ENERGY PERFORMANCE OF SMART BUILDINGS: SIMULATING THE IMPACT OF ACTIVE SYSTEMS AND PASSIVE STRATEGIES

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ABSTRACT

ENERGY PERFORMANCE OF SMART BUILDINGS: SIMULATING THE IMPACT OF ACTIVE SYSTEMS AND PASSIVE STRATEGIES

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Energy efficiency is one of the most important attempts in the world because of various environmental, economical and developmental aspects of energy. In this context, energy performance of buildings has been a critical issue since buildings constitute approximately half of total energy consumption. The concept of smart building which has been attractive recently, contributes to the issue with smart technologies; while some passive design techniques which have been used throughout the history are still applicable for energy saving.

The study aims to evaluate not only comparative impact of technological devices and traditional methods, but also energy saving potential of them for locations where heating load is dominant. While researching impacts of various active or passive building components to energy efficiency, the study not only focused on heating load reduction but also lighting electricity saving by use of daylight.

Selected various active systems and passive strategies is tested on a base-case module, which is a flat in an existing residential tower in Ankara, by the help of computer based energy simulations. Systems and strategies are selected in the light of literature by considering wide availability in market. During the process, three series of simulation variations including forty-two different scenarios are tested. Only active systems is tested in the first series and only passive strategies in the second. Finally, impact of using both active systems and passive strategies together is tested in the third series.

Keywords: Energy performance in buildings, thermal simulation, active systems, passive design strategies, smart / intelligent buildings.

ÖZ

AKILLI BİNALARDA ENERJİ PERFORMANSI: AKTİF SİSTEMLERİN VE PASİF TASARIM İLKELERİNİN KARŞILAŞTIRMALI ETKİSİ

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Enerji verimliliği, enerjinin çeşitli çevresel, ekonomik ve hatta politik boyutlarından ötürü dünya ölçeğinde en önemli konulardan biri haline gelmiştir. Bu bağlamda, dünyadaki toplam enerji tüketiminin yaklaşık yarısını binaların teşkil ettiği göz önünde bulundurulduğunda binaların enerji performansı enerji verimliliği için kritik bir rol üstlenmektedir. Son yıllarda ilgi çekici olan akıllı binalar, akıllı teknolojiler ile konuya katkı sağlamayı amaçlarken tarih boyu süre gelmiş çeşitli pasif tasarım yöntemleri sundukları enerji tasarruf potansiyelleri ile günümüzde de geçerliliğini sürdürmektedir.

Bu çalışmanın amacı sadece çeşitli teknolojilerin ve geleneksel yöntemlerin enerji verimliliğine katkısını karşılaştırmak değil, aynı zamanda ısıtma yükü baskın olan bölgelerde bu aktif sistem ve pasif yöntemlerin enerji tasarruf potansiyelini araştırmaktır. Çalışma ısıtma yükünün azaltılmasına odaklanmakla kalmayıp aydınlatmada kullanılan elektrik enerjisi üzerinde kullanılan sistemlerin etkisini de gözlemlemektedir.

Ankara'da mevcut bir konut bloğunda bulanan bir daire temel durum olarak incelendi ve seçilen çeşitli aktif sistemler ile pasif yöntemler bu temel durum modeli üzerinde bilgisayar tabanlı enerji simülasyonları yardımıyla test edildi. Literatür çalışması ışığında seçilen sistemlerin ve yöntemlerin piyasada yaygın ulaşılabilirlikleri göz önünde bulunduruldu. Toplamda kırk iki farklı senaryo içeren üç simülasyon serisi süreç boyunca test edildi. İlk seride sadece aktif sistemler test edilirken, ikincide sadece pasif yöntemler ele alındı. Son olarak üçüncü seride aktif sistemlerin ve pasif yöntemlerin birlikte kullanımının enerji tasarrufuna etkileri test edildi.

Anahtar kelimeler: Binaların enerji performansı, enerji simülasyonu, aktif sistemler, pasif tasarım yöntemleri, akıllı binalar.

