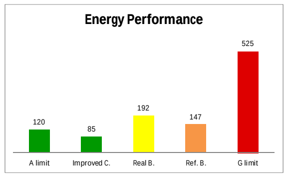
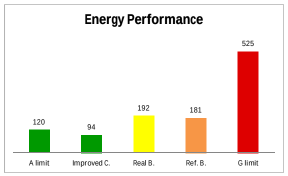
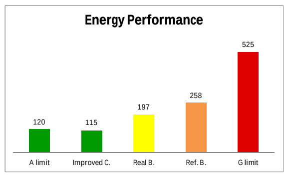
	Case 112	Case 113	Case 114	Case 115	Convergence
Material : AAC 35cm + insulation (U=0.42) Windows : Wi02 # of flats : 6					
WWR	0%	10%	20%	40%	
Energy Need	DB HAP EC EnAd	DB HAP EC EnAd	DB HAP EC EnAd	DB HAP EC EnAd	
Heating	63 60 43 52	56 52 40 47	51 46 38 44	44 38 35 38	
Cooling	3.7 2.4 6.5 4.6	11.2 9.0 13.0 10.8	21.1 18.4 20.4 18.9	43.1 41.2 38.8 38.1	
Lighting	22.5 21.3 21.6 19.3	22.5 21.3 19.5 19.3	22.5 21.3 16.7 19.3	22.5 21.3 15.6 19.3	
DHW	34.6 30.6 23.0 31.8	34.6 30.6 23.0 31.8	34.6 30.6 23.0 31.8	34.6 30.6 23.0 31.8	
Bar graphs Energy Need vs. Case					
Performance Class Energy Performance Evaluation by EnAd (only available in EnAd)	B 	B 	B 	B 	

Table 6.53 Evaluation Results for the Effect of WWR for a 6-Story Building

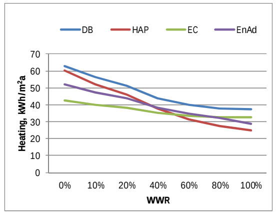
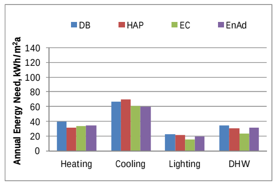
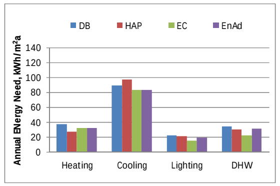
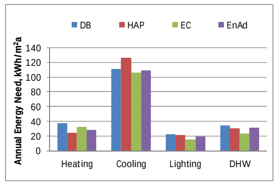
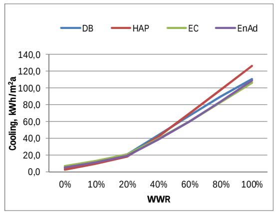
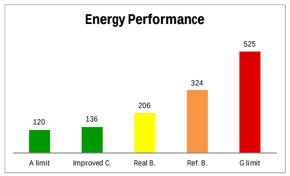
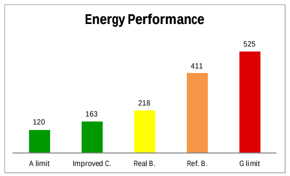
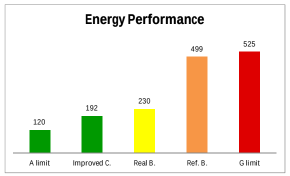
	Case 116				Case 117				Case 118				Convergence
Material : AAC 35cm + insulation (U=0.42) Windows : Wi02 # of flats : 6													
WWR	60%				80%				100%				
Energy Need	DB	HAP	EC	EnAd	DB	HAP	EC	EnAd	DB	HAP	EC	EnAd	
Heating	40	31	34	35	38	27	33	32	37	25	33	29	
Cooling	66.6	69.7	60.3	59.8	89.5	97.3	82.9	83.1	110.9	126.4	106.5	109.0	
Lighting	22.5	21.3	15.5	19.3	22.5	21.3	15.5	19.3	22.5	21.3	15.5	19.3	
DHW	34.6	30.6	23.0	31.8	34.6	30.6	23.0	31.8	34.6	30.6	23.0	31.8	
Bar graphs Energy Need vs. Case													
Performance Class Energy Performance Evaluation by EnAd (only available in EnAd)	B 				B 				B 				

Table 6.54 Evaluation Results for the Effect of WWR for a 15-Story Building

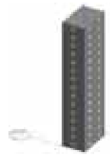
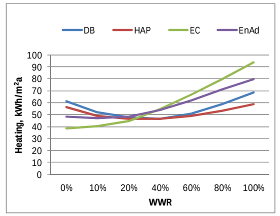
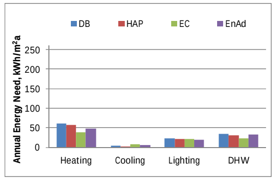
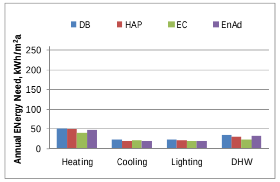
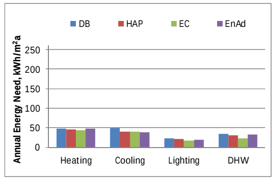
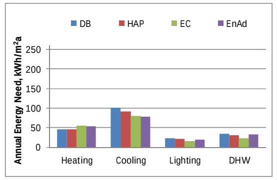
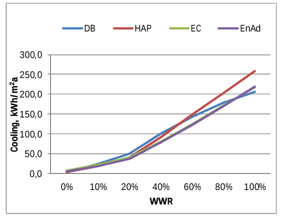
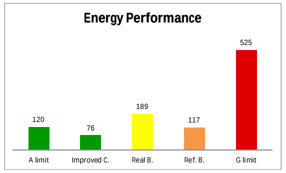
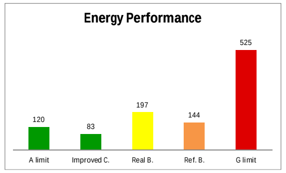
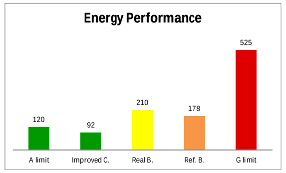
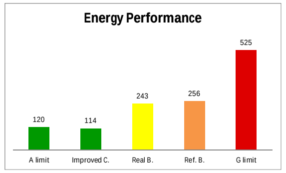
	Case 119				Case 120				Case 121				Case 122				Convergence
Material : AAC 35cm + insulation (U=0.42) Windows : Wi01 # of flats : 15																	
WWR	0%				10%				20%				40%				
Energy Need	DB	HAP	EC	EnAd	DB	HAP	EC	EnAd	DB	HAP	EC	EnAd	DB	HAP	EC	EnAd	
Heating	61	56	38	48	52	49	41	47	48	47	45	48	46	46	55	54	
Cooling	3.2	2.5	7.0	4.9	24.2	18.8	21.9	19.1	49.8	40.7	39.7	37.1	100.2	90.5	80.3	78.0	
Lighting	22.5	21.3	21.6	19.3	22.5	21.3	19.1	19.3	22.5	21.3	16.7	19.3	22.5	21.3	15.6	19.3	
DHW	34.6	30.6	23.0	31.8	34.6	30.6	23.0	31.8	34.6	30.6	23.0	31.8	34.6	30.6	23.0	31.8	
Bar graphs Energy Need vs. Case																	
Performance Class	B				B				B				C				
Energy Performance Evaluation by EnAd (only available in EnAd)																	

Table 6.55 Evaluation Results for the Effect of WWR for a 15-Story Building

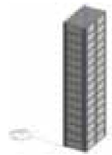
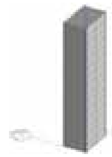
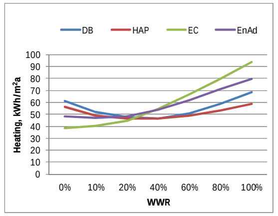
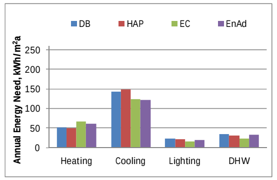
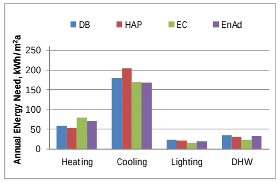
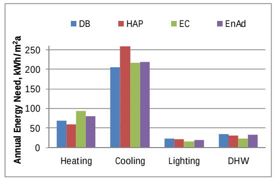
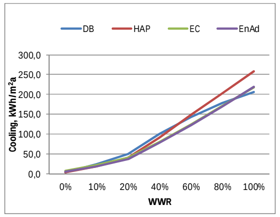
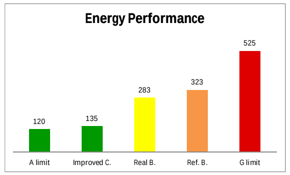
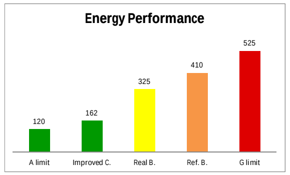
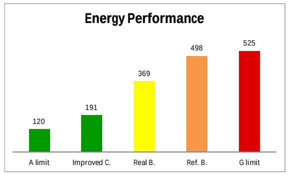
	Case 123				Case 124				Case 125				Convergence
Material : AAC 35cm + insulation (U=0.42) Windows : Wi01 # of flats : 15													
WWR	60%				80%				100%				
Energy Need	DB	HAP	EC	EnAd	DB	HAP	EC	EnAd	DB	HAP	EC	EnAd	
Heating	51	49	67	61	59	53	80	71	68	59	94	79	
Cooling	143.7	148.4	124.6	122.4	178.6	202.9	170.6	169.0	205.9	258.2	217.7	218.5	
Lighting	22.5	21.3	15.5	19.3	22.5	21.3	15.5	19.3	22.5	21.3	15.5	19.3	
DHW	34.6	30.6	23.0	31.8	34.6	30.6	23.0	31.8	34.6	30.6	23.0	31.8	
Bar graphs Energy Need vs. Case													
Performance Class Energy Performance Evaluation by EnAd (only available in EnAd)	C 				D 				E 				

Table 6.56 Evaluation Results for the Effect of WWR for a 15-Story Building

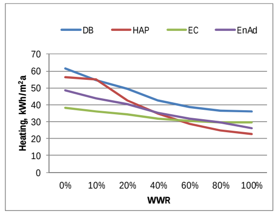
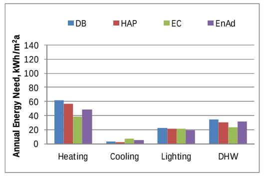
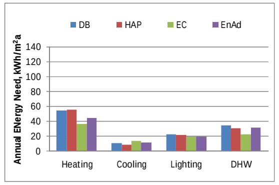
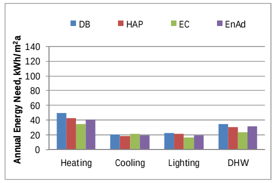
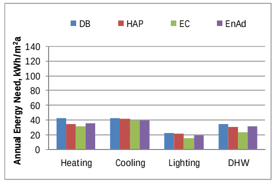
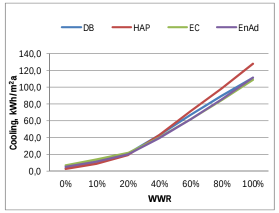
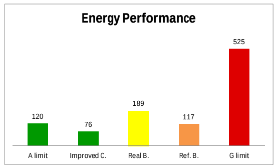
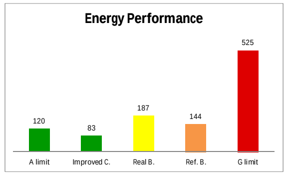
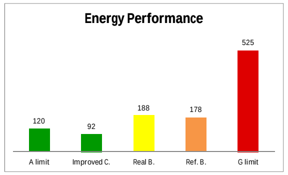
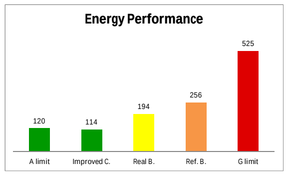
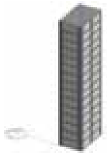
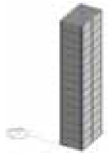
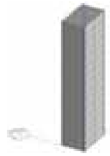
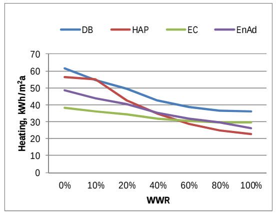
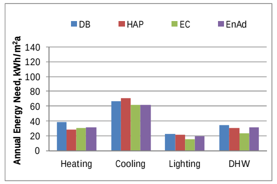
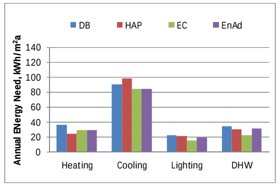
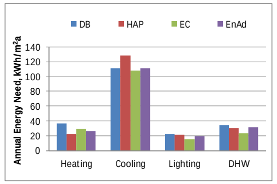
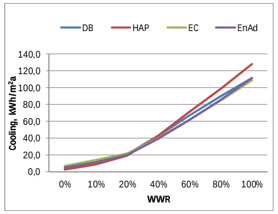
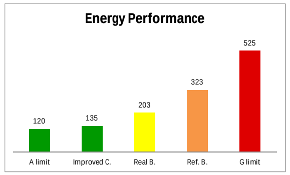
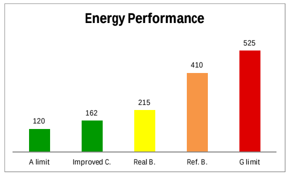
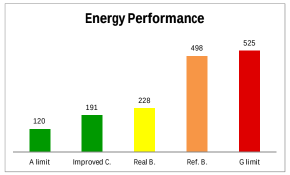
	Case 126	Case 127	Case 128	Case 129	Convergence
Material : AAC 35cm + insulation (U=0.42) Windows : Wi02 # of flats : 15					
WWR	0%	10%	20%	40%	
Energy Need	DB / HAP / EC / EnAd	DB / HAP / EC / EnAd	DB / HAP / EC / EnAd	DB / HAP / EC / EnAd	
Heating	61 / 56 / 38 / 48	55 / 55 / 36 / 44	50 / 43 / 34 / 40	43 / 35 / 32 / 35	
Cooling	3.2 / 2.5 / 7.0 / 4.9	10.7 / 8.8 / 13.7 / 11.4	20.6 / 18.8 / 21.3 / 19.7	42.9 / 42.0 / 40.0 / 39.3	
Lighting	22.5 / 21.3 / 21.6 / 19.3	22.5 / 21.3 / 19.1 / 19.3	22.5 / 21.3 / 16.7 / 19.3	22.5 / 21.3 / 15.6 / 19.3	
DHW	34.6 / 30.6 / 23.0 / 31.8	34.6 / 30.6 / 23.0 / 31.8	34.6 / 30.6 / 23.0 / 31.8	34.6 / 30.6 / 23.0 / 31.8	
Bar graphs Energy Need vs. Case					
Performance Class Energy Performance Evaluation by EnAd (only available in EnAd)	B 	B 	B 	B 	

Table 6.57 Evaluation Results for the Effect of WWR for a 15-Story Building

	Case 130	Case 131	Case 132	Convergence
Material : AAC 35cm + insulation (U=0.42) Windows : Wi02 # of flats : 15				
WWR	60%	80%	100%	
Bar graphs Energy Need vs. Case				
Performance Class Energy Performance Evaluation by EnAd (only available in EnAd)	B 	B 	B 	

Energy Need	DB	HAP	EC	EnAd	DB	HAP	EC	EnAd	DB	HAP	EC	EnAd
WWR	60%				80%				100%			
Heating	39	29	30	32	37	25	30	30	36	23	30	26
Cooling	66.7	71.0	61.8	61.2	89.8	98.6	84.7	84.8	111.4	128.3	108.5	110.9
Lighting	22.5	21.3	15.5	19.3	22.5	21.3	15.5	19.3	22.5	21.3	15.5	19.3
DHW	34.6	30.6	23.0	31.8	34.6	30.6	23.0	31.8	34.6	30.6	23.0	31.8

As shown in Tables 6.42–6.57, the highest discrepancies in the results for heating were observed for fully opaque and fully transparent conditions, while closer results were recorded for cooling. In the cases considering the double-glazed windows with high U-value and solar transmission, as WWR is increased, heating loads showed increases due to increasing heat losses through the windows, while the cooling loads incrementally increased due to the high solar gains. As in the previous cases, as the number of floors increases, a decreasing trend in heating requirements and an increasing trend in cooling requirements were recorded by all programs. On the other hand, a 20% WWR showed a breaking point both for heating and cooling requirements in all buildings using double glazing. As WWR increases, slow decreases in heating and slow increases in cooling were observed for cases with 0–20% WWRs, while rapid increases in heating and cooling loads were recorded for cases with 40–100% WWRs. As WWR is increased, so do solar gains; and accordingly, decreases in heating loads and increases in cooling loads were observed for buildings with 0–20% WWRs. On the other hand, when the WWR is higher than 20%, since U-value of the windows (2.03) is higher than that of walls (0.42), heat losses had a greater effect on heating requirements than solar gain effect; and thus, heating requirements increased for cases with 40–100% WWRs. Since solar gains are more effective than heat losses in the calculation of cooling needs, cooling needs increased to the peak points in all cases as WWR is increased. As can also be seen from the energy performance classes determined according to Turkish Legislation, better performances (B) were recorded for buildings with 10% or 20% WWRs, whereas the lowest performances (E) were observed for 100% WWRs.

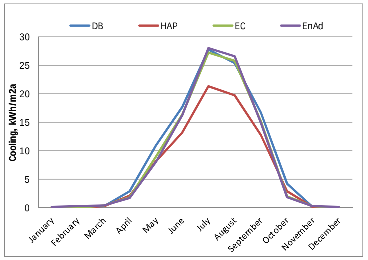
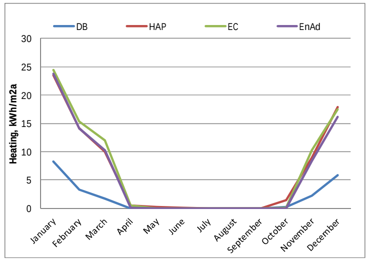
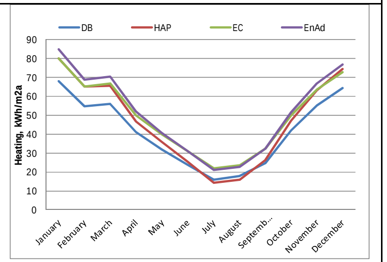
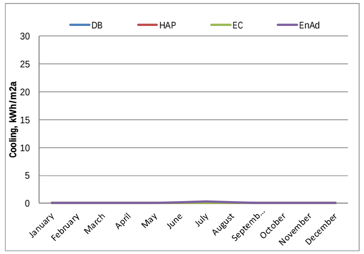
In the cases using high-performance windows, as WWR was increased, heat losses, and thus heating requirements, decreased due to the low U-value of the windows. Since the high performance window has a lower U-value (0.84) than the double-glazed one (2.03) used in the previous cases, heat losses in the buildings decrease as WWR is increased. Accordingly, the lowest heating requirements were observed for fully the transparent building. In contrast, the cooling loads showed increases due to solar gains, but these increases were not as high as in the previous cases using double-glazed windows with higher solar transmittance. As the number of floors is increased from one to fifteen-story, similar results were observed in all programs. Considering the energy performances determined by EnAd, all buildings using high performance windows have the same “B” energy performance class, though with slight differences in values. From the results it can be concluded that the WWR and the type of window used have significant influences on the energy performance of buildings; however, the differences in the results may also be related to the differences in the solar radiation data used by the different programs.

The results also reveal differences in the energy requirements for lighting in EnerCalc as WWR is changed. Since the program takes daylight into account, according to DIN standards, the need for artificial lighting decreases as window area increases, as in Cases 09–16. Since EnerCalc is developed based on DIN standards, the daylight option cannot be turned off, as with infiltration and ventilation. DesignBuilder and HAP also have a daylighting option. When desired, daylighting can be taken into account, drawing data from the ASHRAE weather file if the data is available for the given location. EnAd, on the other hand, does not have a daylighting option, since there is no available daylighting data for the individual cities in Turkey, Ankara included.

6.4.2.6 Effect of Set-Point Temperatures

So far, all of the cases have been evaluated for the same set-point temperatures, being 20°C for heating and 26°C for cooling, as suggested by TS EN ISO 13790. In order to evaluate the effect of set-point temperatures on the heating and cooling requirements of a building, different set point temperatures were used in the following analyses. For the first condition, lower temperatures were examined in all programs, for which heating was set at 10°C and cooling was set at 15°C, as the minimum allowable values in HAP. Higher temperatures were studied for the second condition, 34°C for heating and 40°C for cooling, which are the highest allowable values in HAP. The location was kept as Ankara, and the monthly evaluation results are presented in Tables 6.58–6.61.

Table 6.58 Evaluation Results for the Effect of Set-point Temperatures for One-Story Building

	Case 133	Convergence	Case 134	Convergence
Material : AAC 25cm (U=0.97) Windows : Wi01				
Set-point temperatures	Heating: 10 °C Cooling: 15 °C	  	Heating: 34 °C Cooling: 40 °C	 

Energy Need	Case 133 DB		HAP		EC		EnAd		Case 134 DB		HAP		EC		EnAd	
Heating/Cooling	H	C	H	C	H	C	H	C	H	C	H	C	H	C	H	C
January	8.2	0.0	23.5	0.0	24.5	0.0	23.8	0.1	68.0	0	80.2	0	79.9	0	84.8	0.0
February	3.4	0.0	14.2	0.0	15.4	0.0	14.1	0.2	55.0	0	65.1	0	65.3	0	69.0	0.0
March	1.7	0.2	9.9	0.3	12.0	0.4	10.2	0.4	55.9	0	65.7	0	66.9	0	70.5	0.0
April	0.0	2.9	0.5	2.1	0.5	1.7	0.1	1.7	40.9	0	46.9	0	50.1	0	52.1	0.1
May	0.0	10.8	0.2	8.1	0.0	8.9	0.0	8.0	32.1	0	35.9	0	40.0	0	40.8	0.1
June	0.0	17.6	0.0	13.1	0.0	16.3	0.0	16.1	23.8	0	25.4	0	31.1	0	31.2	0.2
July	0.0	27.7	0.0	21.2	0.0	27.1	0.0	28.0	15.7	0	14.3	0	22.1	0	21.2	0.3
August	0.0	25.4	0.0	19.7	0.0	25.8	0.0	26.5	17.7	0	15.9	0	23.3	0	22.5	0.2
September	0.0	16.6	0.0	12.7	0.0	15.1	0.0	14.8	24.6	0	26.3	0	32.2	0	32.3	0.1
October	0.2	4.2	1.5	2.8	0.0	1.9	0.0	1.8	41.8	0	47.0	0	49.8	0	51.6	0.0
November	2.2	0.0	9.0	0.2	10.2	0.3	8.4	0.3	55.2	0	63.3	0	63.5	0	66.9	0.0
December	5.9	0.0	17.9	0.0	17.4	0.0	16.1	0.1	64.5	0	74.3	0	72.8	0	77.0	0.0

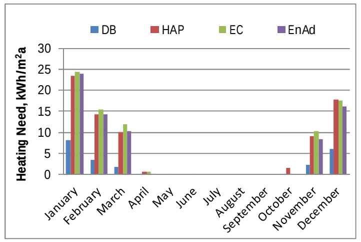
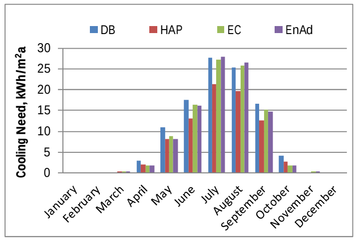
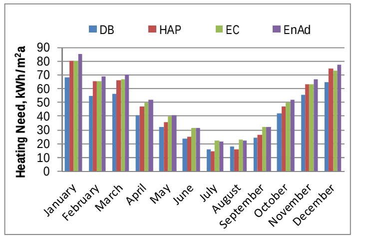
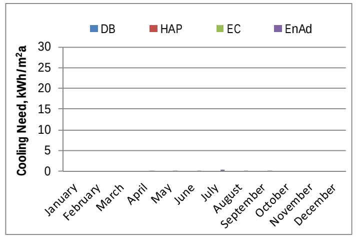
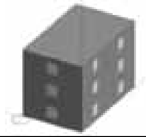
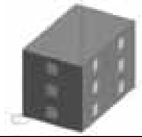
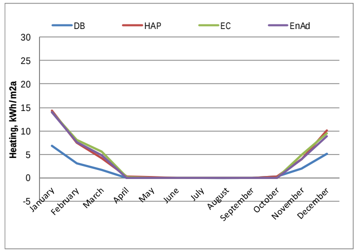
Bar graphs Energy Need vs. Case	Case 133	Convergence	Case 134	Convergence
	 	 	 	

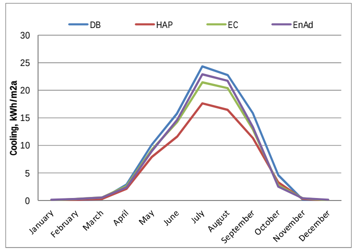
Table 6.59 Evaluation Results for the Effect of Set-point Temperatures for a 3-Story Building

	Case 135	Convergence	Case 136	Convergence
Material : AAC 25cm (U=0.97) Windows : Wi01				
Set-point temperatures	Heating: 10 °C Cooling: 15 °C		Heating: 34 °C Cooling: 40 °C	