To my family

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SYMBOL	DEFINITION
AHUs	Air-handling units
ATUs	Air thermal units
BAS	Building Automation System
BMS	Building Management System
CAD	Computer Aided Design
CAM	Computer Aided Manufacturing
CCMS	Central Control and Monitoring System
CCTV	Closed Circuit Television
DHW	Domestic hot water
DOE	United States Department of Energy
DIB	Dynamical intelligent building
EC	European Commission
EMCS	Energy Management and Control System
EMO	The Chamber of Electrical Engineer in Turkey
EMS	Energy Management System
EPW	Energy Plus Weather
ETKB	Republic of Turkey Ministry of Energy and Natural Resources
EU	European Union
FMS	Facilities Management System

SYMBOL	DEFINITION
GHG	Green house gases
GMT	Greenwich Mean Time
HVAC	Heating Ventilation and Air Conditioning
IB	Intelligent building
IBE	Intelligent Building in Europe
IBD	Integrated building design
IBI	Intelligent Building Institute
IBSs	Intelligent building systems
IEA	International Energy Agency
IP	Internet Protocol
IT	Information Technology
IWEC	International Weather for Energy Calculations
JIBI	The Japanese Intelligent Building Institute
KP	Kyoto Protocol
LAN	Local Area Network
LEDs	Light-emitting diodes
OECD	Organization for Economic Co-operation and Development
PIR	Passive Infrared Detector
PV	Photovoltaic
SB	Smart building
SN	Simulation number
TS 825	Turkish Building Regulations for Thermal Insulation
UN	United Nations

SYMBOL	**DEFINITION**
UNDP	United Nations Development Program
UTBS	United Technology Building Systems Corporation
VAV	Variable air volume
WECT	World Energy Council Turkish Member Committee

CHAPTER 1

INTRODUCTION

This study concerns smart buildings in terms of energy performance by focusing on effect of passive strategies and active systems. In this chapter, the argument, objectives of the study and a short summary of procedure are presented. The chapter concludes with a disposition of following chapters.

1.1 Argument

Energy efficiency phenomena which is one of the most important issues, has become a necessity rather than an alternative as a result of economical, developmental and environmental issues facing the World. Energy performance of buildings is critical since buildings constitute approximately half of total energy consumption in the world (Wigginton & Harris, 2002).

On the other hand, the concept of smart building (SB) which is also known as intelligent building (IB), has been attractive over last few decades, since people have become familiar with them while various smart buildings and technologies have been introduced (Wang, 2010). Smart buildings involve advanced solutions for not only communication networks, facilities management, security and safety but also energy performance of building. Also, the smart building concept is claimed to be adaptable to human needs and environmental changes as well as being cost effective and energy efficient by employing various complicated adaptive and responsive intelligent technologies.

While intelligent active systems recently have become popular with changes and developments in technology, passive design strategies have been used in buildings throughout the history. Wang (2010) discusses what makes a building smart in reality. The author mentions that buildings which can be accepted as smart may not imperatively have technological systems, since buildings which were constructed long time ago provided quite smart properties. Also; the author agrees with the impossibility of being smart without having technology in the context of modern building environment, while being highly equipped with technology is not an assurance to achieve a smart building.

Active systems are the mechanical elements and intelligent technologies that perform self-adjustment according to internal and external environments to achieve comfort conditions by using minimum energy. Passive strategies which are applied during early design process to satisfy comfort conditions according to climatic and contextual necessities are design strategies without mechanical devices. Both type of building components have an effect on energy performance.

It is obvious that smart buildings, which are a combination of complex architectural and engineering solutions, require an interdisciplinary team work and design approach to find the right combination. Integrated building design (IBD) which is a nontraditional collaborative approach has been encouraged by United States Department of Energy (DOE) and United Nations Development Program (UNDP). Whole-building approach, which is the key of IBD, considers a facility as an interdependent system rather than as separate components (DOE, 2011).

In addition, Sinapoli (2010) claims the existence of active smart systems in a green building will have positive effects on energy performance. Also according to Wang (2010), active and passive possibilities should be handled together while integrating intelligent technologies with an intelligent build form.

On the other hand, there is a misunderstanding that mechanical and intelligent technological abilities liberate the architect from working on sustainability and energy performance issues since active systems integrated into the building at the end can provide energy efficiency by default. A survey done by Moghaddam (2012) points out that professionals in Turkey tend to evaluate SB concept with level of integration and integrated technologies, although SB concept covers energy efficiency issue and requires whole-building approach. In addition, various firms in current market structure assert energy saving up to 40% by just using integrated technologies at the end but there is no evidence and it is not clear in which case those integrated systems bring maximum performance if they really achieve such a success.

As an inference, it is important to understand the relation not only between energy performance and its indicators but also between interdependent systems to guide design decisions appropriately. There is still lack of knowledge and studies in this field. To find out and compare impact of active systems and passive strategies, it is necessary in order to generate right combinations for energy performance of smart buildings.

The problem discussed in this study is: how much early architectural design decisions (passive strategies) effective on performance of a building; can integrated intelligent technological devices (active systems) be sufficient by oneself; or is it better to make an optimum combination of active systems and passive design strategies throughout the project (hybrid).