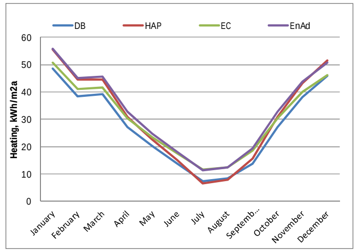
Energy Need	Case 135 DB		Case 135 HAP		Case 135 EC		Case 135 EnAd		Case 136 DB		Case 136 HAP		Case 136 EC		Case 136 EnAd	
Heating/Cooling	H	C	H	C	H	C	H	C	H	C	H	C	H	C	H	C
January	6.9	0.0	14.4	0.0	14.0	0.0	14.0	0.1	48.6	0	55.6	0	50.7	0.0	55.9	0.0
February	3.1	0.0	7.4	0.0	8.1	0.3	7.5	0.2	38.5	0	44.6	0	41.0	0.0	45.1	0.0
March	1.7	0.2	4.2	0.3	5.6	0.5	4.8	0.5	39.1	0	44.7	0	41.6	0.0	45.6	0.0
April	0.0	2.9	0.2	2.0	0.1	2.6	0.0	2.3	27.2	0	30.9	0	30.4	0.0	32.8	0.1
May	0.0	10.1	0.1	7.8	0.0	9.2	0.0	8.9	20.1	0	22.6	0	23.3	0.0	24.7	0.1
June	0.0	15.7	0.0	11.6	0.0	14.2	0.0	14.6	13.8	0	15.0	0	17.5	0.0	18.2	0.2
July	0.0	24.3	0.0	17.6	0.0	21.4	0.0	22.8	7.4	0	6.6	0	11.6	0.4	11.4	0.3
August	0.0	22.7	0.0	16.4	0.0	20.4	0.0	21.7	8.6	0	7.8	0	12.5	0.3	12.4	0.2
September	0.0	15.7	0.0	11.2	0.0	12.9	0.0	13.2	13.7	0	15.6	0	18.6	0.0	19.4	0.1
October	0.2	4.5	0.3	3.3	0.0	2.8	0.0	2.5	27.2	0	30.9	0	30.5	0.0	32.8	0.0
November	1.9	0.1	4.0	0.2	4.9	0.3	3.9	0.3	38.3	0	43.3	0	40.0	0.0	43.7	0.0
December	5.2	0.0	10.1	0.0	9.5	0.0	8.9	0.2	45.8	0	51.5	0	46.1	0.0	50.7	0.0

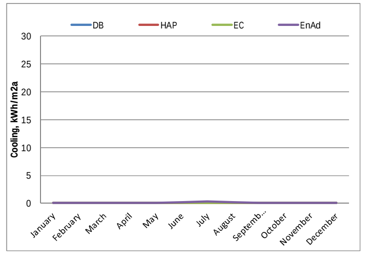
Convergence (Case 135):



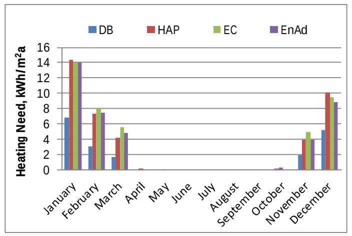


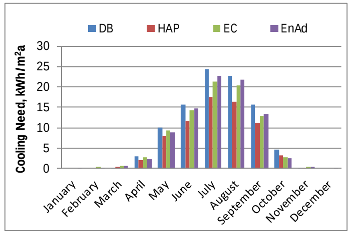
Convergence (Case 136):

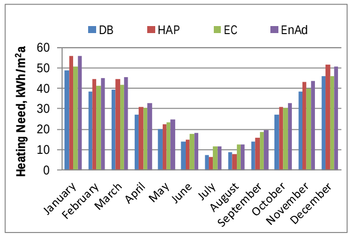




Bar graphs
Energy Need vs. Case







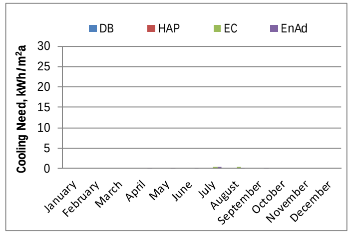
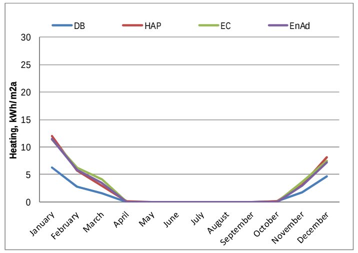
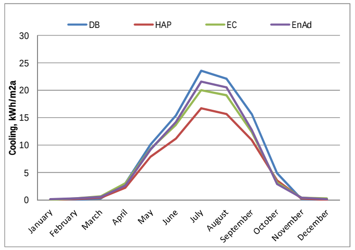
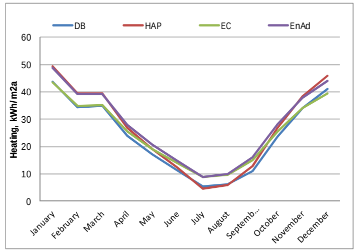
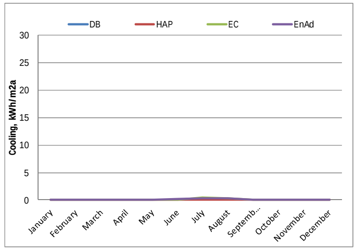


Table 6.60 Evaluation Results for the Effect of Set-point Temperatures for a 6-Story Building

	Case 137	Convergence	Case 138	Convergence
Material : AAC 25cm (U=0.97) Windows : Wi01				
Set-point temperatures	Heating: 10 °C Cooling: 15 °C	 	Heating: 34 °C Cooling: 40 °C	 

Energy Need	Case 137 DB		Case 137 HAP		Case 137 EC		Case 137 EnAd		Case 138 DB		Case 138 HAP		Case 138 EC		Case 138 EnAd	
Heating/Cooling	H	C	H	C	H	C	H	C	H	C	H	C	H	C	H	C
January	6,3	0,0	12,0	0,0	11,4	0,0	11,5	0,1	43,7	0	49,5	0	43,4	0,0	48,7	0,0
February	2,7	0,0	5,8	0,1	6,3	0,3	5,9	0,2	34,4	0	39,5	0	35,0	0,0	39,1	0,0
March	1,5	0,2	3,0	0,3	4,1	0,6	3,5	0,5	34,9	0	39,5	0	35,3	0,0	39,3	0,0
April	0,0	3,0	0,2	2,2	0,0	2,9	0,0	2,7	23,9	0	26,9	0	25,4	0,0	28,0	0,1
May	0,0	10,1	0,0	7,8	0,0	9,3	0,0	9,2	17,1	0	19,2	0	19,2	0,0	20,7	0,1
June	0,0	15,4	0,0	11,2	0,0	13,6	0,0	14,2	11,4	0	12,4	0	14,1	0,0	14,9	0,2
July	0,0	23,5	0,0	16,7	0,0	20,0	0,0	21,5	5,5	0	4,8	0	9,0	0,4	9,0	0,3
August	0,0	22,1	0,0	15,6	0,0	19,0	0,0	20,4	6,4	0	6,0	0	9,8	0,3	9,9	0,2
September	0,0	15,7	0,0	10,9	0,0	12,3	0,0	12,8	11,0	0	12,9	0	15,2	0,0	16,1	0,1
October	0,1	4,9	0,1	3,6	0,0	3,1	0,0	2,8	23,6	0	26,9	0	25,6	0,0	28,1	0,0
November	1,7	0,1	3,0	0,2	3,6	0,4	2,9	0,3	34,0	0	38,4	0	34,1	0,0	37,9	0,0
December	4,7	0,0	8,1	0,0	7,5	0,2	7,1	0,2	41,1	0	45,9	0	39,4	0,0	44,1	0,0

Bar graphs
Energy Need vs. Case

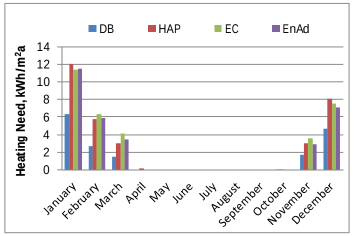
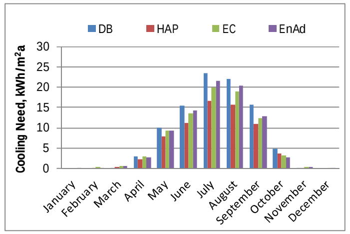
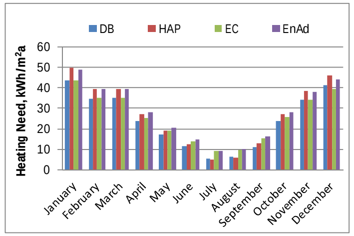
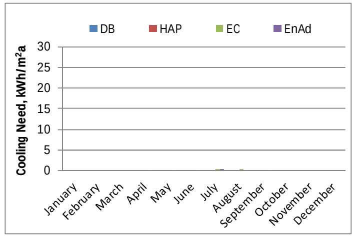
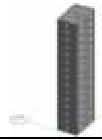
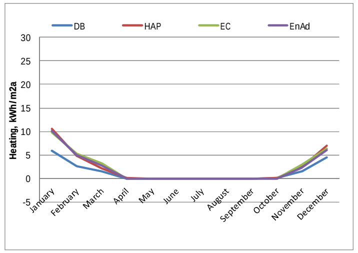
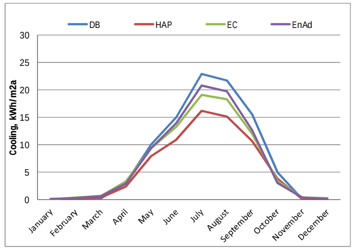
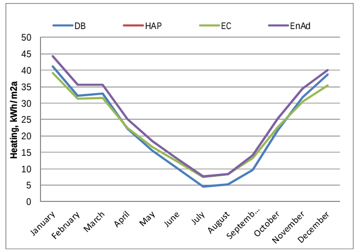
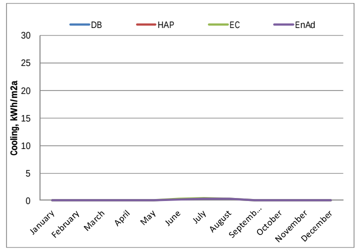
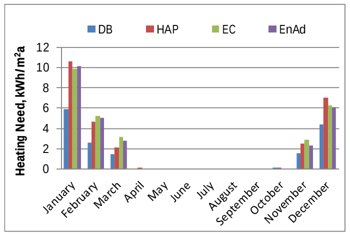
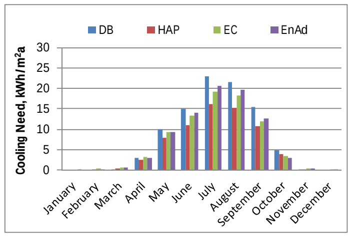
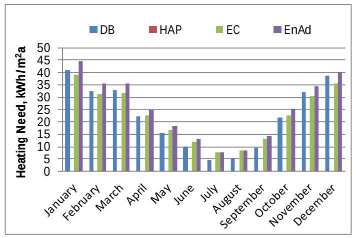
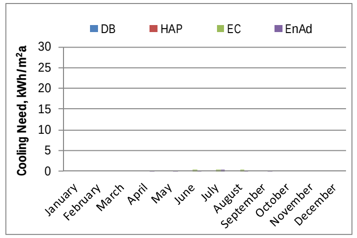





Table 6.61 Evaluation Results for the Effect of Set-point Temperatures for a 15-Story Building

	Case 139								Convergence	Case 140								Convergence
Material : AAC 25cm (U=0.97) Windows : Wi01																		
Set-point temperatures	Heating: 10 °C Cooling: 15 °C								 	Heating: 34 °C Cooling: 40 °C								 
Energy Need	DB		HAP		EC		EnAd			DB		HAP		EC		EnAd		
Heating/Cooling	H	C	H	C	H	C	H	C		H	C	H	C	H	C	H	C	
January	5.9	0.0	10.6	0.0	9.8	0.0	10.1	0.1		41,1	0	NA	NA	39,0	0,0	44,4	0,0	
February	2.6	0.0	4.7	0.1	5.2	0.3	5.0	0.2		32,3	0			31,3	0,0	35,5	0,0	
March	1.5	0.2	2.1	0.3	3.2	0.7	2.8	0.6		32,8	0			31,5	0,0	35,6	0,0	
April	0.0	3.0	0.1	2.4	0.0	3.2	0.0	2.9		22,1	0			22,5	0,0	25,1	0,1	
May	0.0	9.9	0.0	7.8	0.0	9.4	0.0	9.3		15,6	0			16,7	0,0	18,3	0,1	
June	0.0	15.0	0.0	10.9	0.0	13.3	0.0	14.0		10,2	0			12,1	0,3	13,0	0,2	
July	0.0	22.9	0.0	16.1	0.0	19.1	0.0	20.7		4,5	0			7,5	0,4	7,6	0,3	
August	0.0	21.6	0.0	15.1	0.0	18.2	0.0	19.7		5,3	0			8,3	0,4	8,5	0,2	
September	0.0	15.5	0.0	10.7	0.0	12.0	0.0	12.5		9,6	0			13,2	0,0	14,2	0,1	
October	0.1	4.9	0.1	3.8	0.0	3.4	0.0	3.0		21,7	0			22,7	0,0	25,3	0,0	
November	1.6	0.1	2.5	0.2	2.9	0.4	2.3	0.4		31,8	0			30,5	0,0	34,4	0,0	
December	4.4	0.0	7.0	0.0	6.3	0.2	6.1	0.2		38,6	0			35,4	0,0	40,1	0,0	
Bar graphs Energy Need vs. Case																		

As can be seen in Tables 6.58–6.61, when a lower set-point temperature is set, 10°C for heating and 15°C for cooling in Ankara, low heating and high cooling loads were expected. According to the results of the programs, the heating requirements were observed to be one third of the cooling requirements. EnAd, EnerCalc and HAP gave very close results, both for heating and cooling, while DesignBuilder continued to show lower limits for heating and higher limits for cooling. Similar tendencies were recorded for each month by all programs, and as the number of floors increased, discrepancies in the results decreased due to the distribution of the ground-roof effect to each unit.

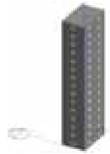
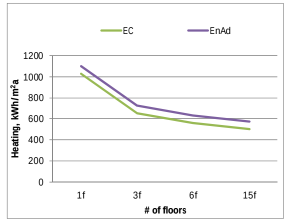
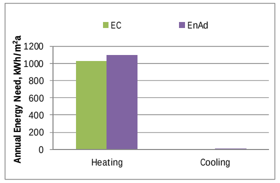
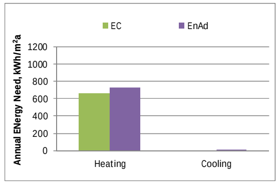
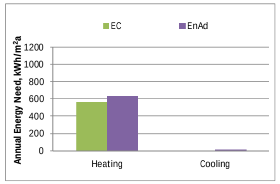
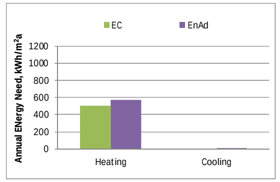
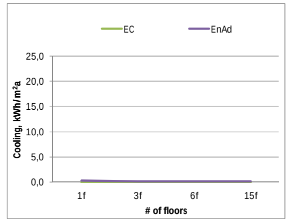
When the highest allowable set-point temperatures were set, 34°C for heating and 40°C for cooling, the heating loads were expected to be very high while no cooling load was estimated for Ankara conditions. Close results were obtained from the four programs, with the results of DesignBuilder converging with the others. In line with expectations, very high heating requirements and no cooling requirements were recorded by the programs. As in the previous cases, the highest discrepancy in the results was observed for the one-story building. One difference was experienced in HAP, in which the set-point temperatures were adjusted among the allowable values. Although HAP computed 1-, 3- and 6-story buildings for high set-point temperatures, the 15-Story building could not be evaluated due to the cooling load calculations, which were negative. Therefore, it was seen that all but one of the programs can work with diverse temperatures. Although there are some differences in the results between the programs, they followed the same tendencies for different set-point temperatures, both for heating and cooling. It can be seen that set-point temperatures are significant in the energy performance of buildings, while no discrepancy in the results was observed between the programs due to changes in set-point temperatures.

6.4.2.7 Effect of Temperature Differences between the Outside and the Inside

In order to observe the effect of temperature differences between the outside and the inside conditions in a controlled medium, temperature differences were evaluated for fixed climatic conditions. The following cases assumed a constant outside temperature, the same set-point temperatures for heating and cooling, and constant solar radiation data throughout the year. These cases were explored under three conditions: lower outside temperature, higher outside temperature, and equal outside and inside temperatures. All of these cases were evaluated only with EnAd and EnerCalc, since weather data cannot be produced for fictitious cases in DesignBuilder and HAP.

Lower outside temperatures were tested in Cases 141-144. In this group, the outside temperature was assumed to be -20°C, and the heating and cooling set-point temperatures were assumed to be 20°C, thus creating a 40°C difference between the outside and inside spaces. These conditions were tested for 1-, 3-, 6- and 15-story buildings in Cases 141, 142, 143 and 144, respectively. All buildings were assumed to have 10% WWR and use a uniform single layer material, AAC 25 cm, with a U-value of 0.97 W/m^2K. The evaluation results are presented in Table 6.62.

Table 6.62 Evaluation Results for the Effect of Lower External Temperatures

	Case 141	Case 142	Case 143	Case 144	Convergence
Material : AAC 25cm (U=0.97) Windows : Wi01					
External Temperature Heating - Cooling	-20 °C 20 °C	-20 °C 20 °C	-20 °C 20 °C	-20 °C 20 °C	
Energy Need	EC / EnAd	EC / EnAd	EC / EnAd	EC / EnAd	
Heating	1032.6 / 1099,5	655.9 / 725,6	561.7 / 632,1	505.2 / 576,0	
Cooling	0 / 0,3	0 / 0,2	0 / 0,1	0 / 0,1	
Bar graphs Energy Need vs. Case					

As shown in Table 6.62, when very low outside temperatures were used, very high heating loads were observed. On the other hand, no cooling load was expected for such a high difference between the outside and the inside spaces. The highest results for heating were recorded for the one-story building, while they decreased as the number of floors increased. Although no cooling load was expected for such a high temperature difference between the outside and the inside spaces, when the cooling requirement calculations were made according to the formulas given in EN ISO 13790, even when the outside air temperature was 40°C lower than the inside temperature, very low cooling loads were recorded by both EnAd and EnerCalc, as in Cases 33 and 34 above. This is not due to an error in the programs, but rather to the formulation of the standard, because the formula assumes internal heat gains and heat transmission to be present in all cases when considering the temperature difference between the outside and the inside spaces, regardless of the actual outside temperature. If the heat transmission effect is reduced or ignored for the cooling season, more accurate results can be obtained for cooling loads. In the calculation of cooling loads, the use of the formula should be limited to a defined temperature difference between the inside and outside, and/or the reliability of the formula should be determined. The formula should be revised, or another formula, calculation or evaluation method(s) should be developed for different climatic zones, or specific to the conditions in Turkey.

An equal outside and inside temperature condition was tested for four buildings in Cases 145-152. In these cases, both outside and inside temperatures were set at 0°C for first group, and at 20°C for the second group, while keeping the solar radiation constant for the four directions throughout the year.

Table 6.63 Evaluation Results for the Effect of Equal Temperatures for the Outside and the Inside

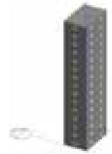
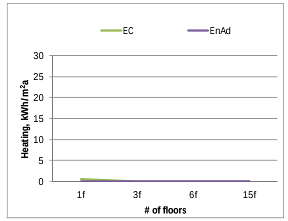
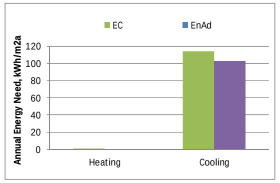
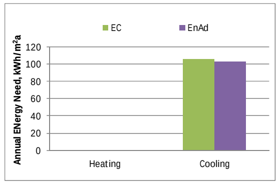
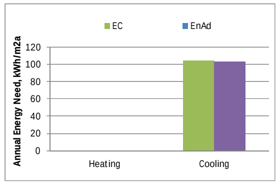
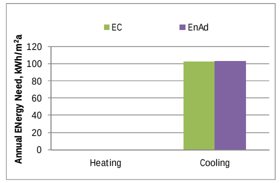
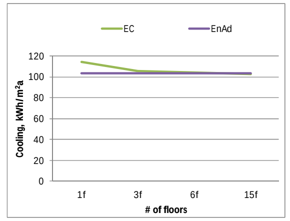
	Case 145		Case 146		Case 147		Case 148		Convergence
Material : AAC 25cm (U=0.97) Windows : Wi01									
External Temperature Heating - Cooling	0 °C 0 °C		0 °C 0 °C		0 °C 0 °C		0 °C 0 °C		
Energy Need	EC	EnAd	EC	EnAd	EC	EnAd	EC	EnAd	
Heating	0.6	0,0	0	0,0	0	0,0	0	0,0	
Cooling	113.9	103,0	105.7	103,0	103.7	103,0	102.5	103,0	
Bar graphs Energy Need vs. Case									

Table 6.64 Evaluation Results for the Effect of Equal Temperatures for the Outside and the Inside

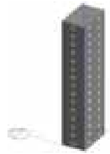
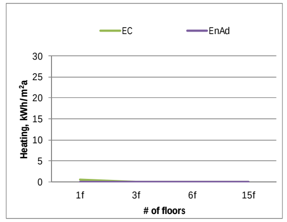
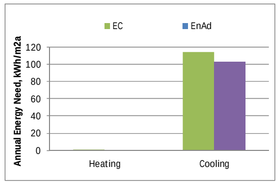
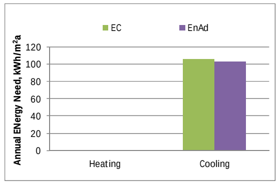
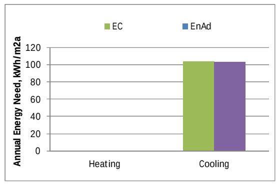
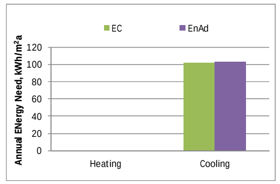
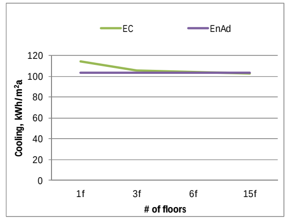
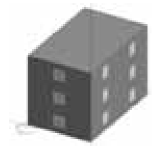
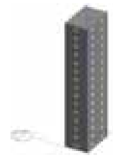
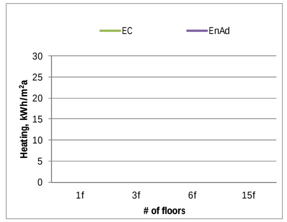
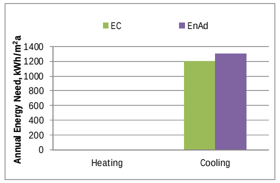
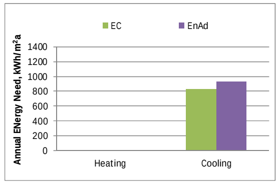
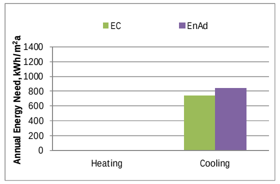
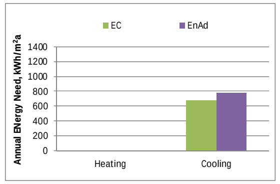
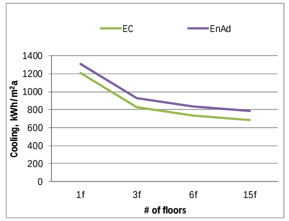
	Case 149		Case 150		Case 151		Case 152		Convergence
Material : AAC 25cm (U=0.97) Windows : Wi01									
External Temperature Heating - Cooling	20 °C 20 °C		20 °C 20 °C		20 °C 20 °C		20 °C 20 °C		
Energy Need	EC	EnAd	EC	EnAd	EC	EnAd	EC	EnAd	
Heating	0.6	0,0	0	0,0	0	0,0	0	0,0	
Cooling	113.9	103,0	105.7	103,0	103.7	103,0	102.5	103,0	
Bar graphs Energy Need vs. Case									

Table 6.63 shows that for equal temperature conditions, no heating was required, while a high cooling requirement was observed both in EnAd and EnerCalc. Since there is no temperature difference between the outside and the inside spaces, no heat transmission was considered by EnAd, which gave the same results for cooling for all buildings, considering only internal and solar gains. The results of EnerCalc, on the other hand, slightly differed as the number of floors was increased. Furthermore, when the outside and inside temperatures were changed to 20°C in Cases 149–152, no difference was observed in the results between the cases 145–148 and 149–152 using an equal temperature for the outside and inside spaces. This proves that these two programs make evaluations based on temperature differences as suggested by EN ISO 13790.

Higher outside temperatures were studied in Cases 153-156, assuming a constant 40°C external temperature, while the heating and cooling set-points were set at 0°C. The evaluation results obtained from EnAd and EnerCalc are presented in Table 6.65.