1.2 Aim and objectives

The study aims to find out clues for appropriate use of SB components by focusing on relation between passive design strategies which are decided in the early design stages and active systems which can be integrated later. In order to achieve this aim, followings are the objectives of the study:

- Determine active components for energy efficiency in smart buildings;
- Determine passive strategies;
- Evaluate active systems, passive strategies and their hybrid usage in smart buildings to determine their influence on building performance for locations where heating load is dominant.

1.3 Procedure

The study, firstly, contains a literature survey to find out active and passive components for energy performance of buildings. Survey contains background information, definitions of SB concept, active features and passive strategies for energy performance, conducted studies on this subject. Secondly, base-case module is designed to evaluate energy performance according to Ankara weather condition and regulations. Active, passive systems and hybrid usage of them are simulated with computer software. At the last stage, simulation results of different alternatives and scenarios are compared among each other in terms of energy performance.

1.4 Disposition

The report is composed of five chapters.

First chapter introduces the subject of study including its argument, aim and objectives with procedure of study and disposition of the report.

Second chapter includes literature survey and presents historical background of SB, definitions of SB concept, active features and passive strategies for energy performance, similar or related previous studies on this subject.

Third chapter presents the method of the study.

Forth chapter evaluates results of simulations and includes discussions.

Fifth, the final, chapter presents the conclusion derived from literature and result evaluation.

CHAPTER 2

LITERATURE SURVEY

In this Chapter, a survey of literature regarding the subject of the study is presented. It contains relevant information about (1) energy performance in architecture, (2) smart buildings, (3) appropriate use of intelligent technologies in smart buildings, (4) active systems for energy performance of smart buildings, and (5) passive design strategies in cold climates. Moreover, a critical review of literature is given at the end of this chapter.

2.1 Energy performance in architecture

Historically, awareness about the relation in between buildings and environment dates back to the writings of Vitruvius. Also, there have been buildings which were designed and constructed with an environmental consciousness throughout history.

Awareness about energy performance in architecture in this century mainly depends on two overlapping issues which are related with environmental, economical and developmental aspects: global warming and oil crises.

It can be said that industrialization led to a memory loss and environmental cognition was ignored. As a result of environmental damage resulting from rapid urbanization and industrialization in the late nineteenth century, ecological impact of buildings became a more widely debated issue during 1960s and 1970s, which is also marked as beginning of ecological design as we know it today (Wigginton & Harris, 2010).

The authors also agree that debates on global warming forced to use renewable energy sources as an alternative instead of fossil fuels and encouraged efficient use of energy in order to decrease energy consumption and greenhouse gases emission in the world.

United Nations (UN) has taken the lead to cope with climate change. There are 192 parties including European Union (EU) and all UN members except Andorra, Canada, South Sudan and United States in Kyoto Protocol (KP) which is an international treaty aimed to set binding obligations on industrialized countries to reduce green house gases (GHG) emissions. For example; European Union (EU) has a target, called the 20-20-20 target, for a 20% reduction in GHG emission from 1990 levels, a 20% improvement in energy efficiency and raising the share of renewable sources in energy consumption up to 20% until 2020.

On the other hand, interest in energy efficiency issues emerged and rapidly increased after the oil crises. This crisis, in the 1970s, contributed to raising concerns about the future of fossil fuels for energy but in terms of price and security of supply rather than an ecological manner (Wigginton & Harris, 2010). Energy efficiency issue became one of most important attempts for this century as a result of increasing energy demand and limited energy resources.

A counter argument by Weisman (2007) reminds many examples from all over the world to claim that people are fighting with nature rather than living in or with it. The author mentions the effort given to protect New York City subway stations from underground water and if the effort is given up, subway will be out of order in half an hour. Also, the author mentions High-Line Park which was formerly part of the New York Central Railroad tracks is now designed as a park because this elevated track started to be covered by vegetation naturally after the trains stopped running there in 1980, and people started to use it as a park much before it was formally designed and converted into a public park. Similarly, the author gives many examples to mention the power which is able to retrieve abandoned places by nature. In the light of examples from all over the world, Weisman (2007) states that when people will disappear, the world will recover naturally in time its original state. According to the author, during the process manmade structures will collapse because of their materials and greenery will cover abandoned zones, problems in system such as air pollution, water and earth pollution will be cured and so on. As a result, there is no need to be worry about the world, as the author points out, all the efforts being expended for sustainability are actually focused at sustaining the current artificial world order. In other words, people are trying to cope with problems that the world is faced with in order to survive.

Even the problem is related with oil crisis or global warming and susceptibility to save the world or surviving; it is the fact that there is a problem and it is crucial for not only nature and humanity but also politics and economy as long as the world survive.

In this worldwide quest for equilibrium in the environmental and economical aspects of energy, Turkey acceded to the KP, but has made no emission reduction commitment. Although Turkey has the lowest per capita GHG emissions in Europe, emissions in Turkey almost doubled in between 1990 and 2007 as a result of economic and demographic development (EEA, 2011).

In addition, a report published by World Energy Council Turkish Member Committee (WECT) in 2012 points out that energy import which costs 54 billion dollars constitutes 23% in total import of Turkey in 2011. Also energy demand of Turkey increases approximately 5% every year (ETKB, 2013). Dependence on foreign sources causes economic and political difficulties while 73% of energy consumption in Turkey is supplied through imports (WECT, 2012).

Energy efficiency in architecture is critical since buildings consume approximately 40% of total energy in the world (UNEP, 2009). It is similar in Turkey with 35.4% of total energy consumption by buildings (ETKB, 2013). Figure 2.1 shows shares in total energy consumption for 2012 in Turkey according to data from Republic of Turkey Ministry of Energy and Natural Resources (ETKB). Also a continuous increase in energy consumption of buildings is expected (IEA, 2008).

While buildings' energy consumption constitutes 38% of total global energy consumption with 2,900 Mtoe, buildings' total direct and indirect CO_2 emissions were 8.8 Gt i.e. 33% of the total CO_2 emissions in 2005 (IEA, 2008).

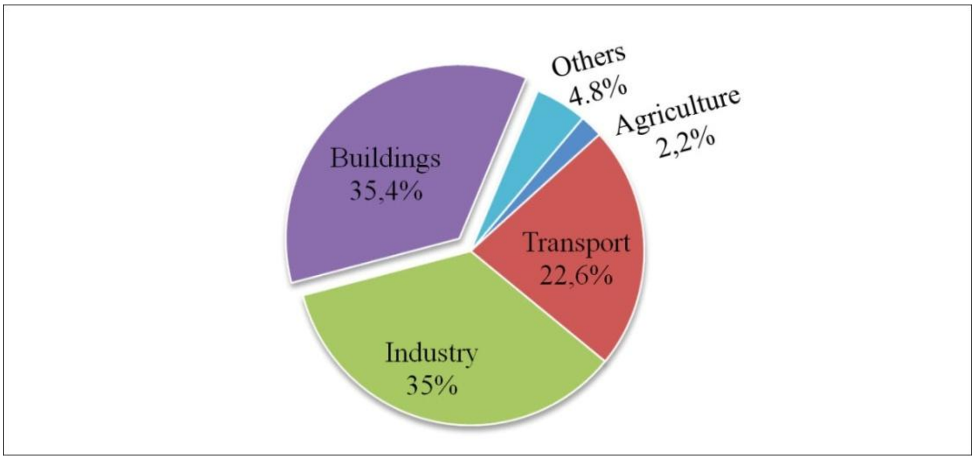

Figure 2.1: Energy consumption in Turkey, by sectors (data by ETKB, 2013 – chart by author)

As can be seen Figure 2.2, it is expected that CO_2 emissions will be more than twice while energy demand will be approximately twice in building sector until 2050 according to different perspectives and studies by the International Energy Agency (IEA) (2008).