Table 6.65 Evaluation Results for the Effect of Higher External Temperatures

	Case 153		Case 154		Case 155		Case 156		Convergence
Material : AAC 25cm (U=0.97) Windows : Wi01									
External Temperature Heating - Cooling	40 °C 0 °C		40 °C 0 °C		40 °C 0 °C		40 °C 0 °C		
Energy Need	EC	EnAd	EC	EnAd	EC	EnAd	EC	EnAd	
Heating	0.0	0	0	0	0	0	0	0	
Cooling	1205.1	1305,2	830.8	931,4	737.2	838,0	681.1	781,9	
Bar graphs Energy Need vs. Case									

As can be seen in Table 6.65, since the outside temperature is fixed at 40°C, which is 40°C higher than the fixed inside temperature (0°C), no heating was required for the buildings in Cases 153–156, and the results showed a “0” (zero) kWh energy need for heating in both EnAd and EnerCalc. This situation gives indicates a consistency of the evaluation approach for heating loads in EN ISO 13790. On the other hand, very high cooling requirements were recorded for high temperature differences. The highest cooling requirements were observed for the one-story building by EnAd and EnerCalc, decreasing the number of floors was increased. Since they have very similar approaches to calculation and evaluation, the two programs produced very similar results in the cases using different temperature differences. The differences in the results can be attributed to the program defaults determined by the national values, as well as the obligatory values in EnerCalc, including those related to daylighting and thermal bridges.

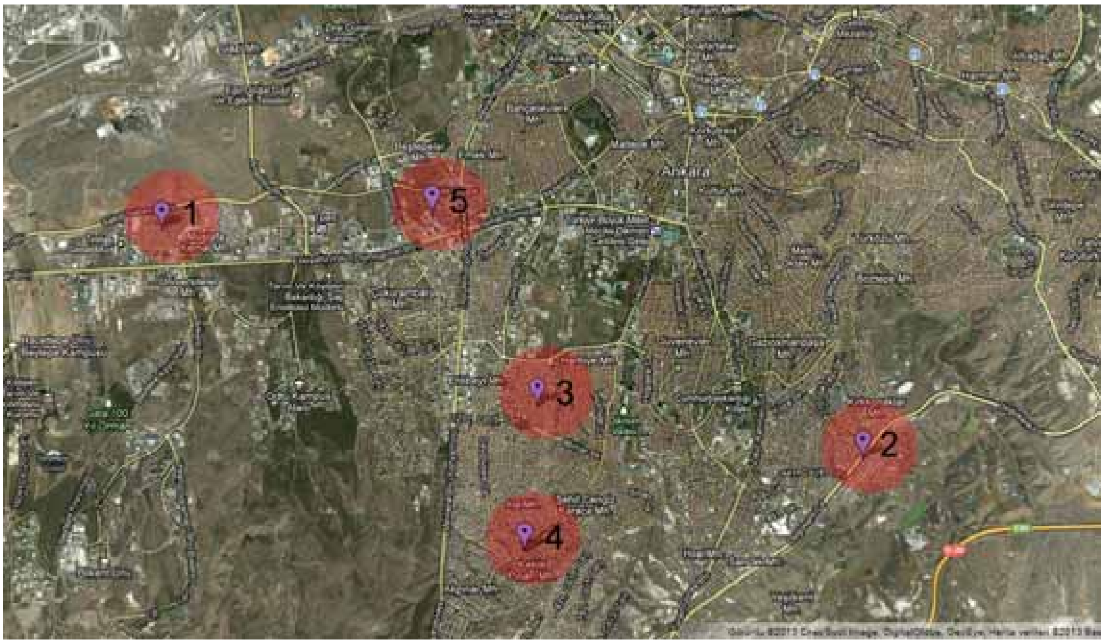
Considering the results obtained from all generic cases, 156 in total, evaluated by the four programs, the precision and reliability of EnAd in the calculation of heating, cooling, lighting and DHW requirements is proven. It can be noted that EnAd gives consistent results in itself and for many cases gives average results for energy requirements for heating, cooling, DHW and lighting. The closest results for heating were recorded by EnAd and HAP, followed by EnerCalc, while the most diverse results were, on the whole, obtained from DesignBuilder. The convergence of the results of EnAd for heating was found to be lower than HAP by 3%, and EnerCalc by 5%, and higher than DesignBuilder by 18%. In this respect, the results from EnAd are near to being an average of the results for heating among the programs. On the other hand, the programs came up with dissimilar results for cooling requirements in many cases, as can be seen in the case studies. The convergence of the results of EnAd for cooling was found to be higher than EnerCalc by 1% and HAP by 8%, and lower than DesignBuilder by 22%, and EnAd shows average results for cooling requirements. The differences in the results for space heating and cooling can be attributed to the different energy models and calculation methods employed by the four programs, and also differences both in the data input and the databases used by the programs related to climate, net area and volume assumptions and construction type, as well as the defaults of each program, such as correlation coefficients and average values. In this respect, the discrepancies in the results for heating and cooling were relatively higher than those for DHW and lighting. Since the need for DHW and lighting was introduced for each unit and/or each person, close results were observed in the programs. The convergence of the results of EnAd for lighting was found to be higher than EnerCalc by 8%, while being lower than HAP by 10% and DesignBuilder by 17%. These discrepancies in the results may be attributed to the different assumptions made by the programs in calculating the net area, as well as the defaults of the programs in the calculations. The difference in the results of EnerCalc for lighting may stem from daylight, which cannot be overruled in the program. The convergence of the results of EnAd for DHW was found to be higher than EnerCalc by 28% and HAP by 4%, while being lower than DesignBuilder by 9%. These discrepancies can be attributed to differences in the net area, since DHW use is introduced for each unit. The difference in the results of EnerCalc for DHW may be a result of the defaults of the program determined by DIN V 18599. The convergence of the results of EnAd for heating, cooling, DHW and lighting, derived from the average of all generic cases, is presented in Table 6.66.

Table 6.66 Convergence of the Results of EnAd for Heating, Cooling, DHW and Lighting

	DesignBuilder	HAP	EnerCalc
Heating	-18%	3%	5%
Cooling	-22%	8%	1%
DHW	9%	-4%	-28%
Lighting	17%	10%	-8%

6.5 Case Studies: Evaluation of Existing Buildings in Ankara

Around 160 generic cases have been analyzed, showing the validity, reliability and precision of the results of EnAd. As mentioned by Wang et al. (2012), the differences between evaluations and actual energy consumption may be up to 70%, depending on such factors as model definition, assumptions in the evaluations, actual weather and operation of the building systems. In order to compare the evaluation results with actual consumption data, five existing buildings were studied of which the energy consumption was documented and known. The five buildings were analyzed by EnAd and the other three programs to allow a comparison of the results of the programs with actual consumption figures. As in the generic cases, all buildings were located in Ankara. To represent different sizes, low-rise, mid-rise and high-rise buildings were selected, four of which were residential buildings, while the other was an office building. The buildings selected all contain central heating systems to avoid biases in the evaluations due to unconditioned spaces and use of different schedules in the buildings. All of the buildings have been constructed in compliance with the appropriate legislation at the time they were built. A strong determinant in the selection of the buildings for analysis was the willingness of the building owner to take part in the study, and the availability of regular and consistent consumption data for the buildings. Another important factor was the availability of the architectural plans of the buildings, showing the sizes and dimensions of the buildings, the system details and the thermal properties of the building materials used. Figure 6.8 shows the locations of the selected buildings, while the following sections present the evaluations of these buildings by the four programs.



1 *Barış Sitesi* in *Mustafa Kemal*
2 *Altınçay Sitesi* in *Birlik*
3 *Maliye* Blocks in *Öveçler*
4 *Maliye* Blocks in *Keklik Pınarı*
5 GAMA Building in *Söğütözü*

Figure 6.8 Existing Buildings Selected for Evaluation

6.5.1 Evaluation of a Low-rise Building

The first case study considers a single-family house, which is located in *Barış Sitesi*, in Mustafa Kemal District in the western part of Ankara. Construction of the site started in 1986 and it has been inhabited since 1994. The site is made up of five twin fourteen-story blocks and more than 500 single-family houses. There are 58 detached houses (150 m^2), 37 semi-detached houses (135 m^2) and 442 terrace houses (115 m^2). The house selected for the case study is a terrace house, representing the majority of dwellings on the site. Figure 6.9 shows the location of the site and the selected house.

Figure 6.9 Location of the Terrace House in *Barış Sitesi* in Western Ankara

Figure 6.10 Views of *Barış Sitesi*

The terraces on the site feature between three and five houses; and the house selected for the study is the center dwelling in a terrace of three houses, oriented in an east-west direction. The total floor area of the house is 115 m^2, of which 60m^2 is the ground floor, measuring 8*7.5m, while the upper floor is 55m^2, measuring 5.8*9.5m. The ground floor contains a living room, kitchen and toilet, and upstairs there are three bedrooms and a bathroom. The house features one meter wide cantilever floors on the first floor, and there are no balconies. The house is constructed using a sandwich wall system and has an unconditioned pitched roof. The ground floor is in contact with the earth, having no basement. It has low insulated walls with a U-value of 0.80 W/m^2K, and a moderately insulated ground floor (0.60), ceiling (0.35) and cantilever floors (0.40). The windows are the standard type for Turkey having a u-value of 2.20 while a very low WWR is used, which is about 8%. Architectural drawings of the building are provided in Figure 6.11.

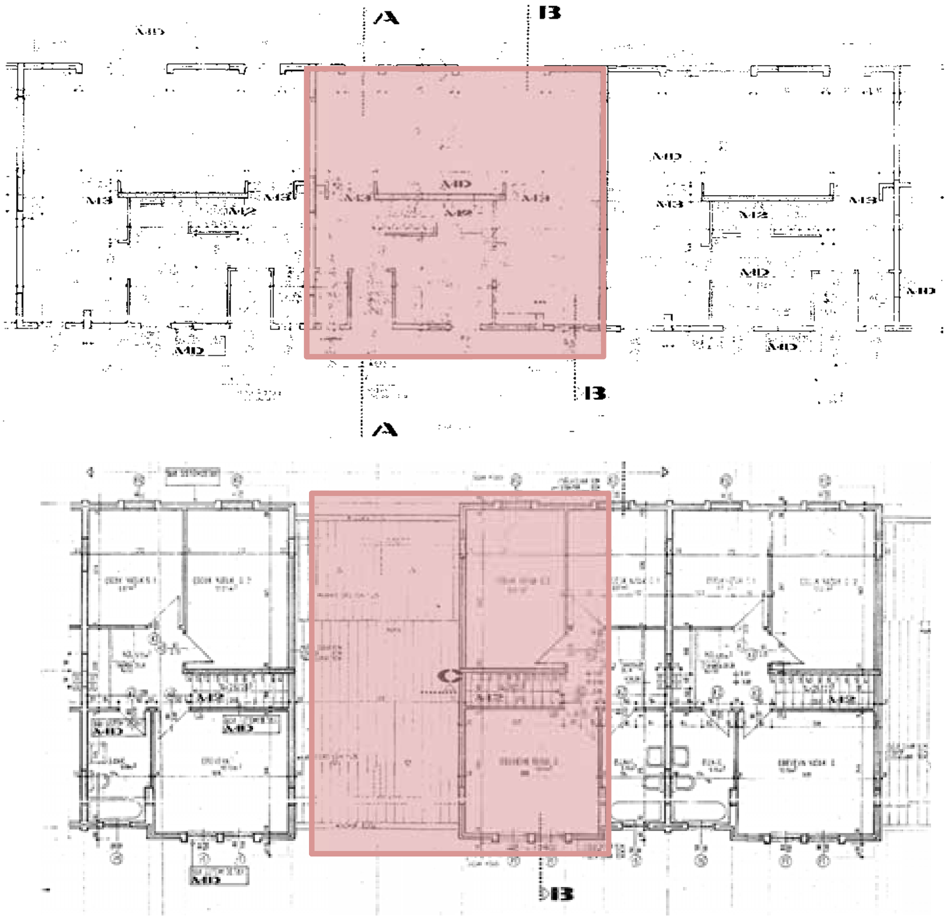


Figure 6.11 Ground Floor Plan (top) and Upper Floor Plan (below)

It was decided to follow the original architectural project for the case study, suggesting no modification to the construction. The owner of the house provided architectural drawings, as well as data on natural gas and electricity consumption for the last four years in the form of bills. The house is heated by a non-condensing combustion boiler without a programmer or thermostatic valves that also provides DHW. The property is naturally ventilated and has no air-conditioner for mechanical cooling. Based on the data provided by the owner and the architectural project, the house was evaluated by EnAd and other three programs. It should be noted that since solar radiation data is not available for intercardinal directions, when the majority of a façade faced a particular direction, it was assumed to wholly face that direction. The effect of thermal bridges was ignored in the evaluations. Detailed information on the thermal properties of the house is presented in Table 6.67, while the evaluation results are presented in Table 6.68.

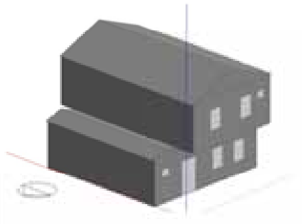
Table 6.67 Input Data for the Terrace House in *Barış Sitesi*

		DesignBuilder	HAP	EnerCalc	EnAd
Location	**Climatic data**				
	Outside temperatures	Esenboğa (ASHRAE/IWEC)	Ankara (ASHRAE 2001 Handbook)	Esenboğa (ASHRAE/IWEC)	Esenboğa (ASHRAE/IWEC)
	Solar gains	Esenboğa (ASHRAE/IWEC)	Ankara (ASHRAE 2001 Handbook)	TS 825	TS 825
	Code compliance	ASHRAE	ASHRAE	DIN V 18599	BEP documents of Turkey
Form definition	**Introduction of the geometry**				
	External dimensions	8*7.5*3m (ground floor) & 5.8*9.5*3m (first floor)	8*7.5*3m (ground floor) & 5.8*9.5*3m (first floor)	8*7.5*3m (ground floor) & 5.8*9.5*3m (first floor)	8*7.5*3m (ground floor) & 5.8*9.5*3m (first floor)
	Net area	107 m^2	107 m^2 (manual input)	107 m^2 (manual input)	110 m^2
	Net volume	220 m^3	220 m^3 (manual input)	220 m^3 (manual input)	276 m^3
	# of floors	2	2	2	2
	# of exposed surfaces	5 surfaces (except south façade)	5 surfaces (except south façade)	5 surfaces (except south façade)	5 surfaces (except south façade)
	Window/wall ratio	9%	9%	9%	9%
	Density of people	0,026 people/m^2	3 people	x	3 people
	Zoning (thermal zone)	Two zones	Two zones	Two zones	Two zones
	Construction				
	Construction type	Heavy	Heavy	Heavy	Heavy
	Material library	Insulated layered surfaces defined by the project	Insulated layered surfaces defined by the project	x	Insulated layered surfaces defined by the project
	U-values	W: 0.80; G: 0.60; R: 0.35	W: 0.80; G: 0.60; R: 0.35	W: 0.80; G: 0.60; R: 0.35	W: 0.80; G: 0.60; R: 0.35
	Windows	Wi: DG (U: 2.20; gl: 0.78)	Wi: DG (U: 2.20; gl: 0.78)	Wi: DG (U: 2,03; gl: 0,78) (D)	Wi: DG (U: 2.20; gl: 0.78)
	Frames	PVC; 2-void	PVC; 2-void	PVC	PVC; 2-void
	Shading				
	from external objects	No shading	No shading	No shading	No shading
	Window shading	No shading	No shading	No shading	x
	Thermal bridges	No thermal bridge	No thermal bridge	With thermal bridges (0.01)	x
	Solar gains	Default	Default	Default	Default
	Internal gains				7 W/m^2
	Average	x	x	x	-
	Living+Kitchen	x	x	x	-
	Other spaces	x	x	x	-
	Occupancy	Default (unknown)	Default (Sen:71.8; Lat:60.1 W/p)	55 Wh/m^2d	-
	Office equipment	1 W/m^2	1 W/m^2	14 Wh/m^2d	-
	Catering	-	x	x	x
	Lighting	Default (unknown)	Default (unknown)	Default (unknown)	-
	DHW use	-	x	-	-
	HVAC system	x	x	-	x
	Other	-	-	-	x
Service systems	**Space heating**				
	Heater type	Combustion Boiler	Combustion Boiler	Boiler	Combustion Boiler
	Fuel type	Natural gas	Natural gas	Natural gas	Natural gas
	Heating set temp.	22°C	22°C	22°C	22°C
	Setback temp.	20°C	20°C	20°C	x
	Programmer	x	-	-	-
	Efficiency	0.84	0.84	0.74 (D)	0.84
	Space cooling				
	Conditioner	Air-conditioner	Chiller	Air cooled compressor, improved	Air-cond., non-duct type
	Fuel type	Electricity	Electricity	Electricity (D)	Electricity
	Cooling set temp.	26°C	26°C	26°C	26°C
	Setback temp	28°C	28°C	28°C	x
	Efficiency class	x	x	x	B
	CoP	4.85	4.85	2.07 (D)	4.85
	DHW supply		x (Miscellaneous energy)		
	Water heater	By space heating system		Default	By space heating system
	Fuel type	Natural gas		Electricity (D)	Natural gas
	Use water temp	50°C		Default (unknown)	50°C
	Supply water t.	10°C		Default (unknown)	10°C
	Daily usage	1.56 l/m^2 d	7.28 kWh/d (manual input)	1.4 kWh/p.d (D)	60 l/p.d
	Efficiency	0.75	0.75	1 (D)	0.75
	Ventilation				
	Natural Vent.	0.5 ac/h	0.5 ac/h (manual input)	0.5 ac/h	0.5 ac/h
	Mechanical Vent.	-	-	-	-
	Infiltration	4 ac/h (n_{50})	0.27 ac/h	4 ac/h (n_{50})	4 ac/h (n_{50})
	Interior lighting				
	Luminaire type	Suspended	Free hanging	x	x
	Lamp type	x	x	Incandescent	Incandescent
	Radiant fraction	0.5	x	Default (unknown)	0.5
	Ballast multiplier	x	1 (min. allowable value)	x	x
	Lighting /Power	5 W/m^2	5 W/m^2	60 lx	5 W/m^2
	Exterior lighting	-	x	x	-
Evaluations and results	**Schedules**				
	Occupancy	Schedule 1 (24h)[1]	Schedule 1 (24h)	Default (24h)	Schedule 1 (24h)
	Electrical equipment	On[2]	On	Default (unknown)	Default
	Lighting	Schedule 2 (8h daily)[3]	Schedule 2 (8h daily)	Default (unknown)	Schedule 2 (8h daily)
	Heating	On[2]	On	Default (24 h)[4]	On
	Cooling	On[2]	On	Default (24h)	On
	Evaluations and results				
	Evaluations	Hourly evaluation	Hourly evaluation	Monthly evaluation	Monthly evaluation
	Annual energy need for				
	Heating	Wh/m^2	kWh/m^2	kWh/m^2	kWh/m^2
	Cooling	Wh/m^2	kWh/m^2	kWh/m^2	kWh/m^2
	Lighting	Wh/m^2	kWh/m^2	kWh/m^2	kWh/m^2
	DHW	Wh/m^2	kWh/m^2	kWh/m^2	kWh/m^2

D: Default W: Wall G: Groundfloor R: Roof Wi: Window DG: Double-glazing

[1] For occupancy; Schedule 1; until 08.00 1; until 18.00 0.25; until 24.00 1 (16 hours daily).
[2] For electrical equipment, heating and cooling; Schedule is always On; until 24 1.
[3] For lighting; Schedule 2; until 06.00 0.15; until 08.00 0.8; until 18.00 0.2; until 22.00 0.8; until 24.00 0.3 (total; 8 hours daily).
[4] The program assumes 17 hours standard and 7 hours reduced heating daily.
In schedules, '1' means On, and '0' means Off, while others like 0.50 mean the percentage of use.

Table 6.68 Evaluation Results for the Terrace House in *Barış Sitesi*



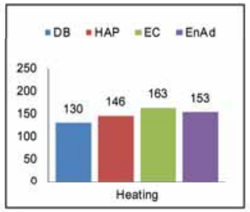
Building	: Terrace House in Barış Sitesi
# of floors	: 2
Material list	: The Architectural project
Material layers	: Multi-layer
Materials	: W: 0.80; G: 0.40; R: 0.35
Window s	: W (DG; U: 2.20; gl: 0.78)
WWR	: 8%

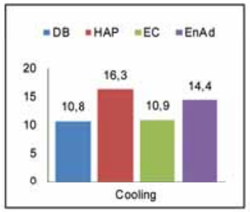
Annual energy need per unit (kWh/m²a)

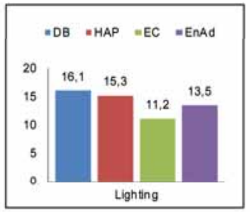
	DB	HAP	EC	EnAd
Heating	130	146	163	153
Cooling	10,8	16,3	10,9	14,4
Lighting	16,1	15,3	11,2	13,5
DHW	26,0	26,4	14,8	27,7

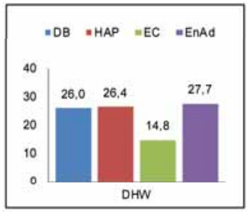
Annual energy use per unit (kWh/m²a)

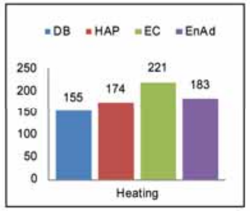
	DB	HAP	EC	EnAd
Heating	155	174	221	183
Cooling	2,2	3,4	5,3	3,0
Lighting	16,1	15,3	11,2	13,5
DHW	34,7	35,2	14,8	36,9

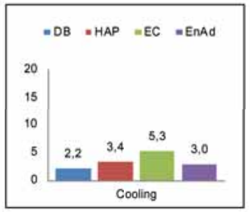


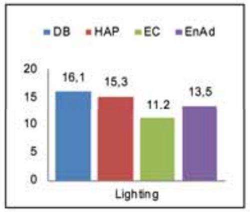


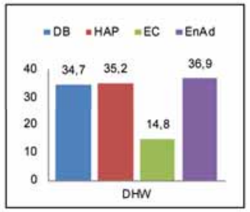












As can be seen in the results of the annual energy need and energy use of the building presented in Table 6.68, EnAd defined a 153.5 kWh/m^{2}a energy need for space heating. As in the generic cases, the closest result to EnAd was observed in HAP, with 145.8 kWh/m^{2}a, followed by EnerCalc with 163.4 kWh/m^{2}a. DesignBuilder, on the other hand, showed the lowest result for heating, recording 129.8 kWh/m^{2}a. Although the building is not cooled mechanically, the energy requirement for space cooling was evaluated for comparison among the results of the programs. EnAd calculated the cooling requirement of the building as 14.4 kWh/m^{2}a, representing an average result among the other programs, with EnerCalc calculating at 10.9 kWh/m^{2}a, and DesignBuilder at 10.8 kWh/m^{2}a. The highest result was observed in HAP, at 16.3 kWh/m^{2}a. For DHW, all programs came up with very close results. EnAd, DesignBuilder, HAP and EnerCalc calculated the annual energy requirement for DHW for three people per unit as 26; 26.4; 27.7 and 14.8 kWh/m^{2}a respectively. As expected, EnerCalc produced the lowest result for DHW due to the assumptions of DIN standards, as explained in the generic case studies. The energy requirement for interior lighting was found to be 16.1 W/m^2 in DesignBuilder, 15.3 kWh/m^{2}a in HAP, 11.2 kWh/m^{2}a in EnerCalc and 13.5 kWh/m^{2}a in EnAd. Since EnerCalc takes daylighting into consideration, the program produced the lowest results for artificial lighting. Regarding the energy use of the building, the results differentiated as a result of the conversion coefficients used by the programs.

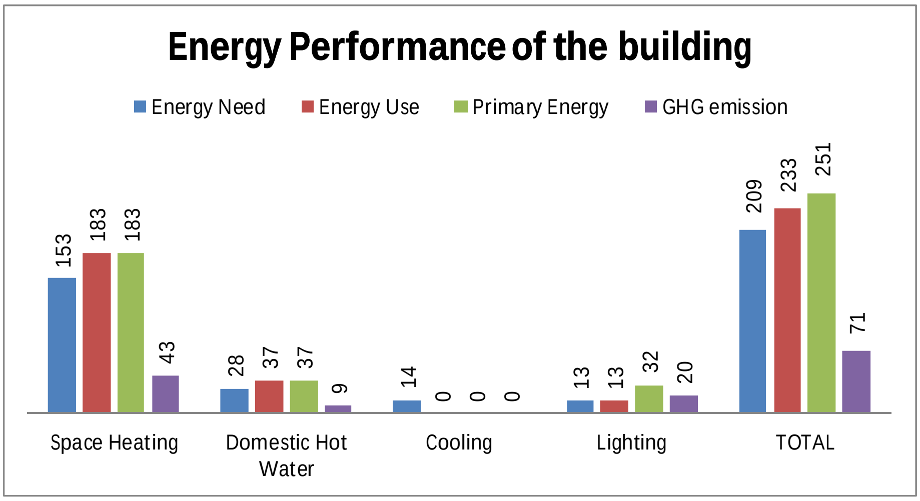


Figure 6.12 Output of EnAd for Energy Performance per Unit

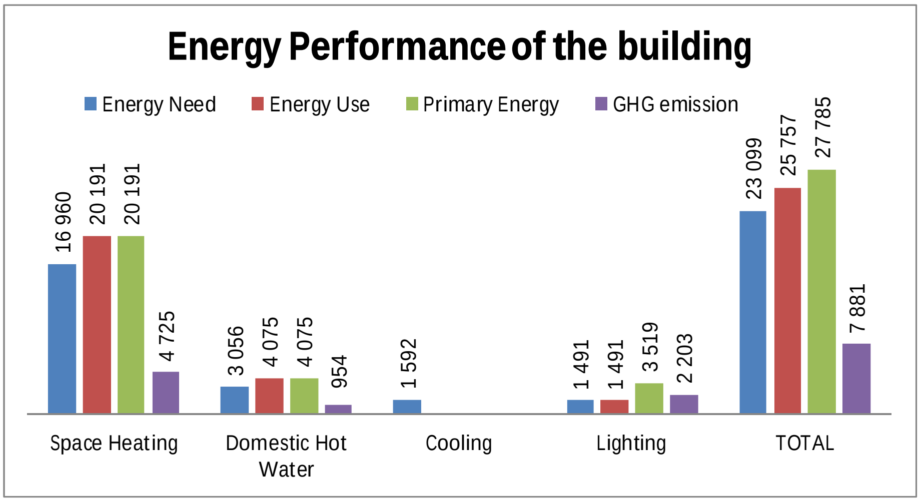


Figure 6.13 Output of EnAd for Energy Performance of the Entire Building

As shown in Figure 6.13, the annual energy consumption for space heating was found by EnAd to be 20,191 kWh, and 4,075 kWh for DHW for the entire building. Based on these results, annual natural gas consumption was calculated at 1,898 m^3 for space heating and 383 m^3 for DHW, meaning about 2,281 m^3 in total. These results are very close to the data taken from the utility bills, which showed about 2,429 m^3 of natural gas consumption annually. Regarding electricity consumption, EnAd only gives results on energy requirements for lighting, disregarding the requirements for other electrical equipment in a building. According to the results provided by EnAd, the building requires 1,491 kWh of electricity for artificial lighting, and so the remaining annual electricity consumption of 3,275 kWh may be attributed to other home appliances. Differences in results may be attributed to the orientation of the building, thermal bridges, window shading, shading from outside objects, occupant behaviors as well as the schedules of the building systems and occupancy. Although shading was an available option in all tools, since the tools were not compared in terms of the shading effect in the generic cases, no shading was considered in the evaluations.

6.5.2 Evaluation of a Mid-rise Building

The second case study considers a mid-rise building at *Altınçay Sitesi* in the *Birlik* District in south-east Ankara. The site was constructed at the beginning of the '90s and started to be inhabited in 1994. The site comprises five blocks, each with seven stories, with four flats on each floor. Among these blocks, Block B was chosen for study since its consumption data could be provided by the building manager. The location of the site and the selected building are shown in Figure 6.14 and 6.15.

Figure 6.14 Location of *Altınçay Sitesi* in *Birlik*

Figure 6.15 Views of *Altınçay Sitesi*

The detached apartment block is seven stories high and contains 28 flats above an unconditioned basement floor. The block has about 570 m^2 of floor area and a total 3980 m^2 of conditioned area. Each flat has a salon, a kitchen, three rooms, a bathroom, a WC, a storage room, and one big and two small balconies. The building is constructed from brick and has an unconditioned pitched roof, in line with the architectural project, respecting the maximum limits of the legislation. Brick walls have a U-value of 0.80 W/m^2K, the reinforced concrete floors above unconditioned basement are 0.51 W/m^2K, and the reinforced concrete ceiling below the unconditioned pitched roof is 0.31 W/m^2K. It was declared that the building is in its original form and no changes have been made, and so the data provided by the project was used in the evaluations. Figure 6.16 shows a typical floor plan and the east elevation of the building.

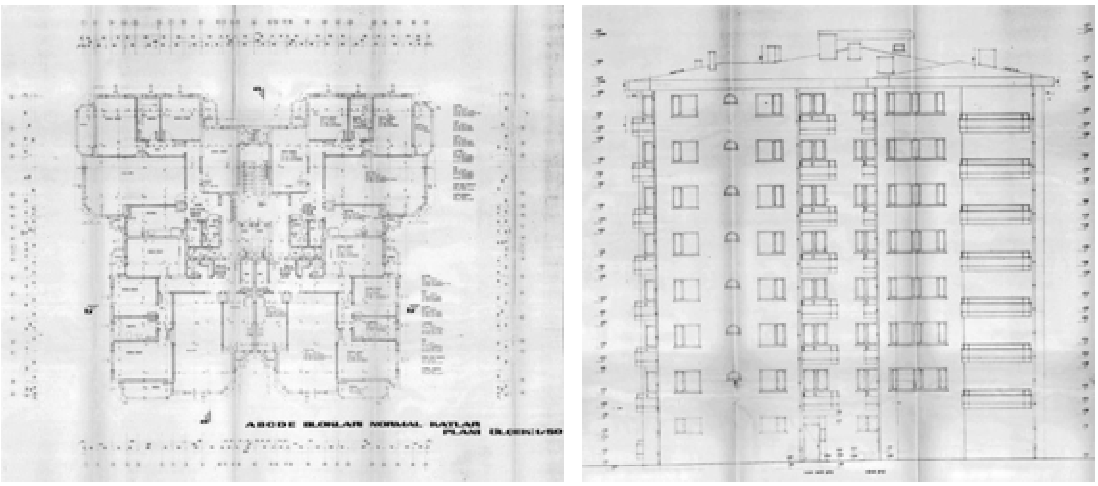


Figure 6.16 Typical Floor Plan and East Elevation of the Building

The block contains a central heating system, while DHW is supplied individually for each flat. It is ventilated naturally with the help of openable windows, and there is no mechanical ventilation or cooling. The building manager was able to supply natural gas consumption data from the last three years, however the collection of other data, including electricity used for lighting and home appliances, and other natural gas consumptions used for DHW supply, was not possible, as each flat produces different results. The building was evaluated using the four programs, however only the natural gas consumption figures of the central heating system could be compared with the evaluation results. The input data entered to the four programs is given in Table 6.69.

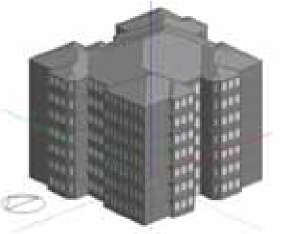
Table 6.69 Input Data for Block B in *Altınçay Sitesi*

		DesignBuilder	HAP	EnerCalc	EnAd
Location	**Climatic data**				
	Outside temperatures	Esenboğa (ASHRAE/IWEC)	Ankara (ASHRAE 2001 Handbook)	Esenboğa (ASHRAE/IWEC)	Esenboğa (ASHRAE/IWEC)
	Solar gains	Esenboğa (ASHRAE/IWEC)	Ankara (ASHRAE 2001 Handbook)	TS 825	TS 825
	Code compliance	ASHRAE	ASHRAE	DIN V 18599	BEP documents of Turkey
Form definition	**Introduction of the geometry**				
	External dimensions	28.3*24.9*2.8m	28.3*24.9*2.8m	28.3*24.9*2.8m	28.3*24.9*2.8m
	Net area	3805 m^2	3805 m^2 (manual input)	3805 m^2 (manual input)	3563 m^2
	Net volume	10654 m^3	10654 m^3 (manual input)	10654 m^3 (manual input)	11135 m^3
	# of floors	7	7	7	7
	# of exposed surfaces	All (6 surfaces)	All (6 surfaces)	All (6 surfaces)	All (6 surfaces)
	Window/wall ratio	21%	21%	21%	21%
	Density of people (for each flat)	0,029 people/m^2	4 people	x	4 people
	Zoning (thermal zone)	7 zones	7 zones	7 zones	7 zones
	Construction				
	Construction type	Heavy	Heavy	Heavy	Heavy
	Material library	Layered surfaces defined by the project	Layered surfaces defined by the project	x	Insulated layered surfaces defined by the project
	U-values	W: 0.80; G: 0.51; R: 0.31	W: 0.80; G: 0.51; R: 0.31	W: 0.80; G: 0.51; R: 0.31	W: 0.80; G: 0.51; R: 0.31
	Windows	Wi: DG (U: 2.80; gl: 0.75)	Wi: DG (U: 2.80; gl: 0.75)	Wi: DG (U: 2,86; gl: 0,78) (D)	Wi: DG (U: 2.80; gl: 0.75)
	Frames	Timber	Timber	Timber	Timber
	Shading				
	from external objects	No shading	No shading	No shading	No shading
	Window shading	No shading	No shading	No shading	x
	Thermal bridges	No thermal bridge	No thermal bridge	With thermal bridges (0.01)	x
	Solar gains	Default	Default	Default	Default
	Internal gains				7 W/m^2
	Average	x	x	x	-
	Living+Kitchen	x	x	x	-
	Other spaces	x	x	x	-
	Occupancy	Default (unknown)	Default (Sen:71.8; Lat:60.1 W/p)	55 Wh/m^2d	-
	Office equipment	1 W/m^2	1 W/m^2	14 Wh/m^2d	-
	Catering	-	x	x	x
	Lighting	Default (unknown)	Default (unknown)	Default (unknown)	-
	DHW use	-	x	-	-
	HVAC system	x	x	-	x
	Other	-	-	-	x
Service systems	**Space heating**				
	Heater type	Standard Boiler	Standard Boiler	Boiler	Standard Boiler
	Fuel type	Natural gas	Natural gas	Natural gas	Natural gas
	Heating set temp.	23°C	23°C	23°C	23°C
	Setback temp.	21°C	21°C	21°C	x
	Programmer	x	-	-	-
	Efficiency	0.79	0.79	0.74 (D)	0.79
	Space cooling				
	Conditioner	Air-conditioner	Chiller	Air cooled compressor, improved	Air-cond., non-duct type
	Fuel type	Electricity	Electricity	Electricity (D)	Electricity
	Cooling set temp.	26°C	26°C	26°C	26°C
	Setback temp	28°C	28°C	28°C	x
	Efficiency class	x	x	x	B
	CoP	4.85	4.85	2.07 (D)	4.85
	DHW supply		x (Miscellaneous energy)		
	Water heater	Stand-alone water heater		Default	Stand-alone water heater
	Fuel type	Natural gas		Electricity (D)	Natural gas
	Use water temp	50°C		Default (unknown)	50°C
	Supply water t.	10°C		Default (unknown)	10°C
	Daily usage	1.27 l/m^2 d	6.2 kWh/d (manual input)	1.4 kWh/p.d (D)	45 l/p.d
	Efficiency	0.65	0.65	1 (D)	0.65
	Ventilation				
	Natural Vent.	0.6 ac/h	0.6 ac/h (manual input)	0.6 ac/h	0.6 ac/h
	Mechanical Vent.	-	-	-	-
	Infiltration	4 ac/h (n_{50})	0.27 ac/h	4 ac/h (n_{50})	4 ac/h (n_{50})
	Interior lighting				
	Luminaire type	Suspended	Free hanging	x	x
	Lamp type	x	x	Incandescent	Incandescent
	Radiant fraction	0.5	x	Default (unknown)	0.5
	Ballast multiplier	x	1 (min. allowable value)	x	x
	Lighting /Power	7 W/m^2	7 W/m^2	75 lx	7 W/m^2
	Exterior lighting	-	x	x	-
Evaluations and results	**Schedules**				
	Occupancy	Schedule 1 (24h)[1]	Schedule 1 (24h)	Default (24h)	Schedule 1 (24h)
	Electrical equipment	On[2]	On	Default (unknown)	Default
	Lighting	Schedule 2 (8h daily)[3]	Schedule 2 (8h daily)	Default (unknown)	Schedule 2 (8h daily)
	Heating	On[2]	On	Default (24 h)[4]	On
	Cooling	On[2]	On	Default (24h)	On
	Evaluations and results				
	Evaluations	Hourly evaluation	Hourly evaluation	Monthly evaluation	Monthly evaluation
	Annual energy need for				
	Heating	Wh/m^2	kWh/m^2	kWh/m^2	kWh/m^2
	Cooling	Wh/m^2	kWh/m^2	kWh/m^2	kWh/m^2
	Lighting	Wh/m^2	kWh/m^2	kWh/m^2	kWh/m^2
	DHW	Wh/m^2	kWh/m^2	kWh/m^2	kWh/m^2

D: Default W: Wall G: Groundfloor R: Roof Wi: Window DG: Double-glazing

[1] For occupancy; Schedule 1; until 08.00 1; until 18.00 0.25; until 24.00 1 (16 hours daily).
[2] For electrical equipment, heating and cooling; Schedule is always On; until 24 1.
[3] For lighting; Schedule 2; until 06.00 0.15; until 08.00 0.8; until 18.00 0.2; until 22.00 0.8; until 24.00 0.3 (total; 8 hours daily).
[4] The program assumes 17 hours standard and 7 hours reduced heating daily.
In schedules, ‘1’ means On, and ‘0’ means Off, while others like 0.50 mean the percentage of use.

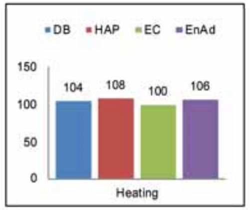
Table 6.70 Evaluation Results for Block B in *Altınçay Sitesi*

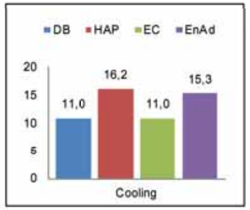


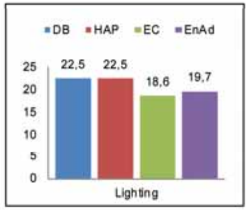
uilding : Block B in Altınçay Sitesi
of floors : 7
laterial list : The Architectural project
laterial layers : Multi-layer
laterials : W: 0.80; G: 0.51; R: 0.31
Vindows : WI (DG; U: 2.80; gl: 0.75)
WR : 21%

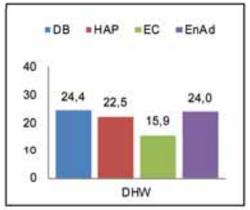
Annual energy need per unit (kWh/m²a)

	DB	HAP	EC	EnAd
Heating	104	108	100	106
Cooling	11,0	16,2	11,0	15,3
Lighting	22,5	22,5	18,6	19,7
DHW	24,4	22,5	15,9	24,0



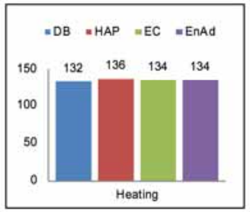


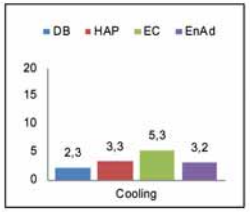


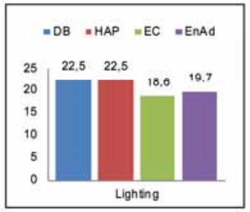


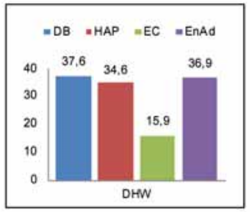
Annual energy use per unit (kWh/m²a)

	DB	HAP	EC	EnAd
Heating	132	136	134	134
Cooling	2,3	3,3	5,3	3,2
Lighting	22,5	22,5	18,6	19,7
DHW	37,6	34,6	15,9	36,9









The building form and thermal features of the building were obtained from the architectural project, disregarding the balconies and their shading and thermal bridge effects. As in the previous case, due to the lack of solar radiation data for intercardinal directions, the building is assumed to be oriented towards the cardinal directions. To allow for a fair comparison between the tools, heat gains and the schedules of the building systems were kept the same as the generic cases, which are defined for residential buildings by the BEP regulation. Considering the location of the site at a higher altitude than the city center, and thus with very little shielding, higher airflow rates were used for natural ventilation and infiltration, as determined in the BEP regulation. As these options are not available in other tools, the airflow rates determined by EnAd were entered into the other tools, as in the generic cases. The boiler used for the central heating of the building since 2001 is a standard boiler, operating at 79% efficiency and without a thermostatic control. Although mechanical cooling is not used in the building, the energy requirement for cooling was computed by all tools. As in the generic cases, artificial lighting power is set at 7 W/m^2 and four people are assumed to live in each flat. The evaluation results for the energy requirement and primary energy requirement for the four energy parameters, which are heating, cooling, DHW and lighting, are presented in Table 6.70.

As in the generic cases, as the number of floors increases, the discrepancies in the results decrease; and closer results were obtained from the tools due to the decreased effect of the ground floor and roof when distributed to each unit. The energy requirement for space heating was calculated as 106.2 kWh/m^2a by EnAd. The closest result was produced by HAP as 107.7 kWh/m^2a, which is followed by DesignBuilder with 104.4 kWh/m^2a while the lowest result was obtained from EnerCalc with 99.5 kWh/m^2a. Energy need for cooling was computed by EnAd as 15.3 kWh/m^2a, HAP as 16.2 kWh/m^2a, and EnerCalc and DesignBuilder as 11 kWh/m^2a. As can be seen in Table 6.70, close results were obtained for the DHW use of the 112 occupants in the building; and since it the energy need for lighting is introduced for each unit, close results were recorded also in this field.

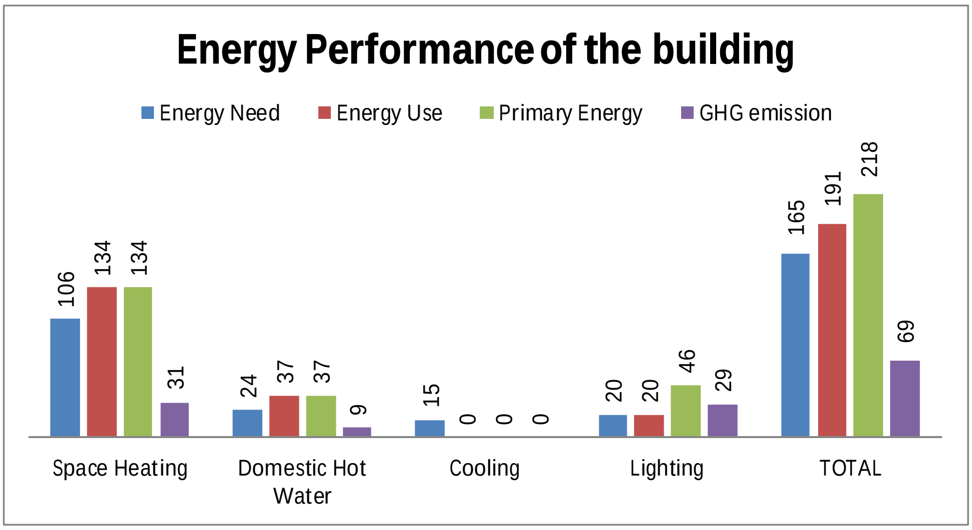


Figure 6.17 Output of EnAd for Energy Performance per Unit

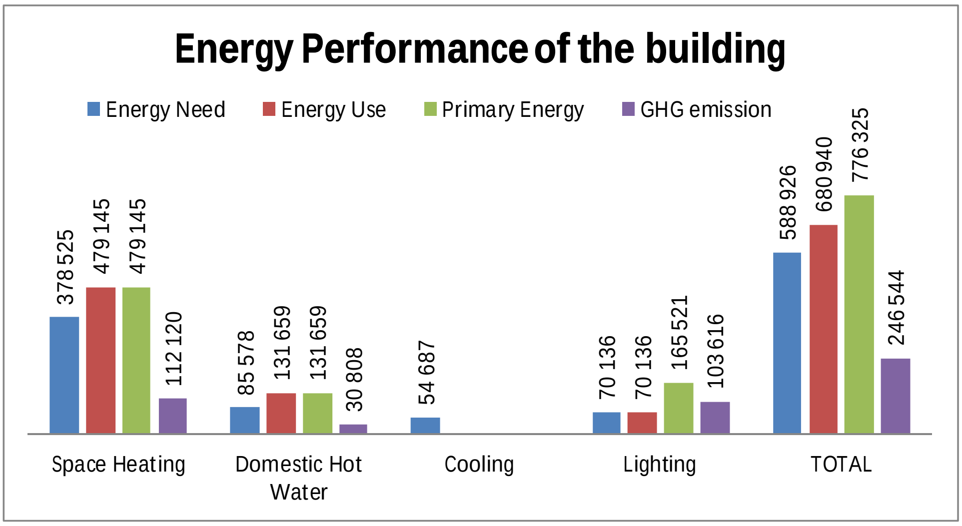


Figure 6.18 Output of EnAd for Energy Performance of the Entire Building

Figures 6.17 and 6.18 show the energy performance of the building. Considering the energy requirements, the building is expected to consume 134.5 kWh/m^{2}a for heating, 3.2 kWh/m^{2}a for cooling, 36.9 kWh/m^{2}a for DHW and 19.7 kWh/m^{2}a for lighting, as calculated by EnAd for the conditions in Turkey. As such, it can be calculated that the annual energy consumption for space heating would be 479,145 kWh for the entire building, which would require 45,032 m^3 of natural gas. Consumption figures for the last four years, provided by the building owner, were 47,795 m^3 for 2009, 45,806 m^3 for 2010, 56,565 m^3 for 2011 and 45,900 m^3 for 2012, corresponding to an average of 49,017 m^3 of natural gas consumption. This figure is very close to the result provided by EnAd. Differences in results may be related to the model definition and assumptions in the evaluations, including orientation of the building, exclusion of the balconies, internal gains from electrical equipment and the occupants (actual number is not known), building operation and actual features of the building envelope.

6.5.3 Evaluation of a Mid-rise Building

The third case study considers the housing complex of the Ministry of Economy, located in the Öveçler District in southern Ankara. The buildings have been inhabited since 1989. The housing complex consists of four detached blocks, each of which has seven stories with four flats on each floor. Among the buildings, Block II was selected for evaluation due to the availability of consumption figures since 2009 from the building manager. Figure 6.19 shows the location of the housing complex, with views from the site presented in Figure 6.20.

Figure 6.19 Location of the Maliye Blocks in Öveçler

Figure 6.20 Views of the *Maliye* Blocks in *Öveçler*

Block II is oriented in an east-west direction. It has an unconditioned basement floor, above which there are seven conditioned stories with four flats on each floor. It is topped by an unconditioned pitched roof. The building has a vertical circulation area in the middle, while each flat contains a kitchen, living room, three bedrooms, bathroom, toilet, a storage room and a balcony. Each floor has about 445 m^2 of floor area, disregarding the balconies, resulting in about 3,125 m^2 of conditioned area in the building. The building was declared to be constructed according to the architectural project and no modifications have been made. The project shows that the building was designed in line with the maximum limits of the legislation at the time of construction. The building has moderately insulated walls with a U-value of 0.70 W/m^2K, insulated floors above an unconditioned basement of 0.50 W/m^2K, and an insulated ceiling of 0.30 W/m^2K. A typical floor plan and a section of the building are provided in Figure 6.21.

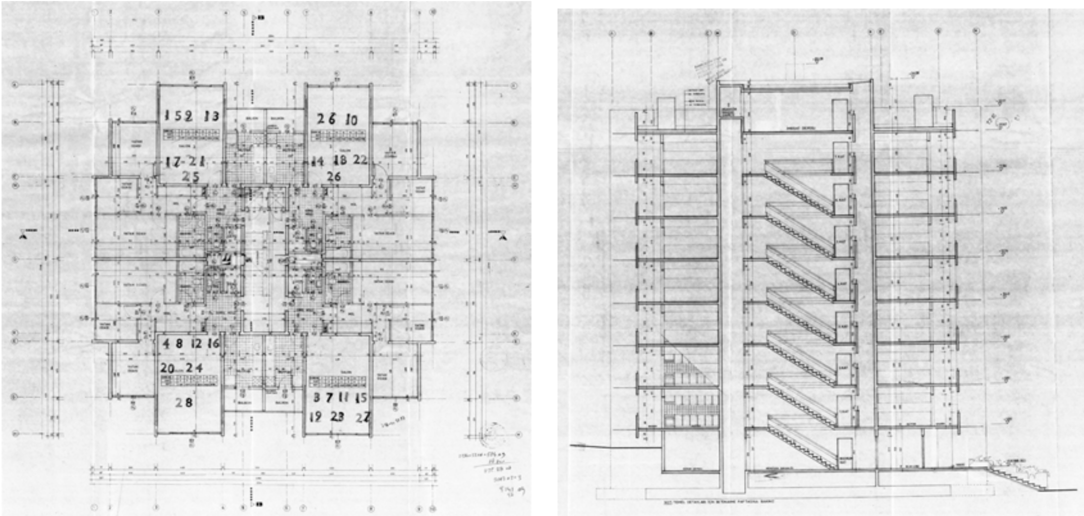


Figure 6.21 Typical floor Plan and Section of Block II

The parameters used in the evaluations are presented in Table 6.71. The building was introduced with its external dimensions to each tool separately, while the physical and thermal features were taken from the architectural project of the building. Each flat was assumed to have four occupants, and internal gains and DHW use were introduced to the four tools accordingly. Regarding the building systems, the building is ventilated naturally, and has no mechanical system for ventilation or cooling. It is heated by a central system, which also provides the DHW requirements of the building. The boiler has been used since 1998 when a natural gas connection was provided to the district, and its efficiency was assumed to be 74% in the evaluations. DHW use was determined according to the number of occupants, while power for lighting was introduced for each unit. The evaluation results are given in Table 6.72.