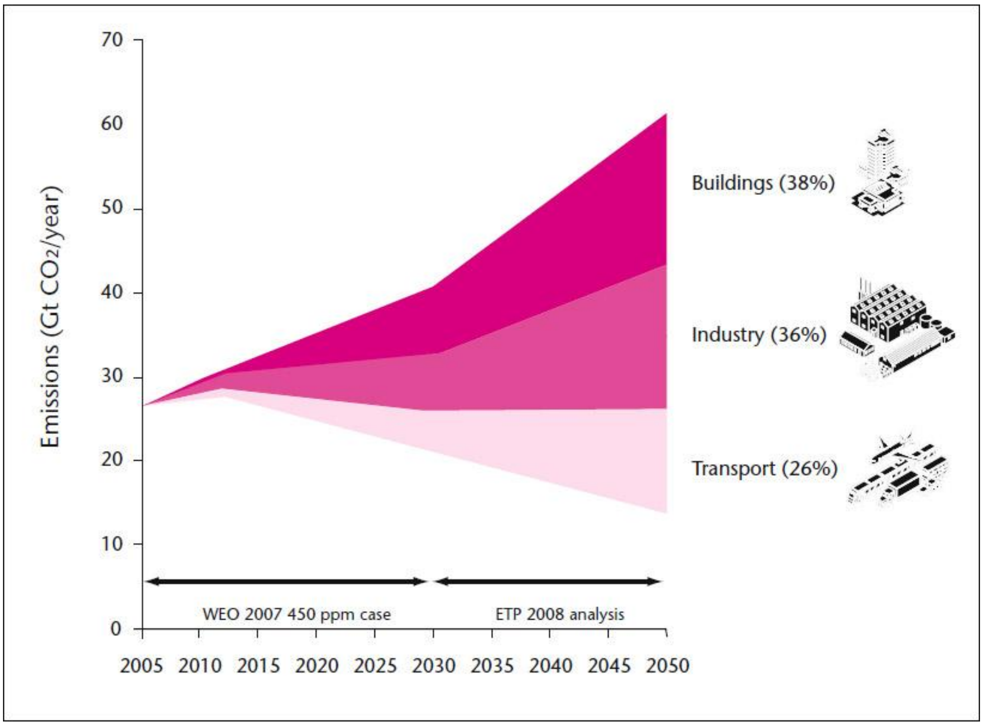

Figure 2.2: expected increase in CO_2 emissions from 2005 to 2050 (WBCSD, 2009)

The report published by IEA in 2008 states that 62% of total direct and indirect emissions in building sector depends on electricity and heat consumption, while coal, oil and natural gas makes 38% in 2005. Also the report mentions that energy consumption in residential sector is more than three times as high as in commercial sector in the world, while difference is less remarkable in OECD countries with the commercial buildings consuming 459Mtoe (39%) and the residential buildings 721 Mtoe (61%).

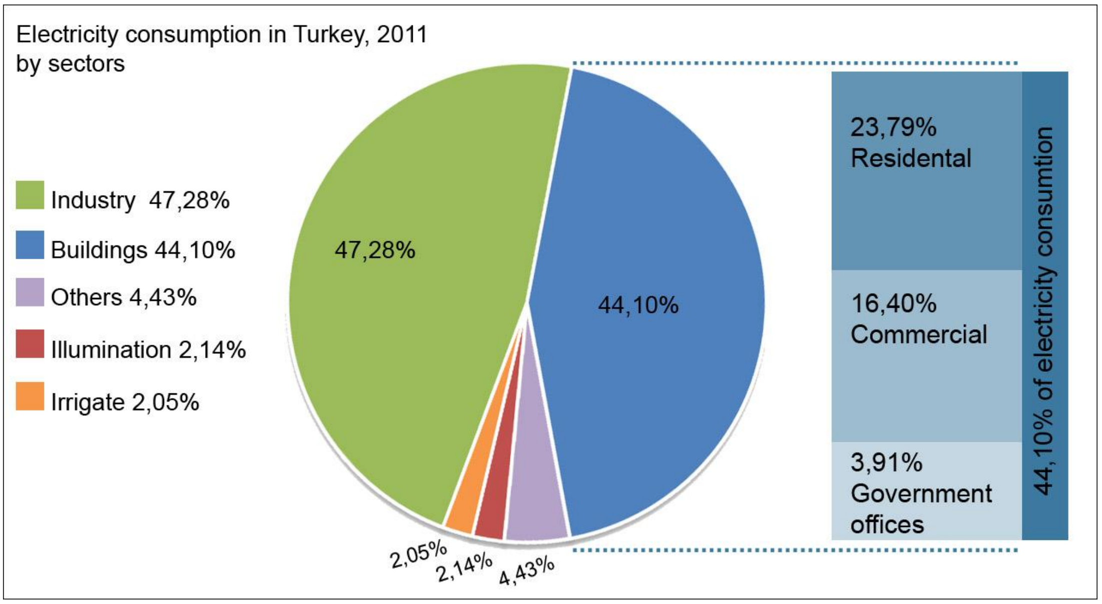

Figure 2.3: Electricity consumption in Turkey (TUIK, 2012).

Buildings sector has 44.10% share on total electricity consumption in Turkey where residential sector has 23.79%, commercial sector has 16.40% and government offices has 3.91% share on total electricity consumption in 2011 as seen in Figure 2.3 (TUIK, 2012).

The highest cost-effective savings potential is available in the residential and commercial buildings sector, partly as a result of its large share of total energy consumption (EC, 2007). As seen in Figure 2.4, estimated energy saving potential for 2020 is around 91 Mtoe for residential and 63 Mtoe for commercial buildings in EU according to European Commission (EC) report published in 2007.

A report published by DOE (2008) states that space heating is the most important consumption indicator in residential buildings with responsibility for 30.7% of total energy consumption while lighting is the most important in commercials. Space heating, space cooling and water heating constitute more than half in residential sector while lighting, space heating and space cooling constitute more than half in commercial sector as seen in Figure 2.5.