Table 6.71 Input Data for Block II in the *Maliye* Blocks

		DesignBuilder	HAP	EnerCalc	EnAd
Location	**Climatic data**				
	Outside temperatures	Esenboğa (ASHRAE/IWEC)	Ankara (ASHRAE 2001 Handbook)	Esenboğa (ASHRAE/IWEC)	Esenboğa (ASHRAE/IWEC)
	Solar gains	Esenboğa (ASHRAE/IWEC)	Ankara (ASHRAE 2001 Handbook)	TS 825	TS 825
	Code compliance	ASHRAE	ASHRAE	DIN V 18599	BEP documents of Turkey
Form definition	**Introduction of the geometry**				
	External dimensions	22.2*23.9*2.8m	22.2*23.9*2.8m	22.2*23.9*2.8m	22.2*23.9*2.8m
	Net area	2975 m^2	2975 m^2 (manual input)	2975 m^2 (manual input)	2800 m^2
	Net volume	8342 m^3	8342 m^3 (manual input)	8342 m^3 (manual input)	7000 m^3
	# of floors	7	7	7	7
	# of exposed surfaces	All (6 surfaces)	All (6 surfaces)	All (6 surfaces)	All (6 surfaces)
	Window/wall ratio	19%	19%	19%	19%
	Density of people (for each flat)	0,037 people/m^2	4 people	**x**	4 people
	Zoning (thermal zone)	7 zones	7 zones	7 zones	7 zones
	Construction				
	Construction type	Heavy	Heavy	Heavy	Heavy
	Material library	Layered surfaces defined by the project	Layered surfaces defined by the project	**x**	Layered surfaces defined by the project
	U-values	W: 0.70; G: 0.50; R: 0.30	W: 0.70; G: 0.50; R: 0.30	W: 0.70; G: 0.50; R: 0.30	W: 0.70; G: 0.50; R: 0.30
	Windows	Wi: DG (U: 2.80; gl: 0.75)	Wi: DG (U: 2.80; gl: 0.75)	Wi: DG (U: 2,86; gl: 0,78) (D)	Wi: DG (U: 2.80; gl: 0.75)
	Frames	Timber	Timber	Timber	Timber
	Shading				
	from external objects	No shading	No shading	No shading	No shading
	Window shading	No shading	No shading	No shading	**x**
	Thermal bridges	No thermal bridge	No thermal bridge	With thermal bridges (0.01)	**x**
	Solar gains	Default	Default	Default	Default
	Internal gains				7 W/m^2
	Average	**x**	**x**	**x**	-
	Living+Kitchen	**x**	**x**	**x**	-
	Other spaces	**x**	**x**	**x**	-
	Occupancy	Default (unknown)	Default (Sen:71.8; Lat:60.1 W/p)	55 Wh/m^2d	-
	Office equipment	1 W/m^2	1 W/m^2	14 Wh/m^2d	-
	Catering	-	**x**	**x**	**x**
	Lighting	Default (unknown)	Default (unknown)	Default (unknown)	-
	DHW use	-	**x**	-	-
	HVAC system	**x**	**x**	-	**x**
	Other	-	-	-	**x**
Service systems	**Space heating**				
	Heater type	Standard Boiler	Standard Boiler	Boiler	Standard Boiler
	Fuel type	Natural gas	Natural gas	Natural gas	Natural gas
	Heating set temp.	23°C	23°C	23°C	23°C
	Setback temp.	21°C	21°C	21°C	**x**
	Programmer	**x**	-	-	-
	Efficiency	0.74	0.74	0.74 (D)	0.74
	Space cooling				
	Conditioner	Air-conditioner	Chiller	Air cooled compressor, improved	Air-cond., non-duct type
	Fuel type	Electricity	Electricity	Electricity (D)	Electricity
	Cooling set temp.	26°C	26°C	26°C	26°C
	Setback temp	28°C	28°C	28°C	**x**
	Efficiency class	**x**	**x**	**x**	B
	CoP	4.85	4.85	2.07 (D)	4.85
	DHW supply		**x** (Miscellaneous energy)		
	Water heater	By space heating system		Default	By space heating system
	Fuel type	Natural gas		Electricity (D)	Natural gas
	Use water temp	50°C		Default (unknown)	50°C
	Supply water t.	10°C		Default (unknown)	10°C
	Daily usage	1.58 l/m^2 d	7.9 kWh/d (manual input)	1.4 kWh/p.d (D)	45 l/p.d
	Efficiency	0.65	0.65	1 (D)	0.65
	Ventilation				
	Natural Vent.	0.6 ac/h	0.6 ac/h (manual input)	0.6 ac/h	0.6 ac/h
	Mechanical Vent.	-	-	-	-
	Infiltration	4 ac/h (n_{50})	0.27 ac/h	4 ac/h (n_{50})	4 ac/h (n_{50})
	Interior lighting				
	Luminaire type	Suspended	Free hanging	**x**	**x**
	Lamp type	**x**	**x**	Incandescent	Incandescent
	Radiant fraction	0.5	**x**	Default (unknown)	0.5
	Ballast multiplier	**x**	1 (min. allowable value)	**x**	**x**
	Lighting /Power	7 W/m^2	7 W/m^2	75 lx	7 W/m^2
	Exterior lighting	-	**x**	**x**	-
Evaluations and results	**Schedules**				
	Occupancy	Schedule 1 (24h)[1]	Schedule 1 (24h)	Default (24h)	Schedule 1 (24h)
	Electrical equipment	On[2]	On	Default (unknown)	Default
	Lighting	Schedule 2 (8h daily)[3]	Schedule 2 (8h daily)	Default (unknown)	Schedule 2 (8h daily)
	Heating	On[2]	On	Default (24 h)[4]	On
	Cooling	On[2]	On	Default (24h)	On
	Evaluations and results				
	Evaluations	Hourly evaluation	Hourly evaluation	Monthly evaluation	Monthly evaluation
	Annual energy need for				
	Heating	Wh/m^2	kWh/m^2	kWh/m^2	kWh/m^2
	Cooling	Wh/m^2	kWh/m^2	kWh/m^2	kWh/m^2
	Lighting	Wh/m^2	kWh/m^2	kWh/m^2	kWh/m^2
	DHW	Wh/m^2	kWh/m^2	kWh/m^2	kWh/m^2

D: Default W: Wall G: Groundfloor R: Roof Wi: Window DG: Double-glazing

[1] For occupancy; Schedule 1; until 08.00 1; until 18.00 0.25; until 24.00 1 (16 hours daily).

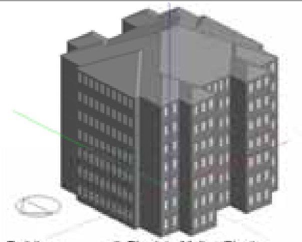
[2] For electrical equipment, heating and cooling; Schedule is always On; until 24 1.

[3] For lighting; Schedule 2; until 06.00 0.15; until 08.00 0.8; until 18.00 0.2; until 22.00 0.8; until 24.00 0.3 (total; 8 hours daily).

[4] The program assumes 17 hours standard and 7 hours reduced heating daily.

In schedules, ‘1’ means On, and ‘0’ means Off, while others like 0.50 mean the percentage of use.

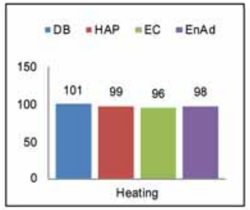
Table 6.72 Evaluation Results for Block II in the *Maliye* Blocks

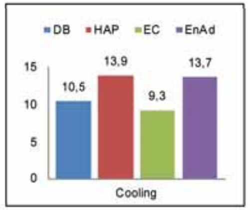


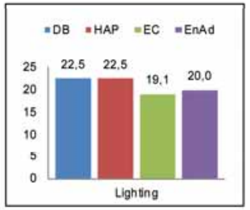
Building : II. Block in Maliye Blocks
\# of floors : 7
Material list : The Architectural project
Material layers : Multi-layer
Materials : W: 0.70; G: 0.50; R: 0.30
Windows : Wi (DG; U: 2.80; gl: 0.75)
WWR : 19%

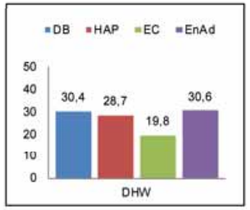
Annual energy need per unit (kWh/m²a)

	DB	HAP	EC	EnAd
Heating	101	99	96	98
Cooling	10,5	13,9	9,3	13,7
Lighting	22,5	22,5	19,1	20,0
DHW	30,4	28,7	19,8	30,6



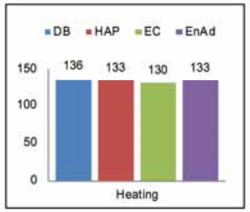


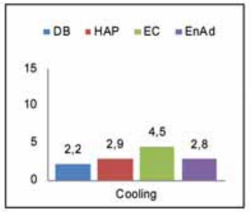


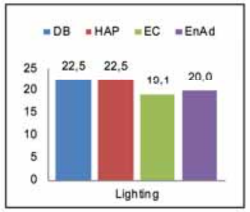


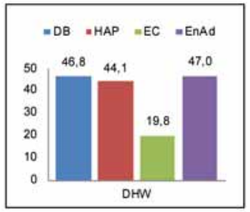
Annual energy use per unit (kWh/m²a)

	DB	HAP	EC	EnAd
Heating	136	133	130	133
Cooling	2,2	2,9	4,5	2,8
Lighting	22,5	22,5	19,1	20,0
DHW	46,8	44,1	19,8	47,0









As can be seen in Table 6.72, very close results were recorded for the energy requirement of the building systems in the four programs. EnAd showed a 98.4 kWh/m^{2}a energy need for heating, while this requirement was calculated by HAP as 98.5 kWh/m^{2}a, by EnerCalc as 96.1 kWh/m^{2}a, and by DesignBuilder as 100.6 kWh/m^{2}a. The cooling requirements of the building were recorded by EnAd as 13.7 kWh/m^{2}a, by HAP as 13.9 kWh/m^{2}a, by EnerCalc as 9.3 and by DesignBuilder as 10.5 kWh/m^{2}a. Similar results were obtained for DHW use (30.4; 28.7; 19.8 and 30.6 kWh/m^{2}a) and for lighting (22.5; 22.5; 19.1 and 19.7 kWh/m^{2}a) by DesignBuilder, HAP, EnerCalc and EnAd, respectively.

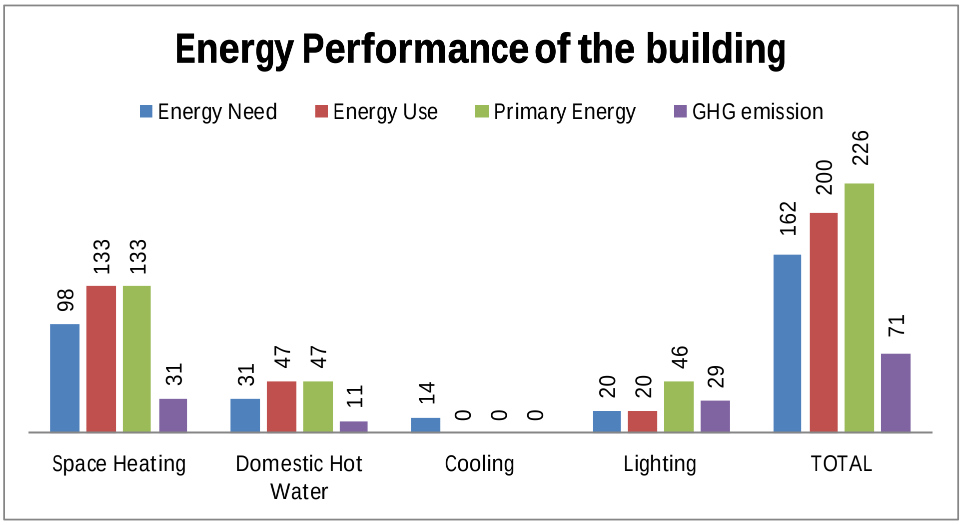


Figure 6.22 Output of EnAd for Energy Performance per Unit

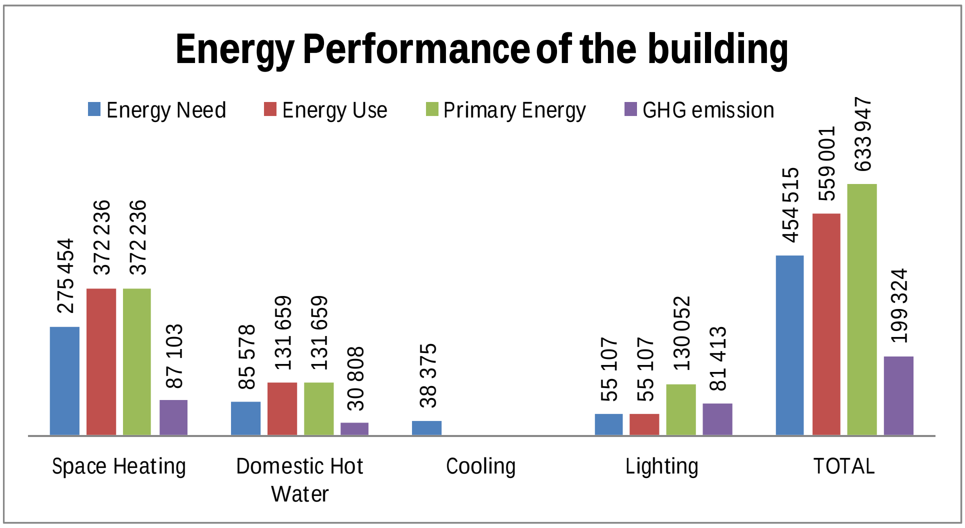


Figure 6.23 Output of EnAd for Energy Performance of the Entire Building

Similar results were obtained for energy use, since the same efficiency values were introduced to all tools, except EnerCalc, which does not permit any change to efficiency values. The energy performance of the building as evaluated by EnAd, both for each unit and for the entire building, is presented in Figures 6.22 and 6.23 respectively. Considering energy use, the building is expected to consume 132.9 kWh/m^{2}a for heating and 47 kWh/m^{2}a for DHW use, corresponding to 372,236 kWh/m^{2}a for heating and 131,659 kWh/m^{2}a for DHW for the entire building. When these figures are converted into natural gas requirement in m^3 with the conversion coefficient of 10.64 used in the calculation of natural gas bills, it can be seen that the building would require 34,985 m^3 of natural gas for heating and 12,374 m^3 for DHW use annually. The building manager provided natural gas consumption data for space heating and DHW use in the building for the last four years in m^3 figures, which are given in Table 6.73.

Table 6.73 Natural Gas Consumption Data of Block II

Months	Natural Gas Consumption (m3)				Average
	2009	**2010**	**2011**	**2012**	
January	10.057	9.693	9.809	11.000	10.140
February	8.240	8.049	8.547	10.136	8.743
March	8.507	7.235	8.171	8.847	8.190
April	4.906	4.980	6.101	3.560	4.887
May	2.318	1.799	3.553	1.496	2.292
June	968	973	1.202	1.104	1.062
July	900	727	863	809	825
August	842	652	833	782	777
September	1.220	770	1.016	800	952
October	2.195	4.499	5.224	1.507	3.356
November	6.571	5.017	8.698	6.318	6.651
December	8.775	8.110	9.209	8.732	8.707
Total	55.499	52.504	63.226	55.091	56.580

As can be seen in Table 6.73, the building uses about 52,000-55,000 m^3 natural gas annually for heating and DHW, aside from in 2011 when there was a very cold winter. Since the same boiler is used for both heating and DHW, it is not possible to separate the natural gas consumption data for the two systems. Assuming no heating is required in the months of June, July, August and September, the annual natural gas consumption for DHW can be estimated as around 12,000-14,000 m^3. The remaining share, about 40,000 m^3, would be used for space heating purposes. These figures are supported by the evaluation results of EnAd, which indicates around 35,000 m^3 of natural gas use for heating and about 12,400 m^3 for DHW, as indicated above. In the evaluations, several assumptions are made based on average values, including the number of occupants, internal gains, DHW use, type and number of lighting appliances and efficiency of the boiler used. For this reason, differences can be expected between the evaluation results and the actual consumption data, related to climatic changes between the years, operation of the system by the apartment manager, annual leave during the summer, number of occupants in the building and their habits regarding DHW use, the actual efficiency and whether periodic inspections of the equipment are carried out, and related system gains and losses.

6.5.4 Evaluation of a High-rise Building

The fourth case study considers a high-rise residential building in another housing complex of the Ministry of Economy in the *Keklik Pınarı*, located in the southern part of Ankara and shown in Figure 6.24. The housing complex consists of three blocks. As can be seen in Figure 6.25, each block has 10 stories and four flats on each floor. The buildings have been used since 1988. Block B, located on *Dikmen* Street, was selected for study due to the availability of consumption data provided from the building manager.

Figure 6.24 Location of the *Maliye* Blocks in *Keklik Pınarı*

Figure 6.25 Views of the *Maliye* Blocks in *Keklik Pınarı*

Similar to the buildings of *Altınçay Sitesi* in *Birlik* and the *Maliye* Blocks in *Öveçler*, Block B has an unconditioned semi-basement floor, providing entry to the building, above which there are typical floors with an unconditioned pitched roof at the top. As can be seen from the typical floor plan of the building shown in Figure 6.26, each flat has a kitchen, living room, three bedrooms, bathroom, WC and two balconies. The architectural project shows the building was designed in line with the maximum limits of the building regulations in use in that time. According to the project, the AAC walls are assumed to have a U-value of 0.80 W/m^2K, while the U-value of reinforced concrete floors above the unconditioned basement is about 0.51 W/m^2K, and the ceiling is about 0.31 W/m^2K.

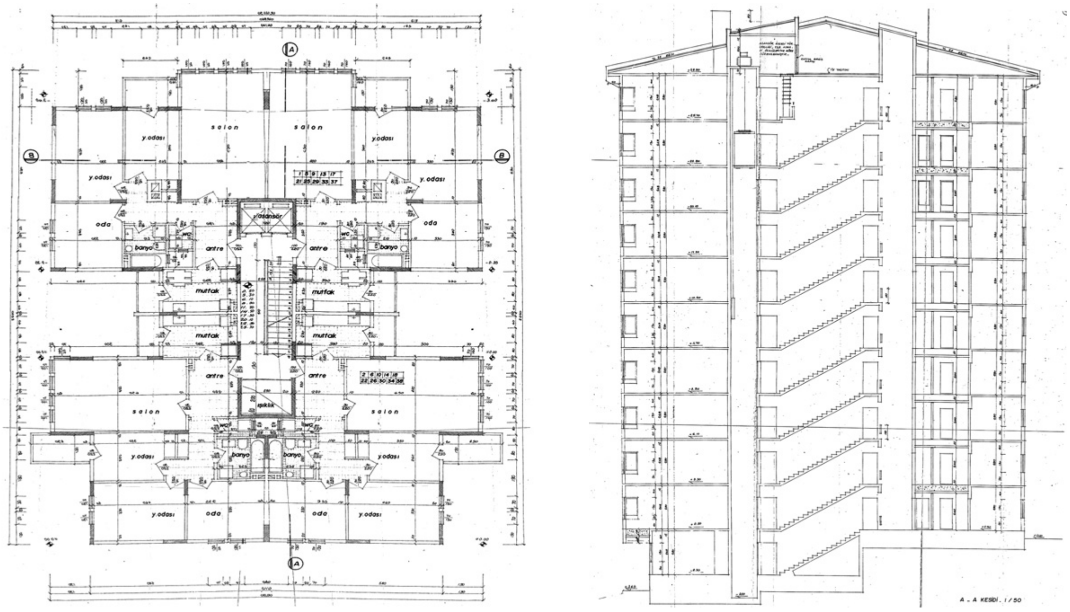


Figure 6.26 Typical Floor Plan and Section of Block B

For the evaluation of the building, the exterior dimensions of the building were introduced to the four tools, again disregarding balconies, as in the previous cases. The thermal properties of the building materials, as defined in the architectural project, were used in the evaluations. In addition to actual data provided by the building manager, the maintenance manager and the occupants, several average values were also used in the evaluations, including the number of occupants (assumed as four per flat), internal gains, lighting and DHW use, schedules of the building systems (since they are changeable for each flat or family). This allowed the evaluations to be made in a controlled way. More detailed information about input data of the building entered into each tool is provided in Table 6.74.

Table 6.74 Input Data for Block B in the *Maliye* Blocks

		DesignBuilder	HAP	EnerCalc	EnAd
Location	**Climatic data**				
	Outside temperatures	Esenboğa (ASHRAE/IWEC)	Ankara (ASHRAE 2001 Handbook)	Esenboğa (ASHRAE/IWEC)	Esenboğa (ASHRAE/IWEC)
	Solar gains	Esenboğa (ASHRAE/IWEC)	Ankara (ASHRAE 2001 Handbook)	TS 825	TS 825
	Code compliance	ASHRAE	ASHRAE	DIN V 18599	BEP documents of Turkey
Form definition	**Introduction of the geometry**				
	External dimensions	20.9*25.6*2.8m	20.9*25.6*2.8m	20.9*25.6*2.8m	20.9*25.6*2.8m
	Net area	4310 m^2	4310 m^2 (manual input)	4310 m^2 (manual input)	4055 m^2
	Net volume	12069 m^3	12069 m^3 (manual input)	12069 m^3 (manual input)	10138 m^3
	# of floors	10	10	10	10
	# of exposed surfaces	All (6 surfaces)	All (6 surfaces)	All (6 surfaces)	All (6 surfaces)
	Window/wall ratio	17%	17%	17%	17%
	Density of people (for each flat)	0,037 people/m^2	4 people	x	4 people
	Zoning (thermal zone)	7 zones	7 zones	7 zones	7 zones
	Construction				
	Construction type	Heavy	Heavy	Heavy	Heavy
	Material library	Insulated layered surfaces defined by the project	Insulated layered surfaces defined by the project	x	Insulated layered surfaces defined by the project
	U-values	W: 0.80; G: 0.51; R: 0.31	W: 0.80; G: 0.51; R: 0.31	W: 0.80; G: 0.51; R: 0.31	W: 0.80; G: 0.51; R: 0.31
	Windows	Wi: DG (U: 2.80; gl: 0.75)	Wi: DG (U: 2.80; gl: 0.75)	Wi: DG (U: 2,86; gl: 0,78) (D)	Wi: DG (U: 2.80; gl: 0.75)
	Frames	Timber	Timber	Timber	Timber
	Shading				
	from external objects	No shading	No shading	No shading	No shading
	Window shading	No shading	No shading	No shading	x
	Thermal bridges	No thermal bridge	No thermal bridge	With thermal bridges (0.01)	x
	Solar gains	Default	Default	Default	Default
	Internal gains				7 W/m^2
	Average	x	x	x	-
	Living+Kitchen	x	x	x	-
	Other spaces	x	x	x	-
	Occupancy	Default (unknown)	Default (Sen:71.8; Lat:60.1 W/p)	55 Wh/m^2d	-
	Office equipment	1 W/m^2	1 W/m^2	14 Wh/m^2d	-
	Catering	-	x	x	x
	Lighting	Default (unknown)	Default (unknown)	Default (unknown)	-
	DHW use	-	x	-	-
	HVAC system	x	x	-	x
	Other	-	-	-	x
Service systems	**Space heating**				
	Heater type	Standard Boiler	Standard Boiler	Boiler	Standard Boiler
	Fuel type	Natural gas	Natural gas	Natural gas	Natural gas
	Heating set temp.	23°C	23°C	23°C	23°C
	Setback temp.	21°C	21°C	21°C	x
	Programmer	x	-	-	-
	Efficiency	0.74	0.74	0.74 (D)	0.74
	Space cooling				
	Conditioner	Air-conditioner	Chiller	Air cooled compressor, improved	Air-cond., non-duct type
	Fuel type	Electricity	Electricity	Electricity (D)	Electricity
	Cooling set temp.	26°C	26°C	26°C	26°C
	Setback temp	28°C	28°C	28°C	x
	Efficiency class	x	x	x	B
	CoP	4.85	4.85	2.07 (D)	4.85
	DHW supply		x (Miscellaneous energy)		
	Water heater	Stand-alone water heater		Default	Stand-alone water heater
	Fuel type	Natural gas		Electricity (D)	Natural gas
	Use water temp	50°C		Default (unknown)	50°C
	Supply water t.	10°C		Default (unknown)	10°C
	Daily usage	1.58 l/m^2 d	7.8 kWh/d (manual input)	1.4 kWh/p.d (D)	45 l/p.d
	Efficiency	0.65	0.65	1 (D)	0.65
	Ventilation				
	Natural Vent.	0.6 ac/h	0.6 ac/h (manual input)	0.6 ac/h	0.6 ac/h
	Mechanical Vent.	-	-	-	-
	Infiltration	4 ac/h (n_{50})	0.27 ac/h	4 ac/h (n_{50})	4 ac/h (n_{50})
	Interior lighting				
	Luminaire type	Suspended	Free hanging	x	x
	Lamp type	x	x	Incandescent	Incandescent
	Radiant fraction	0.5	x	Default (unknown)	0.5
	Ballast multiplier	x	1 (min. allowable value)	x	x
	Lighting /Power	7 W/m^2	7 W/m^2	75 lx	7 W/m^2
	Exterior lighting	-	x	x	-
Evaluations and results	**Schedules**				
	Occupancy	Schedule 1 (24h)[1]	Schedule 1 (24h)	Default (24h)	Schedule 1 (24h)
	Electrical equipment	On[2]	On	Default (unknown)	Default
	Lighting	Schedule 2 (8h daily)[3]	Schedule 2 (8h daily)	Default (unknown)	Schedule 2 (8h daily)
	Heating	On[2]	On	Default (24 h)[4]	On
	Cooling	On[2]	On	Default (24h)	On
	Evaluations and results				
	Evaluations	Hourly evaluation	Hourly evaluation	Monthly evaluation	Monthly evaluation
	Annual energy need for				
	Heating	Wh/m^2	kWh/m^2	kWh/m^2	kWh/m^2
	Cooling	Wh/m^2	kWh/m^2	kWh/m^2	kWh/m^2
	Lighting	Wh/m^2	kWh/m^2	kWh/m^2	kWh/m^2
	DHW	Wh/m^2	kWh/m^2	kWh/m^2	kWh/m^2

D: Default W: Wall G: Groundfloor R: Roof Wi: Window DG: Double-glazing

[1] For occupancy; Schedule 1; until 08.00 1; until 18.00 0.25; until 24.00 1 (16 hours daily).

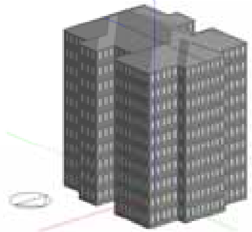
[2] For electrical equipment, heating and cooling; Schedule is always On; until 24 1.

[3] For lighting; Schedule 2; until 06.00 0.15; until 08.00 0.8; until 18.00 0.2; until 22.00 0.8; until 24.00 0.3 (total; 8 hours daily).

[4] The program assumes 17 hours standard and 7 hours reduced heating daily.

In schedules, '1' means On, and '0' means Off, while others like 0.50 mean the percentage of use.

Table 6.75 Evaluation Results for Block B in Maliye Blocks



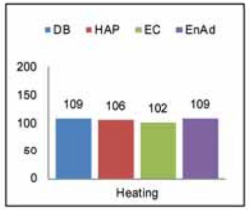
Building	: Block B in Maliye Blocks
# of floors	: 10
Material list	: The Architectural project
Material layers	: Multi-layer
Materials	: W: 0.80; G: 0.51; R: 0.31
Window s	: WI (DG; U: 2.80; gl: 0.75)
WWR	: 17%

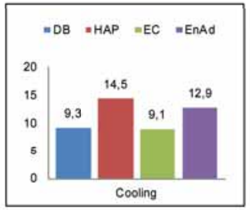
Annual energy need per unit (kWh/m²a)

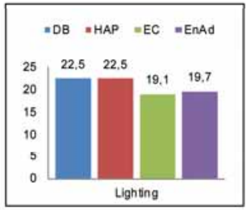
	DB	HAP	EC	EnAd
Heating	109	106	102	109
Cooling	9,3	14,5	9,1	12,9
Lighting	22,5	22,5	19,1	19,7
DHW	30,4	28,3	19,8	30,1

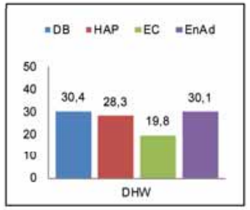
Annual energy use per unit (kWh/m²a)

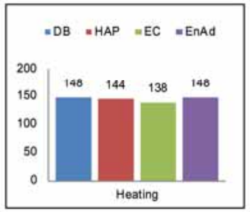
	DB	HAP	EC	EnAd
Heating	148	144	138	148
Cooling	1,9	3,0	4,4	2,7
Lighting	22,5	22,5	19,1	19,7
DHW	46,8	43,5	19,6	46,4

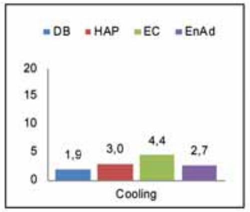


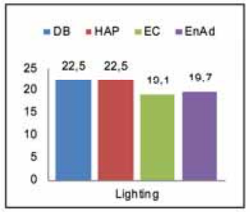












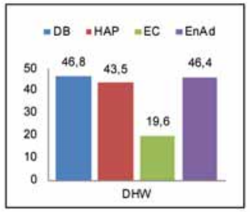


Table 6.75 shows that close results were obtained from all four programs. According to these figures, the building would require energy of between 102-109 kWh/m^{2}a for heating, 9-14 kWh/m^{2}a for cooling, 19-30 kWh/m^{2}a for DHW and 19-22 kWh/m^{2}a for lighting. If the efficiency values for the building systems are assumed to be close to the actual values, the building would be expected to use 130-147 kWh/m^{2}a for heating, 2-7 kWh/m^{2}a for cooling, 19-46 kWh/m^{2}a for DHW and 19-22 kWh/m^{2}a for lighting. When these figures are converted into natural gas consumption, it is seen that the building is expected to consume 55,259 m^3 of natural gas for heating and 17,677 m^3 for DHW in a year. Although the building is heated by a central system, DHW supply is provided by each flat individually. The annual consumptions of the building for space heating were recorded at about 55,000 m^3 for 2010, 65,000 m^3 for 2011 and 58,000 m^3 for 2012, corresponding to a yearly average of 59,000 m^3 – a figure that is close to the evaluation results. Since it was not possible to get individual bills for electricity and natural gas consumption, DHW and lighting results could not be verified with actual consumptions. EnAd provides energy performance diagrams for the building, both for each unit and for the building as a whole, which are shown in Figures 6.27 and 6.28.

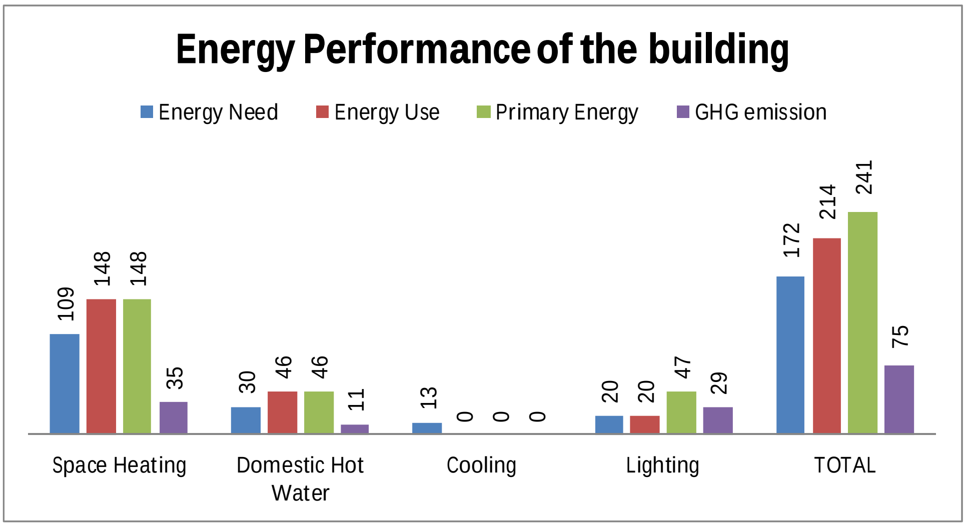


Figure 6.27 Output of EnAd for Energy Performance per Unit

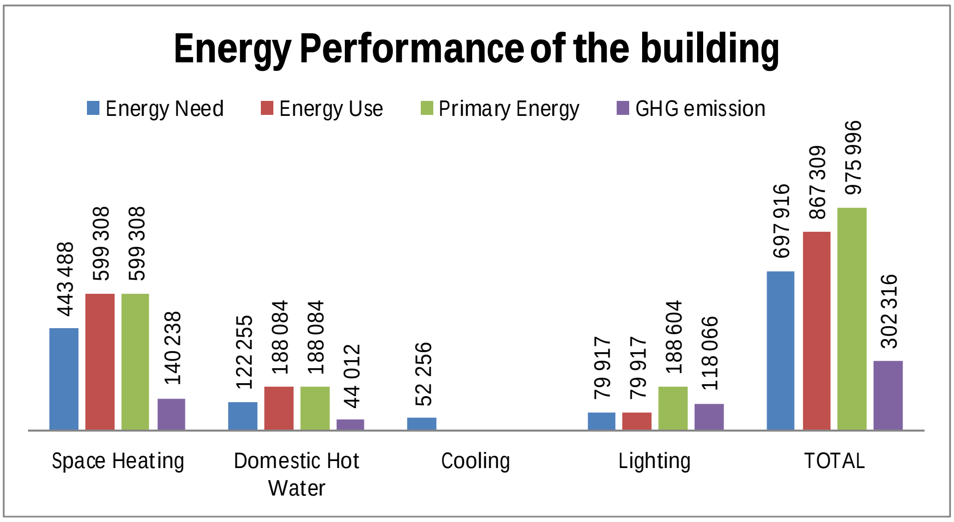


Figure 6.28 Output of EnAd for Energy Performance of the Entire Building

6.5.5 Evaluation of a High-rise Building

The final case study considers a high-rise office building in the *Söğütözü* of western Ankara. The building is used as the headquarters of GAMA Holding, and is the first building in Turkey to be awarded with a LEED EB GOLD certificate with 71 points by the US Green Building Council (GAMA Building, 2013). The building base has a curvilinear form, while the tower is oriented in a north-south direction. The location of the building on the site defined in Figure 6.29. It is a very new building, which underwent initial occupation at the end of 2010.

Figure 6.29 Location of GAMA Building in *Söğütözü*

Figure 6.30 Views of GAMA Building

The building comprises three parts; two floors of unconditioned basement used as a garage; the ground floor and first two floors, which serve for common services and social facilities, including a business center, conference hall, cafe, restaurant and fitness center; and the 16-storey office block. The architectural project was prepared respecting the maximum limits of the building regulations at the time. The walls have a U-value of 0.40 W/m^{2}K, while the floors are 0.50 W/m^{2}K and the flat roof is 0.30 W/m^{2}K. As can be seen in Figure 6.29, the majority of the building envelope is glass, dominating the thermal performance of the entire building. However, the glass façade also has maximum limits of the legislation, with a U-value of 2.1 W/m^{2}K and a 0.55 solar transmittance. Figure 6.31 presents a plan and section of the building.

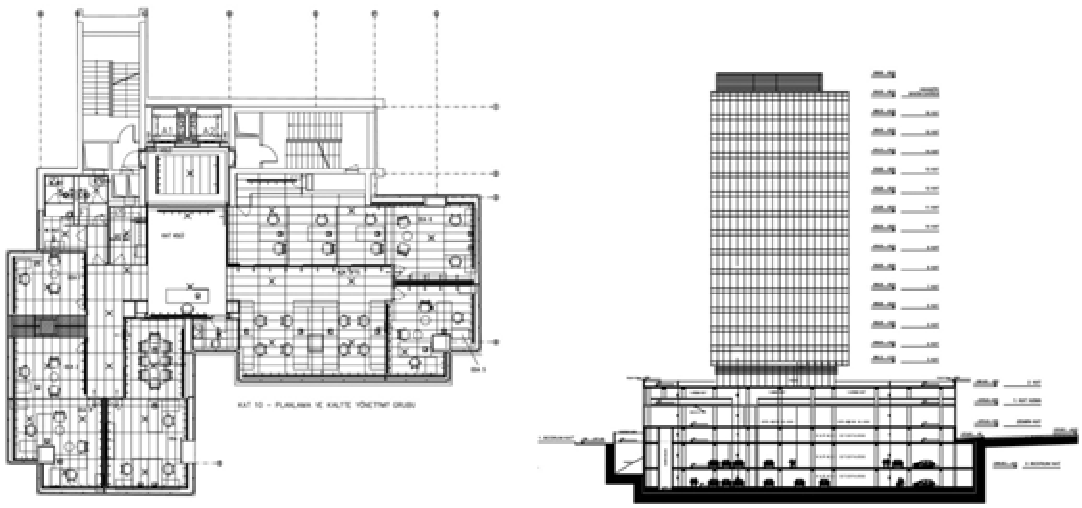


Figure 6.31 Typical Floor Plan and Section of GAMA Building

In the evaluations, the building was introduced to each program separately. Since EnAd, EnerCalc and HAP all require text-based input, a simplification was required to introduce the curvilinear-formed base floors of the building to the tools. For DesignBuilder, a solid 3D model of the building was created. Elliptical surfaces were trisected, each of which was assumed to face one direction, while the northern façade has a linear surface. The same area and volume was introduced to each of the tools. The lighting power and internal gains from office equipment were assumed to be 10.8 W/m^2, as defined in the BEP Regulations, while the actual schedules of the building were used in the evaluations. The building features an automated building management system system for the control of the heating, cooling, mechanical ventilation and lighting of the entire building, which sets room temperature to 23.5°C while providing the occupants with individual control mechanisms allowing ±4°C changes in room temperatures. The schedules used by the automated building management system were introduced to the tools with one difference, as the 200-person capacity conference hall in the ground floor is the only space that is not conditioned regularly. For ease of evaluation, the hall was assumed to be conditioned the same as the other spaces. In HAP, it is not possible to set the same temperature both for heating and cooling, and thus a set-point temperature of 24°C was set for heating and 25°C for cooling. The other major difference in input data was related to mechanical ventilation, for which a 2 m/s airflow rate, as defined in the project, was used by EnAd, EnerCalc and DesignBuilder with a schedule of twelve hours in daily operation. On the other hand, since HAP is used primarily for HVAC system sizing, mechanical ventilation is defined in a very different way in this program, requiring very detailed information about the system, including airflow control type, sizing method, schedule, outdoor air CO_2 level, duct system, exhaust fan, humidification, dehumidification, ventilation fan type, and overall efficiency and total static pressure for operation. More detailed information regarding the input data entered into the four programs is presented in Table 6.76.

Table 6.76 Input Data for GAMA Building in *Söğütözü*

		DesignBuilder	HAP	EnerCalc	EnAd
Location	**Climatic data**				
	Outside temperatures	Esenboğa (ASHRAE/IWEC)	Ankara (ASHRAE 2001 Handbook)	Esenboğa (ASHRAE/IWEC)	Esenboğa (ASHRAE/IWEC)
	Solar gains	Esenboğa (ASHRAE/IWEC)	Ankara (ASHRAE 2001 Handbook)	TS 825	TS 825
	Code compliance	ASHRAE	ASHRAE	DIN V 18599	BEP documents of Turkey
Form definition	**Introduction of the geometry**				
	External dimensions	25.4*25.8*3.4m tower with curvilinear formed first floors	25.4*25.8*3.4m tower with curvilinear formed first floors	25.4*25.8*3.4m tower with curvilinear formed first floors	25.4*25.8*3.4m tower with curvilinear formed first floors
	Net area	13590 m^2	13590 m^2 (manual input)	13590 m^2 (manual input)	14154 m^2
	Net volume	42994 m^3	42994 m^3 (manual input)	42994 m^3 (manual input)	39114 m^3
	# of floors	17	17	17	17
	# of exposed surfaces	All	All	All	All
	Window/wall ratio	66%	66%	66%	66%
	Density of people	0,035 people/m^2	380 people	**x**	380 people
	Zoning (thermal zone)	17 zones	17 zones	17 zones	17 zones
	Construction				
	Construction type	Heavy	Heavy	Heavy	Heavy
	Material library	Insulated layered surfaces defined by the project	Insulated layered surfaces defined by the project	**x**	Insulated layered surfaces defined by the project
	U-values	W: 0.40; G: 0.50; R: 0.30	W: 0.40; G: 0.50; R: 0.30	W: 0.40; G: 0.50; R: 0.30	W: 0.40; G: 0.50; R: 0.30
	Windows	Wi: U: 2.10; gl: 0.55	Wi: U: 2.10; gl: 0.55	Wi: U: 2.10; gl: 0.55	Wi: U: 2.10; gl: 0.55
	Frames	No frame	No frame	No frame	No frame
	Shading				
	from external objects	No shading	No shading	No shading	No shading
	Window shading	No shading	No shading	No shading	**x**
	Thermal bridges	No thermal bridge	No thermal bridge	With thermal bridges (0.01)	**x**
	Solar gains	Default	Default	Default	Default
	Internal gains				
	Average	**x**	**x**	**x**	-
	Living+Kitchen	**x**	**x**	**x**	-
	Other spaces	**x**	**x**	**x**	-
	Occupancy	Default (unknown)	Default (Sen:71.8; Lat:60.1 W/p)	30 Wh/m^2d	Defaut (Sen: 75 W/p; Lat: 55 W/p)
	Office equipment	10.8 W/m^2	10.8 W/m^2	42 Wh/m^2d	10.8 W/m^2
	Catering	-	**x**	**x**	**x**
	Lighting	Default (unknown)	Default (unknown)	Default (unknown)	Default
	DHW use	-	**x**	-	-
	HVAC system	**x**	**x**	-	**x**
	Other	-	-	-	**x**
Service systems	**Space heating**				
	Heater type	Fan Coil Unit	4-pipe Fan Coil Unit	Boiler	Condensing Boiler
	Fuel type	Natural gas	Natural gas	Natural gas	Natural gas
	Heating set temp.	24°C	24°C	24°C	24°C
	Setback temp.	22°C	22°C	22°C	**x**
	Programmer	**x**	-	-	-
	Efficiency	0.98	0.98	0.74 (D)	0.98
	Space cooling				
	Conditioner	Fan Coil Unit	4-pipe Fan Coil Unit	Air cooled compressor, improved	Air-cond., non-duct type
	Fuel type	Electricity	Electricity	Electricity (D)	Electricity
	Cooling set temp.	24°C	25°C	24°C	24°C
	Setback temp	26°C	27°C	26°C	**x**
	Efficiency class	**x**	**x**	**x**	A+
	CoP	6	6	2.07 (D)	6
	DHW supply		**x** (Miscellaneous energy)		
	Water heater	By Space Heating System		Default	By Space Heating System
	Fuel type	Natural gas		Electricity (D)	Natural gas
	Use water temp	50°C		Default (unknown)	50°C
	Supply water t.	10°C		Default (unknown)	10°C
	Daily usage	0.8 l/m^2 d	530.3 kWh/d (manual input)	1.4 kWh/p.d (D)	30 l/p.d
	Efficiency	0.85	0.85	1 (D)	0.85
	Ventilation				
	Natural Vent.	-	-	-	-
	Infiltration	-	-	-	-
	Mechanical Vent.	2 ac/h	-	2 ac/h	2 ac/h
	Ventilation Requirement	-	2.5 L/(s.person) (D)	-	-
	Ventilation Requirement	-	0.3 L/(s.m^2) (D)	-	-
	Airflow control	-	ASHRAE 62.1 – 2007	-	-
	Outdoor Air CO2 level	-	400 ppm	-	-
	Ventilation fan type	-	Forward curved	-	-
	Total static		500 Pa		
	Overall efficiency		50%		
	Interior lighting				
	Luminaire type	Suspended	Free hanging	**x**	**x**
	Lamp type	**x**	**x**	Fluorescent	Fluorescent
	Radiant fraction	0.18	**x**	Default (unknown)	0.35
	Ballast multiplier	**x**	1 (min. allowable value)	**x**	**x**
	Lighting /Power	10 W/m^2	10 W/m^2	200 lx	10 W/m^2
	Exterior lighting	-	**x**	**x**	-
Evaluations and results	**Schedules**				
	Occupancy	Schedule 1 (12h)[1]	Schedule 1 (12h)	Default (unknown)	Schedule 1 (12h)
	Electrical equipment	Schedule 2 (12h)[2]	Schedule 2 (12h)	Default (unknown)	Schedule 2 (12h)
	Lighting	Schedule 3 (12h)[3]	Schedule 3 (12h)	Default (unknown)	Schedule 3 (12h)
	Heating	Schedule 4 (14h)[4]	Schedule 4 (14h)	Schedule 4 (14h)	Schedule 4 (14h)
	Cooling	Schedule 4 (14h)	Schedule 4 (14h)	Schedule 4 (14h)	Schedule 4 (14h)
	Mechanical Ventilation	Schedule 4 (14h)	Schedule 4 (14h)	Default (unknown)	Schedule 4 (14h)
	Evaluations and results				
	Evaluations	Hourly evaluation	Hourly evaluation	Monthly evaluation	Monthly evaluation
	Annual energy need for				
	Heating	Wh/m^2	kWh/m^2	kWh/m^2	kWh/m^2
	Cooling	Wh/m^2	kWh/m^2	kWh/m^2	kWh/m^2
	Lighting	Wh/m^2	kWh/m^2	kWh/m^2	kWh/m^2
	DHW	Wh/m^2	kWh/m^2	kWh/m^2	kWh/m^2

D: Default W: Wall G: Groundfloor R: Roof Wi: Window

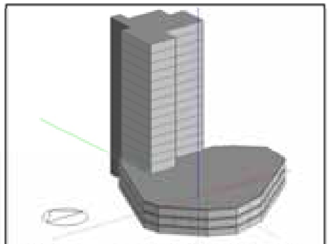
[1] For occupancy; Schedule 1; until 08.00 0; until 20.00 0.80; until 24.00 0.

[2] For electrical equipment, Schedule 2; until 08.00 0; until 20.00 1; until 24.00 0.

[3] For lighting; Schedule 3; until 08.00 0; until 20.00 0.75; until 24.00 0.

[4] For heating, cooling and mechanical ventilation; Schedule 4; until 06.00 0; until 20.00 1; until 24.00 0.

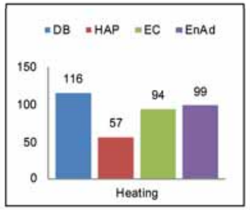
Table 6.77 Evaluation Results for GAMA Building in *Söğütözü*

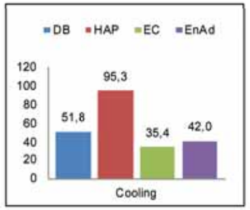


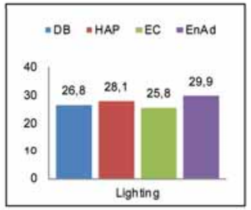
Building	: GAMA Building in Söğütözü
# of floors	: 17
Material list	: The Architectural project
Material layers	: Multi-layer
Materials	: W: 0.40; G: 0.50; R: 0.30
Windows	: W; U: 2.10; gl: 0.55
WWR	: 66%

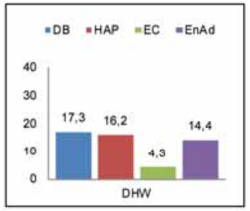
Annual energy need per unit (kWh/m²a)

	DB	HAP	EC	EnAd
Heating	116	57	94	99
Cooling	51,8	95,3	35,4	42,0
Lighting	26,8	28,1	25,8	29,9
DHW	17,3	16,2	4,3	14,4



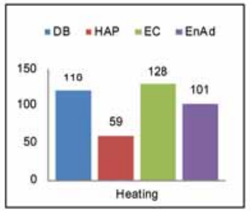


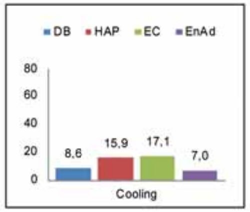


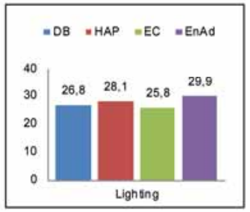


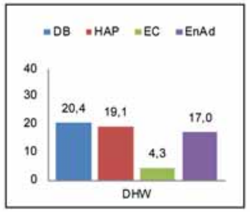
Annual energy use per unit (kWh/m²a)

	DB	HAP	EC	EnAd
Heating	118	59	128	101
Cooling	8,6	15,9	17,1	7,0
Lighting	26,8	28,1	25,8	29,9
DHW	20,4	19,1	4,3	17,0









As the complexity of the building increases, so do differences between the assumptions and evaluations due to differences in the structures of the programs used; and as a result, discrepancies in results become inevitable. High discrepancies were observed for such transparent buildings with 66% WWR. As in the generic cases, large glass façades on a building lead to high heat losses due to high U-values, and high solar gains due to the high solar transmittance of the glass façade. The office block would be expected to require high cooling and low heating due to the solar gains through the glass façade. The first floors, on the other hand, have very large floor and ceiling areas, resulting in high heat losses due to their horizontal geometry. Accordingly, these floors are expected to have higher heating loads.

According to evaluation results shown in Table 6.77, the energy requirement of the building for heating varies between 40–116 kWh/m^{2}a. The closest results for heating were obtained from EnAd (98.9 kWh/m^{2}a) and EnerCalc (94.5 kWh/m^{2}a), using very similar calculation methods and the same solar radiation data, followed by DesignBuilder (116 kWh/m^{2}a) and HAP (57.4 kWh/m^{2}a). Lower discrepancies were recorded for cooling requirements. According to the evaluation results, the cooling requirement of the building is around 35-51 kWh/m^{2}a, excluding HAP showing 95.3 kWh/m^{2}a, while the energy requirements for DHW and lighting did not differ between the programs since they were introduced for each unit. The results show that the energy requirement for lighting is around 26-30 kWh/m^{2}a, while for DHW the results vary between 14–17, excluding EnerCalc (4.3 kWh/m^{2}a), which uses the default values defined by the DIN standards. As in the previous cases, EnAd gave average results for heating, cooling, DHW and lighting among the other programs. It should be noted here that since the monthly calculation method of ISO 13790 considers the number of days in a week for cooling rather than hours, it is not so precise when calculating cooling requirements. As mentioned in the generic cases, the calculations used for cooling requirements need improvement.

The differences in the results can be attributed to the complexity of the building, such as the curvilinear form of the horizontal block, for which it is difficult to determine directions, especially when calculating solar gains. Furthermore, since each program uses different solar radiation data for Ankara, the differences increase further. As explained in the generic cases, the effect of an exposed ground floor and ceiling is distributed to each unit, while each program evaluates the ground floor and ceiling in different ways, resulting in major variations in the results. Since the building has large for ground floor and ceiling areas, about 5000 m^2 in total, the effects of the exposed floor and ceiling can be another reason for differences in the evaluation results. The net area and volume calculated by the programs can be another reason for differences in the results. Since EnAd, EnerCalc and HAP are text-based programs, the same values were introduced to the tools, including the wall and window areas facing the same directions, while the same material properties and schedules were also entered. Although almost all features are the same, EnAd and EnerCalc produced very similar results, while HAP gave very different results, both for heating and cooling requirements. One reason can be due to the introduction of mechanical ventilation features into HAP, as explained above.