Sector	Energy consumption 2005 (Mtoe)	Energy consumption 2020 (Mtoe)	Energy saving potential 2020 (Mtoe)	Energy saving potential 2020 (%)
Households (residential)	280	338	91	27
Commercial buildings	157	211	63	30
Transport	332	405	105	26
Manufacturing industry	297	382	95	25

Figure 2.4: Energy saving potentials by sector (EC, 2007).

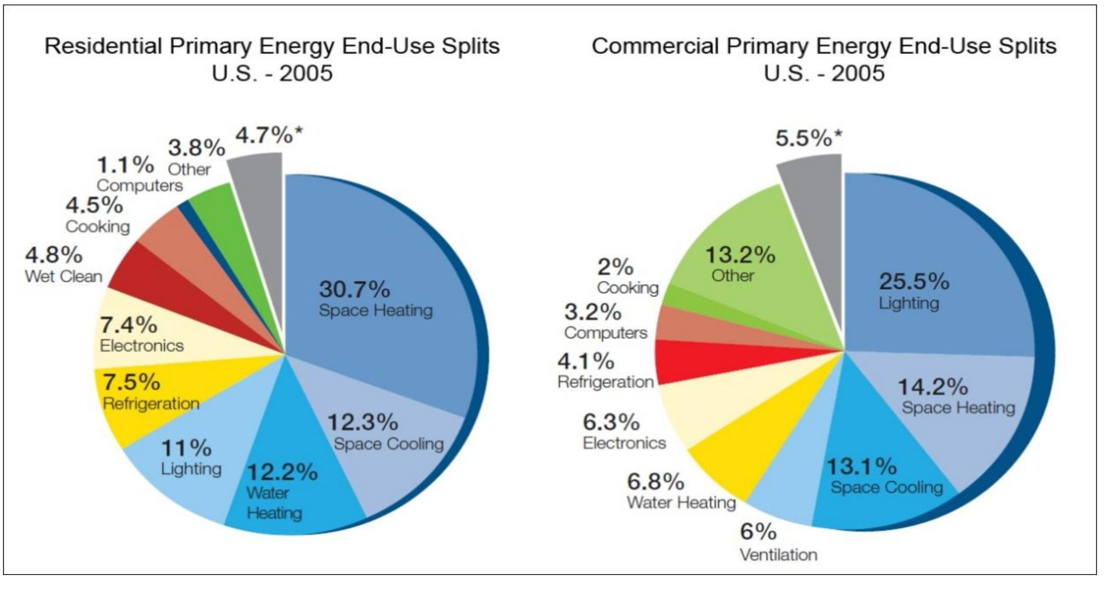

Figure 2.5: Energy consumption by use (DOE, 2008).

In order to describe the efforts needed to reduce CO_2 emissions and energy consumption, IEA developed some scenarios which explore different technological pathways to reduce emissions and energy consumption in comparison with baseline scenario which forecast the business-as-usual situation in absence of policy change. There are two main groups of scenarios; first one is the ACT map scenario which returns CO_2 emissions to 2005 levels by 2050 with the help of technological developments and second one is the BLUE map scenario which is more ambitious in order to return emissions at 50% of 2005 levels by 2050 with the need of higher investment costs and greater developments in technology and policy.

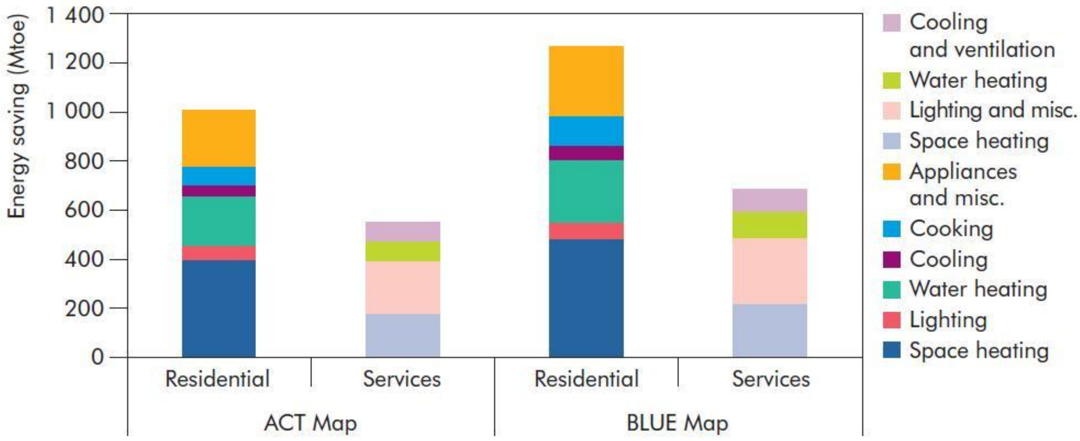

Figure 2.6: Energy saving potentials in different scenarios by use (IEA, 2008).