Regarding consumption data, the building has very high electrical consumption and natural gas usage. According to the data from the provided utility bills, presented in Table 6.78, the building, with an approximate conditioned area of 15,000 m^2, consumes 175,000 kWh of electricity on average when no cooling is required, although it is used for many purposes in the building, such as lighting, electrical equipment and lifts, as well as pumps, fans, coolers and boilers in the building systems. In this respect, the electricity requirement for cooling can be calculated from the extra consumptions between May and September, corresponding to 111,003 kWh in total. Natural gas is used for different purposes such as heating, DHW supply and cooking in the building, with DHW use for office buildings assumed to be 30 lt/pd, provided by the heating system of the building. The remaining natural gas consumption was assumed to be used by the heating system, with usage in the kitchens of the restaurant and cafe disregarded due to uncertainties. Water is used by different systems for different purposes in the building, including DHW supply, cleaning, toilets, kitchen and chillers. For this reason, it is very difficult to determine the exact water consumption values for a specific purpose.

Table 6.78 Consumption Data of GAMA Building for 2012

	Electricity (kWh)	Natural Gas (m^3)	Water (m^3)
January	178,001	24,923	919
February	173,001	33,711	1,074
March	180,001	31,348	954
April	164,000	19,601	1,090
May	177,001	7,787	1,462
June	195,000	3,515	1,319
July	226,001	3,869	1,687
August	199,001	569	1,646
September	189,001	1,049	1,547
October	170,001	1,988	1,603
November	174,000	4,812	1,087
December	175,001	19,180	1,088
Average	183,334	12,696	1,290
Total	2,200,008	152,352	15,476

Figures 6.32 and 6.33 present the energy performance of the building, as shown by EnAd. According to these outputs, the building is expected to use 101 kWh/ m^2a (1,351,923 kWh in total) of energy for heating, 7 kWh/m^2a (93,885 kWh in total) for cooling, 17 kWh/m^2a (227,729 kWh in total) for DHW, and 30 kWh/m^2a (400,777 kWh in total) for lighting. According to these results, the building has an energy performance class of B, and a class of G for GHG emissions. Regarding natural gas consumption, the building is expected to consume 127,060 m^3 of natural gas for heating and 21,403 m^3 for DHW, in total 148,464 m^3, annually, which complies with the actual consumption figures. The building is expected to consume 93,885 kWh electricity for cooling, which can be accepted as close to the predicted values of around 111,000 kWh garnered from the bills. Finally, it is estimated that the building uses about 400,780 kWh electricity for interior lighting. Since the building takes maximum advantage of daylighting, the consumption values for interior lighting can be lower than the estimated values. The remaining share of electricity consumption can be attributed to other facilities, such as lifts, exterior lighting, office equipment and the HVAC system of the building. Since EnAd only evaluates electricity consumption for lighting and cooling, other consumptions are left out of the scope of the tool.

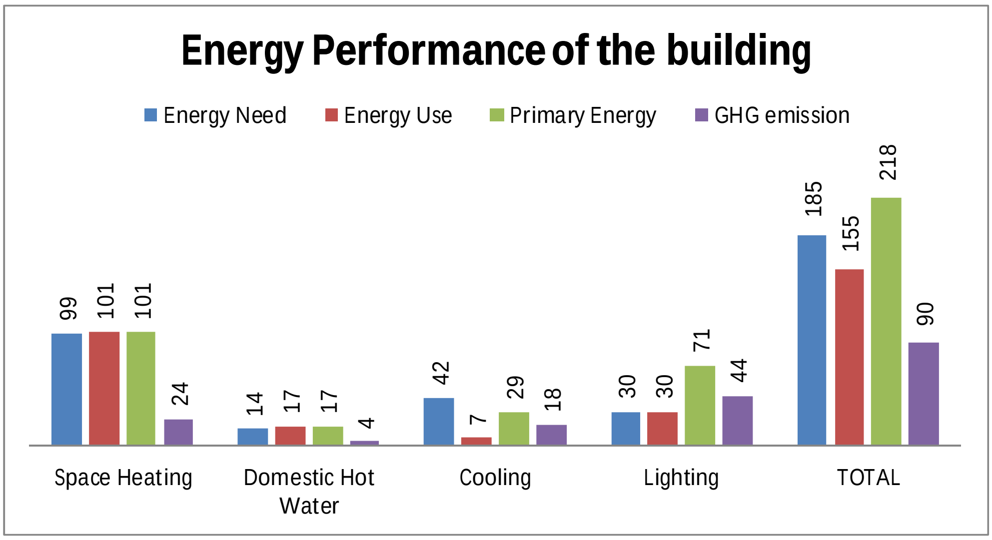


Figure 6.32 Output of EnAd for Energy Performance per Unit

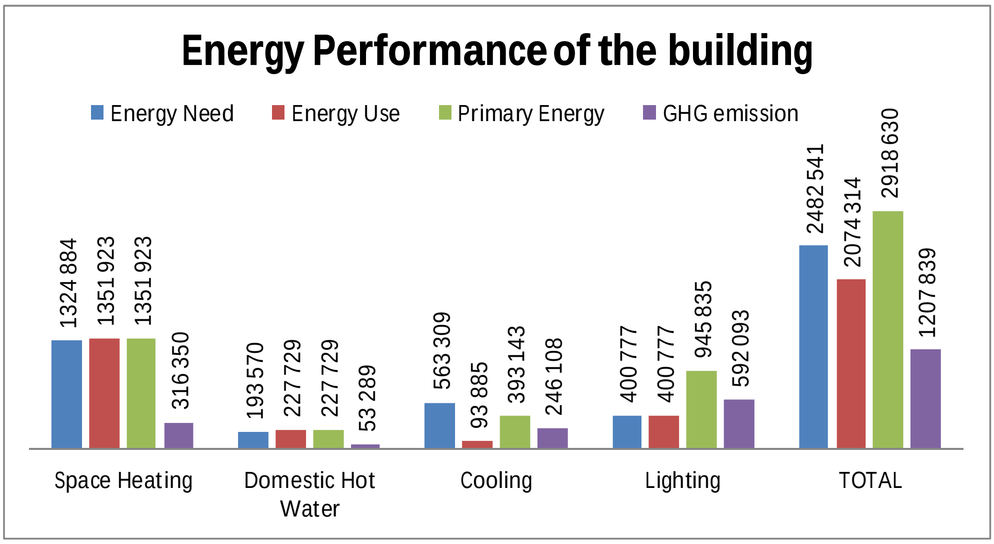


Figure 6.33 Output of EnAd for Energy Performance of the Entire Building

6.6 Usability of EnAd: Re-design of the Existing Building Studied

In this section, the house studied in section 6.5.1 was re-designed using EnAd, with the intention being to show how the design could have been improved if the designer had used the program in the design phase and had taken into account the results and feedback provided by the program. It would appear that the building project was conducted in accordance with the design limits of the heat insulation regulation for new buildings that entered into force in 1985, in that it satisfies the minimum requirements of the Regulation. Since Ankara is in the third heating degree-day region, the U-value for exterior walls should be maximum 0.80 W/m^{2}K; however, today this value is assumed to be 0.50 W/m^{2}K in TS 825 and in the BEP Regulation, indicating an update to the legislation since then.

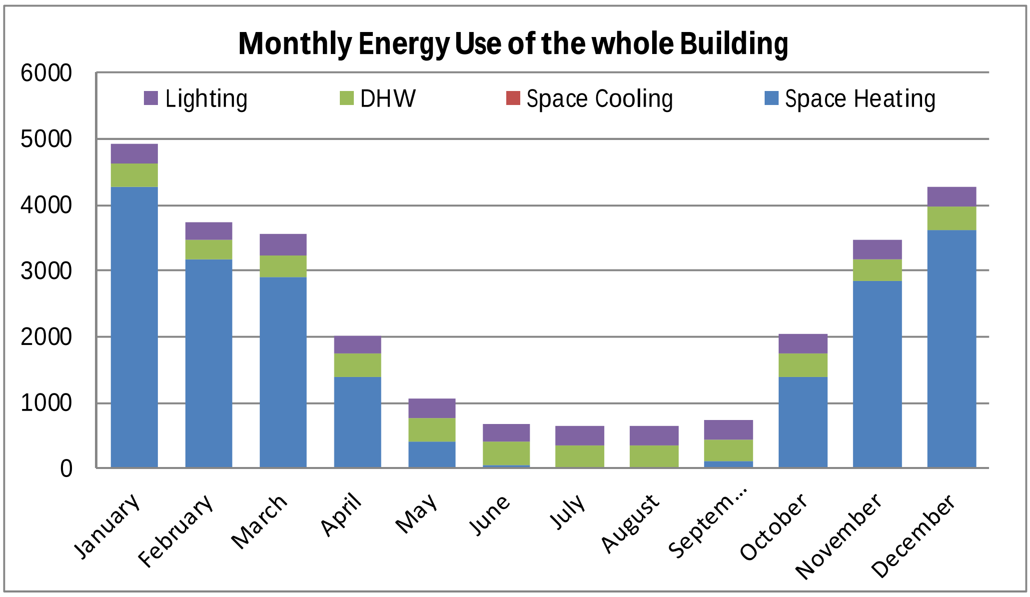


Figure 6.34 Monthly energy use of the whole building, as presented in EnAd

In redesigning the building, it is not possible to make any changes in site characteristics, such as location or building size and dimensions; and so it was decided to keep the design as it is, and rather make improvements to the building by changing its material properties and by trying different varieties of building systems.

Considering the heat transfer table provided by EnAd (Figure 6.35) showing heat transfers by transmission through the building envelope, it can be observed that the highest heat loss is through the windows and doors, although the WWR is very low (9%). In this respect, the first improvement that can be made is changing the window type to one with higher energy efficiency. The selection of a window with a U-value of 1.40 reduces heat loss from the windows from 35.2 to 22.4 W/K. The second highest heat losses are through the façades, and the program reminds the maximum limit as 0.50 W/m^{2}K for this element. For exterior walls, a wall with a U-value of 0.35 can be used to ensure higher performances, which would result in about 48 W/K reduction for the exterior walls.

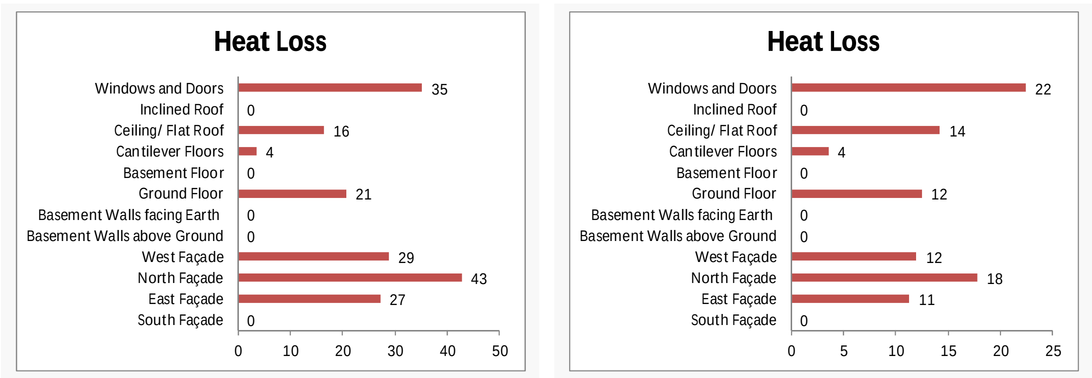


Figure 6.35 Heat Loss Table for the Real Building (left) and for the Improved Design (right)

The program also warns about ground floors and ceilings with high U-values, and similar steps can be followed and improvements made in the material properties of ground floor and ceiling. As a result, transmission heat losses can be reduced from 175 W/K to 94 W/K by following the warnings made by the program (Figure 6.36). Since the natural ventilation and shade of the building remain static, no changes in ventilation heat losses were recorded.

Considering the building systems in place, the building is heated by a standard natural gas boiler without thermostatic control; however the housing complex has about 560 single family houses, and almost 1,000 residences in total when including the high-rise blocks. If a community heating system is used for space heating and DHW supply, more efficient results can be achieved. For lighting, more efficient types of lamps can be used as well. On the other hand, since mechanical cooling and mechanical ventilation are not used in the house, and airflow rate for the natural ventilation cannot be changed, no change was made for these systems.

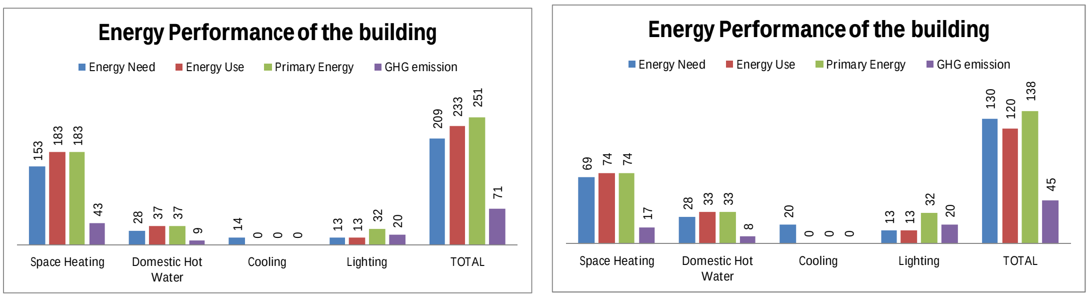


Figure 6.36 Energy performance of the Real Building (left) and Simulated Building (right)

By complying with the recommendations put forward by EnAd, the energy performance class of the existing building would be changed from C to B, while the GHG emission performance class would change from F to C. The annual energy requirement per unit would reduce from 209 to 130 kWh/m^{2}a, while the primary energy requirement would be 138 kWh/m^{2}a, reduced from 251 kWh/m^{2}a (Figure 6.37). Furthermore, GHG emissions would drop from 71 to 45 kg eq. CO_2/m^{2}a. These values result from only one step of improvements, however further significant improvements in performance may be achieved through recursive use of the program.

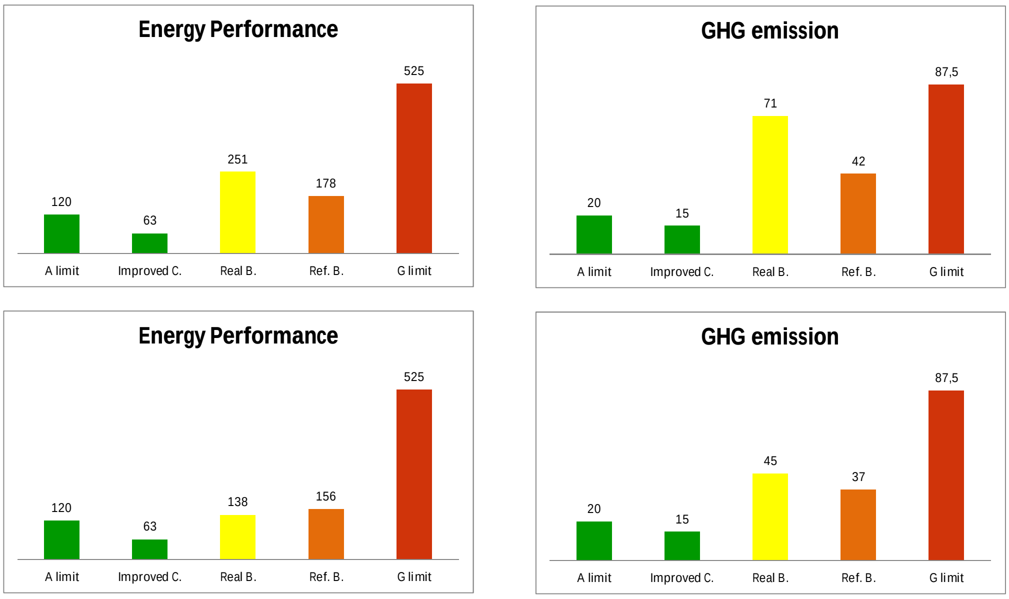


Figure 6.37 Performance Class of the Real Building (top) and the Improved Design (bottom)

CHAPTER 7

CONCLUSIONS

7.1 Conclusions

This dissertation has shown the strong relationship between sustainable environment and energy in architecture, and has underlined the role of legislation in the architectural design process. It has also emphasized the importance of the design-evaluation tools and design-support tools in the design of buildings, considering energy as a performance criterion. Since the complicated nature of the subject requires mathematical models for the energy performance evaluation of buildings, many performance evaluation tools and methods have been developed to date, ranging from simple calculations based on mathematical models to highly-sophisticated software tools performing hourly simulations. However, these can only be used during the post-design phase, and require very detailed data input, complex solid models and high expertise, both in the software and the subject. The need for better evaluation tools and methods has motivated this study into the creation of a design-support tool that is usable from the very beginning of the design process. In the scope of this study, a computer program, given the name "Energy performance Advisor (EnAd)," has been developed for the evaluation of the energy performance of buildings based on EPBD and related standards, laws and regulations of Turkey. Like many other programs, EnAd has several limitations besides the advantages it offers. The main advantages of the program can be listed as follows:

i. Easy to use
ii. Usable in all phases of the building design process
iii. No requirement for complex models
iv. Providing numerical and graphical outputs for the energy performance
v. Providing feedback for the improvement of design decisions
vi. Providing data on related legislation to be covered
vii. Informative about design limits
viii. Providing results in a reliability range

The limitations of the program can be listed as follows;

i. Unable to accept solid models or read file imports
ii. Difficulties encountered in the introduction of complex geometries and non-linear forms
iii. Unable to recognize intercardinal directions
iv. Unable to compute daylighting
v. Unable to respond to passive and renewable energy systems.

7.2 Contributions of the Study

The main outcomes, obtained from the literature review, the data collection, the development process of the program, the use of the program and the comparisons of generic and real case studies conducted, constituted the contributions of the study to the literature, which are presented below.

The primary outcome of the study has been a rich literature review, presenting the relationship between natural and built environment, performance data and energy-related legislation, as well as their impacts on architectural design and architectural practices in a chronological order since the 1970s. The study has listed energy-related EU directives, standards, laws and regulations enacted and/or adopted by Turkey, which have then been classified according to subject. Next, the performance goals and limits were extracted from related documents and included in EnAd, both for calculations and feedback.

The second contribution of this dissertation to literature is the determination of missing documents in the legislation, inconsistencies between the documents (including overlaps or contradictions), and missing values and performance criteria in the documents and in the national database that are necessary for the evaluation of the energy performance of buildings, as explained in Chapter 3. The study also highlights the differences between Turkish legislation and the DIN and ASHRAE standards in terms of method of calculation, assumptions and defaults, such as ground floors, U-values, construction types, and daily or monthly usage profiles.

The third and the most important outcome of the study is the program itself, as a usable and reliable program facilitating the integration of energy performance criterion and the legislation into the building design process. As presented in Chapter 6, the results of the generic case studies and the evaluations of the existing buildings have shown that the program falls within the reliability range of the three evaluation programs selected for comparison that are currently in use around the world. EnAd, even under extreme conditions, mostly gave average results for heating, cooling, DHW and lighting requirements among the other programs used.

The fourth contribution of this thesis is the usability of the program. As presented in Chapter 5, usability tests were made to show the usability, understandability and efficiency of the developed program, and its ability to reach pre-defined performance criteria under the guidance of the feedback provided by the program. When not given access to the feedback option, the design of the results section of the program allowed the users to achieve the defined performance goals, although it took them almost two or three times longer than those given access to the feedback function. The usability tests also showed that the evaluation of a building’s energy performance using EnAd is not a time-consuming process, and does not require complex models.

The fifth contribution made by the study relates to the information provided during the use of the program. Many programs on the market make energy performance evaluations, but give no information about the design decisions or feedback to encourage improvements. EnAd, on the other hand, provides warnings and feedback based on current legislation, the reference building and the improved case for the improvement of the design, while allowing the designer to follow the effect of each design decision on the results and on the energy performance class of the building. The conducted usability tests and the simulation of an existing building revealed the informative nature of EnAd, and proved its usefulness with the explanations and feedback provided for improving the design. In this respect, the program brings a unique and highly informative function to the field.

In this study, the intention is to present the designer with a tool that helps them understand the legal framework and design limits related to their task during the design process. Although some of the comparative programs use the standards in an embedded way, they provide no feedback to the designer about the subject. EnAd, on the other hand, being developed as a design-support tool, aims to inform the user about the legal framework to be covered and the design limits defined by the legislation, making EnAd unique in the field.

The sixth contribution of this dissertation is the creation of standard data sets to minimize biases during comparisons. In this context, the program structures and features of the four programs were mapped, and their common features and differences were determined. This mapping study allowed the development of standard data sets that could be inputted into all of the programs, while also showing the common and different features of the programs. It also allowed the reasons behind the differences between the results of the programs to be understood. The method of development, as well as the data sets, may be used for further evaluation studies.

The final contribution of this study is related to the findings derived from the case studies. The evaluation of generic cases by the four programs allowed the drawing of two types of conclusions for each case: one related to the discrepancies in the results in determining the reliability and precision of the results of EnAd, and the other related to the physical world that could be used as feedback in real projects, which are explained in detail in the following section.

7.3 Findings

The case studies, which allowed for a comparison of the results of the four programs, indicated that the size of a building, number of floors, number of flats, type and number of exposed surfaces (like walls, floors and ceilings), natural ventilation, infiltration, U-values, WWR, type of windows, set-point temperatures and temperature differences between the outside and the inside spaces are crucial parameters influencing the energy performance of a building. The results of the case studies show the effects of each parameter clearly on the energy performance of a building, and their outcomes may also be applicable to the building design process.

The first effect on energy performance relates to the size of a building, which was questioned in three ways in the case studies in terms of the net area and volume computed by the programs, the number of floors and the number of flats on each floor. Since each program follows a different approach when calculating net area and volume, minor differences were observed in the results. The changes in the number of floors and number of flats on each floor had similar effects on the results of the programs. Regarding energy performance, better performances can be achieved as the number of flats and number of flats on each floor increase. Here, the most important issue is the “compactness ratio” of a building, showing the ratio of the thermal envelope (heat losing) area compared to the conditioned volume. As the number of floors and flats increase, this ratio decreases rapidly from one-story to three-story buildings, becoming moderate and changing more slowly after three stories. The three-story building example shows a breaking point in energy performance, implying that although they have the same thermal characteristics, one- or two-story buildings have lower energy performances than low-rise and mid-rise buildings. A similar conclusion can be drawn for larger types of buildings. Buildings with four flats on each floor have higher energy performances than those with one flat; hence the lower the compactness ratio of the building, that is, the more compact the design, the better performances can be achieved. As mentioned before, the energy performance of a building depends on four energy parameters, which are the energy requirements for heating, cooling, DHW and lighting. As the number of floors and the number of flats on each floor increase, the total energy need for heating and cooling decreases due to the lower compactness ratio, while no change occurs in DHW and lighting requirements, since they are defined according to per person and/or per unit, and the number of occupants and the size of a flat remain constant.

The second effect analyzed through generic case studies is the number of surfaces exposed to the ground, external temperatures and unconditioned spaces. The case studies revealed that each program has different calculation methods for different surfaces, like the ground floor and roof. It can be seen from the results that the programs use similar calculation methods for the façades and give very close results to each other, while the calculations for the exposed ground floor and roof differ between the programs. The results also revealed that the effects of an exposed ground floor and roof are distributed to each unit area, meaning that their effects decrease as the number of floors increase. Considering energy performance, as the number of exposed surfaces decreases, the heating requirements decrease significantly, dominating the cooling requirements, which increase slightly; and thus better performances can be achieved.

The third effect on the energy performance of buildings is natural ventilation and infiltration. The evaluation results showed that natural ventilation has a major effect on the energy performance of a building, while infiltration has only a minor effect. The activation of natural ventilation leads to high increases in heating requirements and low decreases in cooling requirements, while the inclusion of infiltration results in very low increases in heating demands and very low decreases in cooling demands. All of the programs show similar tendencies with both the inclusion and exclusion of natural ventilation and infiltration, while very low discrepancies between the results were observed with differences in net area and volume. Since natural ventilation and infiltration is determined based on the characteristics of the site and the conditioned volume, which were kept the same for all cases, no discrepancies in the results were observed as the number of floors in a building was changed.

The fourth and the most important effect on energy performance in a building is thermal conductivity, that is, the U-values of the opaque surfaces. Since energy requirements for heating and cooling are related directly to U-values, the higher the U-values of the building surfaces, the more energy a building needs. The evaluation results support this hypothesis. The effect of U-values was studied in three ways: with the addition of a layer of insulation to AAC surfaces; for different thicknesses of brick layers; and for three types of construction, being light, medium or heavy. The addition of an insulating material to AAC surfaces decreased the U-value significantly, and thus reduced heating demand while increasing cooling demand. The addition of another AAC layer had no effect on the U-value or energy demand. The use of a very thin (9 cm) brick layer with a very high U-value (2.89 W/m^2K) resulted in the most different results between the programs, recording the highest heating and cooling requirements. Since energy requirements have an inverse relation with material thickness, the use of thicker brick layers (18 cm and 50 cm) resulted in lower U-values, and consequently lower heating and cooling requirements. For the cases using the same U-values with different thicknesses of brick and insulation material, very close results for heating and cooling were recorded. This shows that the effect of U-values is more significant than material thickness and construction type on energy performance. The most diverse results were recorded for cases with high U-values, while they converged for lower U-values. It was also observed that changing the order of the materials made no difference to the U-values.