The biggest energy saving potential for residential sector lies in space heating, water heating and appliances (IEA, 2008). However, space heating and lighting provide the highest energy saving opportunity for commercial sector (IEA, 2008). Also, Figure 2.6 shows that residential buildings have more energy saving potential than commercial buildings as parallel to Figure 2.4

2.2 Smart buildings

The world is facing some challenges and opportunities as a result of changes in society and technology (Clements-Croome, 2004). While changes in technology and society are shaping our future, the important point is new buildings should be appropriate to respond for all issues which come with changes (Clements-Croome, 2004).

It is obvious that energy issue, basically arising from industrialization, has vital role on economy, development and environment. On the other hand, intelligent technologies and buildings give an opportunity to the person and society not only for efficient use of energy but also for shifting from being consumer to producer. Challenge on energy may turn to an opportunity for better life and better world with this perspective.

2.2.1 Definition of smart buildings

In order to cope with a potential conflict, Wigginton & Harris (2002) mention the term ‘intelligent’ for buildings is used firstly in 1980s and then it has been accompanied by ‘smart’ which is an American term used to refer same kind of abilities in materials, structures and buildings.

Clements-Croome (2004) defines smart buildings as the one that is sustainable, healthy, and technologically aware in order to satisfy the requirements of users and business while dealing with changes in environment as being flexible and adaptable. The author mentions that background of smart buildings consist of sustainable issues, social change and technological developments including information and communication technologies, robotics, smart materials.

Smart buildings which should be sustainable and energy efficient employ advanced and integrated building technologies such as building automation, life safety systems, security systems, facility management systems, telecommunication systems and user systems in order to allow managing building or space according to needs of occupants by providing adaptable information about individual spaces, or entire building (Sinopoli, 2010). Economics, energy and technology are defined as driving forces for smart buildings by the author. Smith (2002) mentions adaptability and responsiveness as measure of intelligence. Youssef (2005) mentions components of intelligence in Figure 2.7.

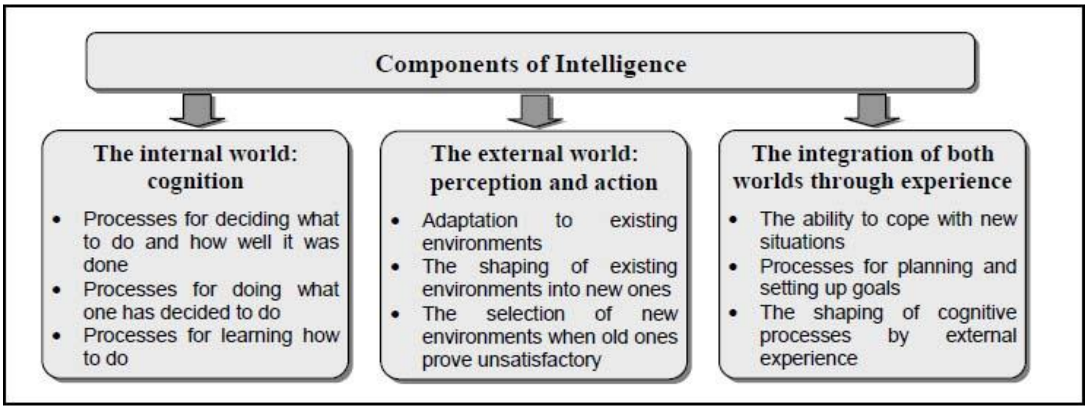

Figure 2.7: Components of intelligence (Youssef, 2005).

According to Wong & Li (2008), SBs with help of the interaction between systems flexibly respond to user requirements and changing conditions. Wang (2010) agree that smart buildings should be adaptable in response to internal or external conditions and changing demands of users.

Wang (2010) mentions that many definitions have been put forth during last two decades, but what an SB contains is changing while building industry and information technologies have been developing. The author categorizes definitions in 3 groups in order to make clear understanding of the concept by mentioning that a unique conception cannot be formulated easily:

- Performance based definitions
- Service based definitions
- System based definitions

Wang (2010) refers to Intelligent Building Institute (IBI) in the United States which state performance based definition for smart buildings as the building which satisfies four fundamental demands: structure, system, service and management, and optimizing their interrelationships in order to provide a highly efficient, comfortable and convenient environment. The author noted that performance based definition highlights building performance and the needs of occupants rather than technological features and systems.