The fifth effect on building energy performance is the WWR and the window type. As WWR increases, heating loads decrease and cooling loads increase incrementally due to the high solar gains associated with windows. A 20% WWR is a breaking point in the rate of decrease in heating requirements, both for double- and triple-glazed windows depending on the U-values (and heat losses) of the windows. The higher the solar transmittance of a window, the higher the solar gains of the building. This results in lower heating loads and higher cooling loads; however, the solar transmittance of windows is more effective on the cooling requirements of a building, decreasing the heating requirement slightly, while increasing the cooling requirement very rapidly. As WWRs increase, higher discrepancies in the results of the four programs were recorded, which may be due to different solar radiation data and the different calculation methods for solar gains used by the programs.

The sixth effect is related to set-point temperatures for heating and cooling modes. Since energy requirements are related directly to set-point temperatures, the lower the set-point temperature is adjusted for the heating mode, the less heating is needed in a building. However, a lower set-point temperature affects cooling requirements adversely. When lower temperatures are set for the cooling mode, the temperature difference between the external and internal spaces increases, and thus, more cooling is required in a building. On the other hand, as set-point temperatures for the heating and cooling modes are increased, heating demands increase significantly, while conversely, little or no cooling is required due to the high cooling set-point temperature. As in the previous cases, EnAd, EnerCalc and HAP gave very close results each other, while DesignBuilder indicated a lower band for heating and higher results for cooling requirements, although the results of DesignBuilder converged with the others for higher set-point temperatures.

As the final step, the effect of different temperature differences between the outside and the inside spaces was examined in a controlled medium using fixed climatic conditions. Three fictitious cases were created in which the temperature difference between outside and inside were lower, equal and higher than the set-point temperatures for the heating and cooling modes. For very lower external temperatures, no cooling was needed, while the highest heating requirements were recorded. For equal temperature differences between the outside and inside spaces, no heating was needed, while some cooling of the building was required. Finally, for very high external temperatures and very low set-point temperatures, no heating was required, while cooling loads reached a peak. These fictitious cases can only be run by EnAd and EnerCalc due to difficulties in introducing weather data into DesignBuilder and HAP. Since they have very similar calculation methods, very close results were recorded by both EnAd and EnerCalc for the different temperature differences.

The four programs used produced similar results in almost all cases. The closest results were observed in EnAd and HAP, followed by EnerCalc, while DesignBuilder gave lower heating demands and higher cooling demands for many of the cases. Higher discrepancies in the results were observed for the one-story building cases due to the prevailing effect of an exposed ground floor and roof, while discrepancies in the results decreased as the number of floors were increased due to the distribution of the effect of exposed surfaces among each unit. The discrepancies in the results increased for fully transparent buildings, which can be attributed to the different methods of calculation used for solar gains and the solar radiation data used by the programs. The highest discrepancies in the results were recorded for the cases using very high U-values, while very low discrepancies were observed for the cases using low U-values. This may be due to the different energy models and heat transfer functions used in the calculations and simulations of the programs, as explained in Chapter 6. It should be reiterated here that the intention of the study is not to criticize the programs used, as they have already proved their reliability. The intention is rather to compare the results of established programs with those of the program developed within the scope of this thesis, and to show the convergences in the evaluations.

The evaluations of existing buildings and the comparisons of the results of EnAd with the actual consumption data reveal strong similarities, although differences in the results may be attributed to a number of different factors:

i. Use of different climatic data by the tools
ii. Variations in climatic conditions between years
iii. Model definition
    - Use of external dimensions, resulting in differences in net area and volume
    - Difficulty in the introduction of curvilinear forms
    - Introduction of the sum of the surfaces facing in one direction into the text-based tools, disregarding any shading on the surfaces due to the building form
    - Exclusion of balconies and their related shading and thermal bridges

iv. Assumptions
    - Site conditions
    - Properties of building envelope
    - Number of occupants
    - Airflow rates for natural ventilation and infiltration
    - DHW use
    - Supplied and used water temperatures
    - Set-point temperatures for heating and cooling modes
    - Type and number of lighting appliances
    - Schedules
    - Equipment features

v. Program defaults and limitations
    - Use of different types of input data

- Units of measurement
- Internal gains
- Solar gains
- Daily use patterns
- Thermal bridges
- Material properties
- Available building systems
- Efficiency values
- Conversion coefficients
- Schedules
- Calculation methods

vi. Real consumptions
- Method and/or period of data collection
- Operation of HVAC systems (i.e. schedule, experience of the users)
- Actual efficiency of HVAC systems
- Design and placement of HVAC systems in a building
- Regular inspection of the equipment
- System gains and losses
- Construction quality (affecting thermal bridges and air-tightness of the building envelope)
- Schedules (occupancy, electrical equipment, HVAC systems)
- Annual leave (especially during summer)
- Occupant behaviors

Even though the quantitative values and the calculation methods differ between the tools, since they all result in an assessment of energy performance, the final assessment grades may be very alike, as can be seen in the evaluation of both generic cases and existing buildings.

Usability tests and the simulation of an existing building showed that the energy performance of poorly insulated buildings may be improved (by following the feedback provided by EnAd) and higher performances may be achieved. This also indicates that the improvement of the building envelope of such buildings is of great importance. For well-insulated buildings, on the other hand, due to the impermeable nature of the building envelope, heat losses and heating requirements are reduced to a minimum, while internal gains and solar gains become more effective, and cooling requirements begin to play a determining role in the energy performance of the building. In this context, WWRs and the type of window used in such buildings are also crucial, since higher WWRs and windows with high solar transmittance require higher cooling due to the high solar gains involved.

This study has proved the validity, reliability, precision and usability of EnAd as a design-support tool. EnAd gives consistent and average results among the other three programs which are currently in use around the world. In this respect, it can be said that the program gives results in a reliability range. Schlueter and Thesseling (2009) assert that it is very important for a design-support tool to give tendencies for design decisions instead of giving very precise results in early design phases, which has also been accomplished by EnAd. Usability tests showed that energy performance evaluation of buildings can be performed easily and quickly, and it can be used recursively for the improvements of the design while being informed about the design limits and the related legislation on the subject.

7.4 Future Remarks

In this section, potential future works are summarized and some concluding remarks are presented. EnAd has been developed for the evaluation of residential and office buildings from the very beginning of the design process. In future, EnAd should be improved regarding its interface and its content as follows;

i. ***An improved interface***, allowing architects to either make their decisions verbally or based on simple sketches, i.e. 3D models.
ii. ***Data exchange between different evaluation tools***, which provides users with the opportunity to evaluate the design in different media in different phases of the design process, allowing them to compare results and decide upon further improvements.
iii. ***Evaluation of public buildings*** such as hospitals, schools and libraries.
iv. ***Evaluation of buildings with complex topologies***, featuring non-linear and curvilinear forms, for which it is difficult to make observations related to orientation.
v. ***Inclusion of passive systems in energy evaluation***, which are becoming more and more important.
vi. ***Calculation of hourly data*** in order to be used in detailed evaluations.

Factors such as location, orientation, number of occupants, schedules, shading, balconies and thermal bridges, which are explained in detail in the previous section, are all subjects of future works to evaluate their effects on the energy performance of buildings. Studying different cities in the different climate bands of Turkey may contribute to the development of a national design guide and a national database on the subject. Such a database would be beneficial both for the design of energy-efficient buildings in the future, and for the further development of related legislation. The database contained within the tool should be linked to, and become an integral part of, the national BIM software, allowing its use in design authorization matters in Turkey.

As a conclusion, this thesis has shown that BEP evaluation tools are essential for improving the energy performances of buildings. It is also necessary to point out that these tools should be integrated into the architectural design process from the very beginning in order to achieve higher performances. As the thesis illustrates, decision makers, from students to designers, and from architects to engineers, should be fully aware of the effects of their decisions on the energy performance of buildings. While legislation is the means by which international and national policies are put into practice, all legislation should be organized as a “guideline” to the architectural design process to assist the decision makers in their assigned tasks. Legislation aims to satisfy minimum targets; however they should also provide optimum values/criteria for the optimization of design. As the thesis shows, the existing buildings studied only satisfy the maximum limits of the legislation. Rather than being satisfied with achieving the minimum requirements, decision makers should be encouraged to aim for the best possible solution. In current applications, a consistent approach should be identified in the currently eclectic Turkish legislation. Foreign legislation should be adapted to fit in with the conditions in Turkey in terms of the formulation, assumptions and usage patterns; and there should be a declaration of ideas and a clear indication of the formulas to be implemented without causing any misunderstandings, as exemplified in Chapter 3.

It is imperative that the national databases be kept updated to ensure their continued accuracy in energy performance evaluations, and should be expanded to include solar radiation and daylighting data for the cardinal and intercardinal directions for each city. There is currently some confusion about the type of temperature data to be used in assessments, with mean temperatures, long-term mean temperatures and typical climatic year data all in contention. Accordingly, it is vital that a national consensus be reached on the subject. Furthermore, appropriate requirement, usage and consumption data related to the use profiles such as ventilation, lighting and DHW should be defined on a nation scale; which can lead to the alleviation of the problem of bias due to the different available databases, and thus to more reliable results, while still using the same databases. It should be noted that the more reliable data sources are used, the more reliable assessments and results can be achieved.

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APPENDIX A

THE LISTS OF RELATED LEGISLATIONS

EN and ISO standards used in energy performance assessments are listed in the following Tables A.1-A.5.

Table A.1 Umbrella documents regarding energy performance of buildings

Aspect	Related documents	Explanations
Energy performance of buildings	CEN/TR 15615	Explanation of the general relationship between various European standards and the Energy Performance of Buildings Directive (EPBD) – Umbrella document
	Directive 2002/91/EC	Definition of basic requirements for buildings
	ISO 16818	Terminology regarding energy efficiency
	ISO 23045	Guidelines to assess energy efficiency of new buildings
	EN 15315	Overall energy use, primary energy and CO_2 emissions
	EN 15203	Assessment of energy use and definition of ratings
	EN 15603	Overall energy use and definition of energy ratings
	EN 15429 TS EN 15459	Data requirements for standard economic evaluation procedures related to energy systems in buildings, including renewable energy sources
	TS EN 15217	Methods for expressing energy performance and for energy certification of buildings
	Law 5627	General principles on enhancement of energy efficiency
	EPB regulation	Calculation methods for energy use assessment Minimum energy performance requirements Feasibility of renewable source use
Energy efficiency	Directive 93/76/EEC	General principles to limit CO_2 emission by improving energy efficiency (SAVE)
	Directive 2006/32/EC	General principles on energy end-use efficiency
	Energy efficiency regulation	Definition of general principles regarding efficient use of energy sources and energy
	Heat insulation regulation	General principles in heat insulation project preparation
Environmental impact assessment	ÇED[37]	Definition of administrative and technical method and principles, including use of renewable sources

Table A.2 Legislations about regional characteristics & climatic conditions

Aspect/ Decision sub-aspect	Related documents	Explanations
Use of climate data to City - Region	TS EN ISO 15927-1	Calculation and presentation of climatic data for monthly means of single meteorological elements
	TS EN ISO 15927-4	assessing the annual energy use for heating and cooling
	TS EN ISO 15927-6	accumulated temperature differences (degree days)
Heating load - solar radiation	TS 825	Data for assessing annual energy demand for heating with four heating degree-day region
Cooling load	38	Data for assessing annual energy demand for cooling with four cooling degree-day region
Wind potential	Wind map published by ETKB[39]	Five different topographic region
Functional use of the building	TS 825	Determination of energy demand for HVAC
Dwelling type	TS 825	Determination of energy demand for HVAC and lighting conditions

[37] ÇED, the regulation on environmental impact assessment by the Ministry of Environment and Forest
[38] Since there is no standard or legislation, scientific studies were benefited for the determination of cooling degree-day regions of Turkey (Büyükalaca et al., 2000 and 2001, and Bulut et al., 2007).
[39] ETKB, The Ministry of Energy and Natural Resources

Table A.3 Legislations regarding sub-decisions

Aspect/ Decision sub-aspect	Related documents	Explanations
Orientation and neighborhood	TS 825	Data for assessing shading coefficient, and heat loss/ gaining
Building size	TS 825	Data for assessing conditioned area and volume
Window size	ISO 9050	Determination of light transmittance, solar direct transmittance, total solar energy transmittance, ultraviolet transmittance and related glazing factors
	TS EN ISO 14438	Calculation method regarding energy balance value for glass in buildings

Table A.4 Legislations about building design decisions

Aspect/ Decision sub-aspect	Related documents	Explanations
Building skin	Directive 89/106/EC	Requirements for Construction Products
	Directive 92/59/EEC	General product safety
	EN ISO 10456	Building material and products - hygrothermal properties - tabulated design thermal values and procedures for determining declared and design values
	EN ISO 13786	Calculation method for thermal performance of building components - Dynamic thermal characteristics
	TS EN ISO 13788	Calculation method of hygrothermal performance of building components and building elements
	EN ISO 13789	Calculation method of transmission and ventilation heat transfer coefficients
	EN ISO 13790	Calculation of energy use for space heating and cooling
	EN 13947	Thermal performance of curtain walling – Calculation of thermal transmittance
Thermal performance	ISO 7345	Physical quantities and definitions
	ISO 7726	Instruments for measuring physical quantities
	ISO 9869	Building elements - in-situ measurements of thermal resistance and thermal transmittance
	EN ISO 10077-1 EN ISO 10077-2	Calculation of thermal transmittance and performance of windows, doors and shutters — General — Numerical method for frames
	EN ISO 10211	Detailed calculations for thermal bridges, heat flows and surface temperatures
	EN ISO 13370	Calculation methods of heat transfer via the ground
	EN ISO 13791 EN ISO 13792	Calculation of internal temperatures of a room in summer without mechanical cooling — General criteria and validation procedures — Simplified methods
Thermal performance	EN ISO 14683	Simplified methods and default values for linear transmittance
	TS EN ISO 6946	Calculation method of thermal resistance and thermal transmittance
	TS EN 832	Calculation of energy demand of residential buildings for heating
	TS EN 13829	Determination of air permeability of buildings
Fenestration	ISO 15099	Detailed calculations regarding thermal performance of windows, doors and shading devices
	TS EN 12207	Classification of air permeability of windows and doors
Energy control system	TS EN 15232	Impact of building automation, controls and building management

Table A.5 Legislations about energy consuming and producing systems

Aspect/ Decision	Related documents	Explanations
Heating system	Directive 76/492/EEC	Rational use of energy
	EN ISO 13790	Calculation of energy use for space heating and cooling
	EN 12828	Design for water-based heating systems
	EN 12831	Method for calculation of the design heat load
	EN 14336	Installation and commissioning of the water based heating systems
	EN 15316-1 EN 15316-2-1 EN 15316-2-3	Method for calculation of system energy requirements and system efficiencies — General — Space heating emission systems — Space heating distribution systems
	EN 15316-4-1 EN 15316-4-2 EN 15316-4-5 EN 15316-4-6 EN 15316-4-7 EN 15377-1 EN 15377-2 EN 15377-3	Method for calculation of system energy requirements and system efficiencies - Space heating generation systems; — combustion systems — heat pump systems — the performance and quality of district heating and large volume systems — photovoltaic systems — biomass combustion systems — determination of the design heating and cooling capacity — design, dimensioning and installation — design of embedded water based surface heating and cooling systems
	EN 15378	Inspection of boilers and heating systems
	TS EN 832	Calculation of energy use for heating of residential buildings
	TS 2164 TS 2192	Installation requirements for heating plant
Domestic hot water supply	Directive 92/42/EEC	Efficiency requirements for new hot-water boilers
	TS ISO 9459-1 TS ISO 9459-2 TS ISO 9459-3	Solar water heating systems for residential buildings
	EN 15316-3-1 EN 15316-3-2 EN 15316-3-3 EN 15316-4-3 EN 15316-4-4	Method for calculation of system energy requirements and system efficiencies; — Domestic hot water systems — Domestic hot water systems, distribution — Domestic hot water systems, generation — Heat generation systems, thermal solar systems — Heat generation systems, building-integrated cogeneration systems
	TS 615 EN 26	Gas-fired instantaneous water heaters for sanitary uses production
	TS EN 89	Gas-fired storage water heaters
	TS EN 12975-1	Solar collectors, general rules
	TS 3817	General requirements for solar water heaters
Ventilation	EN 12792	Symbols, terminology and graphical symbols
	EN 15239	Guidelines for inspection of ventilation systems
	EN 15242	Calculation methods for the determination of air flow rates in buildings including infiltration
	EN 12792	Symbols, terminology and graphical symbols
	EN 15243	Calculation of room temperatures and of load and energy for buildings with room conditioning systems
Cooling	EN ISO 13790	Calculation of energy use for space heating and cooling
	TS EN 378-1 TS EN 378-2 TS EN 378-3 TS EN 378-4	Cooling systems and heat pumps — Basic rules — Design and installation — Installation — Maintenance
	TS 3419 TS 3420	Installation requirements of ventilation and acclimatization plants
	TS 5895	Central air-conditioner and ventilation
IAQ	TS CR 1752	Design criteria for the indoor environment
	EN 15251	Indoor environmental input parameters for design and assessment of energy performance of buildings addressing indoor air quality, thermal environment, lighting and acoustics

Table A.5 Legislations about energy consuming and producing systems (continued)

Aspect/ Decision sub-aspect	Related documents	Explanations
Lighting & appliances	Directive 2000/55/EC	Energy efficiency requirements for ballasts for fluorescent lighting
	Directive 2006/95/EC	Regarding electrical equipment
	ISO 9050	Determination of light transmittance and related glazing factors
	TS EN 15193	Energy requirements for lighting
	TS EN 15251	Indoor environmental input parameters for design and assessment of energy performance of buildings addressing indoor air quality, thermal environment, lighting and acoustics
	Appliance regulation	Energy efficiency of ballasts for fluorescent lighting
Cooking	TS 616-2-1 EN 30-2-1 TS 616-2-2 EN 30-2-2	Rational use of energy for domestic cooking appliances burning gas — General — Appliances having forced-convection ovens and/or grills
Circulation	TS ISO 4190-6	Planning and selection of passenger lifts to be installed in residential buildings
Renewable energy	Directive 2009/…/EC	Promotion of the use of energy from renewable sources (amending 2001/77/EC, 2003/30/EC)
	EN 15429 EN 15459	Data requirements for standard economic evaluation procedures related to energy systems in buildings, including renewable energy sources
Aspect/ Decision sub-aspect	Related documents	Explanations
Energy producing systems		
Solar energy	ISO 9488	Solar energy — Vocabulary
	ISO 9050	Determination of light transmittance, solar direct transmittance, total solar energy transmittance, ultraviolet transmittance and related glazing factors
	ISO 9060	Specification and classification of instruments for measuring hemispherical solar and direct solar radiation
	EN 15316-4-6	Photovoltaic systems - Method for calculation of system energy requirements and system efficiencies of space heating generation systems
	TS EN 12975-1	Solar collectors, general rules
Wind energy	ISO 81400-4	Wind turbines - Design and specification of gearboxes

CURRICULUM VITAE

PERSONAL INFORMATION

Surname, Name : Çakıcı, Fatma Zehra
Nationality : Turkish (TC)
Date & Place of Birth : 30 March 1981, Çorum
Marital Status : Married
Phone : +90 312 210 62 17
Fax : +90 312 210 79 66
Email : fzcakici@yahoo.com.tr

EDUCATION

Degree	Institution	Year of Graduation
MS	METU Architecture Department, Ankara	2005
B. Arch	Selçuk University Architecture Department, Konya	2002
High School	Atatürk High School, Konya	1998

WORK EXPERIENCE

Year	Place	Enrollment
2002 - Present	METU Department of Architecture, Ankara	Research Assistant
2002 Summer	Delfi Group, Konya	Architect
2001 Summer	Delta Group, Konya	Intern Architect
2000 Summer	Mustaş Group, Konya	Intern Architect

FOREIGN LANGUAGES

Advanced English

PUBLICATIONS

Journal Papers

Zelef, M.H., Bursa, N., **Çakıcı, F.Z.**, "Mimarlık Eğitiminde Temsil Yöntemleri Üzerine Bir Deneme: Evler", *Mimaran*, vol. 7, p. 100-108, Board of Chamber of Architects Konya Branch, Spring 2011.

Conference Papers presented and published in Refereed International Conferences

Çakıcı, F.Z., Dikmen, N., "Building Disassembly Practices in Turkey", *5th International Postgraduate Research Conference on Built and Human Environment*, the University of Salford, Blackwell publishing, U.K., April 14-15, 2005, vol. I, p. 267-278.

Er Akan, A., Çakıcı, F.Z., "The Influence of Climate in the Formation of Traditional Turkish Houses", *5th International Postgraduate Research Conference on Built and Human Environment*, the University of Salford, Blackwell publishing, U.K., April 14-15, 2005, vol. I, p. 338-347.

Çakıcı, F.Z., Er Akan, A., "Osmanlı Cami Mimarisinin Balkan Ülkelerindeki Yansımaları", *6th International Turkish Culture Congress*, Ankara, November 21-26, 2005; Atatürk Kültür Merkezi Publishing, Ankara, 2009, vol. I, p. 187-202.

Er Akan, A., Çakıcı, F.Z., "Klasik Osmanlı Mimarisinde Minarelerin Cami Mimarisine Etkileri: Sinan Minarelerinin Şehir Siluetindeki Yeri", *6th International Turkish Culture Congress*, Ankara, November 21-26, 2005; Atatürk Kültür Merkezi Publishing, Ankara, 2009, vol. I, p. 47-52.

Er Akan, A., Selçuk, S.A., Çakıcı, F.Z., "Antalya'daki Kırkgöz Han'ın Sonlu Elemanlar Yöntemi ile Deprem Analizi", *7th International Congress on Advances in Civil Engineering (ACE 2006)*, İstanbul, October 11-13, 2006, p. 246.

Çakıcı, F.Z., Sorguç, A.G., "Not Restrictive, Target Directives", *International Ecological Architecture and Planning Symposium 2009*, October 22-25, Antalya, vol. I, p. 144-150 (Turkish); vol. II, p. 137-143 (English).

Sorguç, A.G., Çakıcı, F.Z., "New Level of Precision in Architecture", *the 2nd International Symposium on Computing in Science & Engineering (ISCSE 2011)*, Gediz University the Faculty of Engineering and Architecture, Kuşadası, Aydın, June 1-4, 2011, p. 1036-1041.

Sorguç, A.G., Selçuk, S.A., Çakıcı, F.Z., "Computer Simulation as an Integral Part of Digital Design Education in Architecture", *Education and Research in Computer Aided Architectural Design in Europe (eCAADe 2011)*, University of Ljubljana, Faculty of Architecture, Ljubljana, Slovenia, September 21-24, 2011, p. 43-50.

Refereed National Conference Papers

Er Akan, A., Selçuk, S.A., Çakıcı, F.Z., "Kültür Turizmi Açısından Kırkgöz Han'ın Yeniden İşlevlendirilmesi Olanakları Üzerine Bir Çalışma", *Antalya Tourism and Architecture Symposium, Social, Cultural and Physical Developments in Tourism: Problems and Suggestions,* Antalya, April 28-29, 2006, p. 132-137.

Zelef, M.H., Bursa, N., Çakıcı, F.Z., "Düşüncenin İzi: Mimarlık ve Sanat Eğitiminde Eskiz Geleneği", *1. Sanat ve Tasarım Eğitimi Sempozyumu Dün, Bugün, Gelecek",* Başkent Üniversitesi Güzel Sanatlar Tasarım ve Mimarlık Fakültesi, Ankara, April 27-29, 2011, p. 533-538.

Posters

Presented and Published at Refereed International Conferences

Çakıcı, F.Z., Özkan, S.T.E., "Recovery and Reuse of Building Materials in Turkey", *XXII. World Architecture Congress (UIA 2005)*, İstanbul, July 4-7, 2005.

Çakıcı, F.Z., "Problems in Recovery of Used Building Materials", *1st International CIB Endorsed METU Postgraduate Conference, Built Environment & Information Technologies,* MF Publishing, Ankara, March 17-18, 2006, p. 765-766.

Memberships

CIB METU Student Chapter, "the International Council for Innovation and Research in Building and Construction (CIB) Endorsed Students Chapters at METU", charter member, 2005 - ...

DoCoMoMo, "International Working Party for Documentation and Conservation of Building Sites and Neighborhoods of the Modern Movement", member, 2006 -…

Other Activities

International Conference Organization

1st International CIB Endorsed METU Postgraduate Conference, Built Environment & Information Technologies, Ankara, March 17-18, 2006.

IX. International DoCoMoMo Conference on Other Modernisms, by İstanbul Technical University, Middle East Technical University, Yıldız Technical University, İstanbul-Ankara, Turkey, September 25-29, 2006.

Co-Editor

METU Faculty of Architecture Department of Architecture, ARCH 190 Summer Practice in Surveying 2009-2010 (ODTÜ Mimarlık Fakültesi Mimarlık Bölümü, ARCH 190 Mimari Belgeleme Yaz Stajı 2009-2010) Kastamonu, İnebolu, ODTÜ Mimarlık Fakültesi Basım İşliği, Ankara, March 2011.

Exhibitions

"7. Ankara'da Kastamonu Günleri", Başkent Atatürk Kültür Merkezi, Ankara, March 16-20, 2011.

Workshop Advisor

23rd International Building and Life Congress, Plan B Workshop, Uludağ University Department of Architecture and Board of Chamber of Architects Bursa Branch, Bursa, March 24-26, 2011.