In order to describe service-based definition which defines SB by focusing on services and/or quality of services that SBs include; Wang (2010) refers to The Japanese Intelligent Building Institute (JIBI) which states SB as the one with features such as communication, building automation, office automation, efficient management, services to users, reaction to the change in environment flexibly and economically.

Wang (2010) describes system based definition from the perspective of the technological features and systems provided and optimal integration of them with structure, service and management to provide efficiency, convenience, comfort and safety to occupants. While the author agrees with the general opinion that it is difficult to suggest a unique definition for smart buildings, he states that it is not necessary to define it in a standard form; as the important point is to understand how to make a building intelligent in reality. According to the author, what makes a building smart is not integration of technology; but the evaluation criteria should be the qualities which are achieved with the application of technology and strategies.

Himanen (2004) agree with that the definition of smart buildings is not unique or standard. The author points out six highlights in the light of various definitions which are used for practical purposes within research, education and the construction industry:

- The need of building owners and end-users
- The integration of building systems
- The integration of sophisticated operational environment with building architecture, structures and systems
- The importance of advanced technology and economics
- Concerns over the building life cycle and the necessity of flexibility in changing economy and as a result of globalization
- The importance of including sustainability –human and ecological- in the concept.

Table 2.1: Definitions, proposals and viewpoints of architectural intelligence (Youssef, 2005).

Terms	Definitions and Conceptions
Intelligent Architecture	Creating a convenient microclimate, and exploiting free energy resources (20)
	Bringing together three main spatial environments: mind, world and networks (13)
Smart Architecture	Green, and environmentally oriented (18)
	Durability, self-generating energy, scarcity, and symbiosis with nature (17)
	Green solutions and sustainability (19)
Smart Communities	Information technology, economic development, job growth, and quality of life (4)
Intelligent City	Emergency management via telecommunications technology (21)
	Promoting broadband and telecommunications technologies (15)
Smart Cities - Soft Cities	Linking isolated islands (14)
	Tele-served, e-topia lean-and-green, soft cities (7)
Intelligent Buildings (IBs)	Productivity and personal environmental control (9)
	Self-knowing, deciding and responding (11)
	Lowering cost, and cabling for future expansion (6)
	Sensory-motor adaptation to support life (22)
	Information technology, environmental quality, and building performance (23)
	Automation, telecommunication technologies, and responsiveness to changes (10)
	Self-adaptation, environmental control, users' comfort, and saving energy (24)
	Using the technology, the environment, and individuals as controllers (25)
	Inhabited by intelligent beings (26)
	Environmental control, information technology, and users' participation (27)
	Automation, lowering cost, users' participation, and productivity (28)
	Automation, and responsiveness to environmental changes (29)
	Flexibility (30),(31)
	Management and communications systems (3)
	A part of the worldwide telecommunication network (16)
	Building within a sustainable built environment (32)
	Promoting broadband and telecommunications technologies (15)
	Installing intelligent systems: energy efficiency, life safety, workplace automation, and telecommunications systems (33)
	Sustainability, automation, and responsiveness to environmental changes (35)
	Buildings are designed and constructed based on an appropriate selection of ' Quality Environmental Modules' to meet the user's requirements by mapping with appropriate building facilities to achieve long term building values' (34)
	Ecological energy, avoiding non-renewable resources, recycling, understanding of topography, and cost awareness (36)
	Self-knowing, anticipating behavior, self-adaptability, comfort, and saving energy (37)
	Network cabling solutions, and environmental adaptability (38)
	Installing the four-Cs: computer, control, communication and CRT graphic display technologies (39)
	Cabling solutions (40),(41)
	Automation, and installing the four-Cs (12)
	Telecommunications technology (42)
	Sustainable future (43)
Smart Innovative Places	Hardware, architectural elements, and connectivity to globally linked places (7)
Intelligent Facade – Skin – Walls – Building Envelope	Responding to environmental changes, and automation (44)
	Responding to demands and environmental changes (45)
	Responding to the environmental changes (37)
Intelligent Energy	Appropriate renewable sustainable energy: PhotoVoltaic (PV) as an example (46)

Main attributes that a smart building should have are determined by Atkin (1988) in three points:

- SBs should "know" what is occurring inside and immediate outside.
- SBs should "decide" the most efficient way to provide required environment for the users.
- SBs should "respond" instantly to the need of users.

Clements-Croome (2004) and Wigginton & Harris (2002) agree definition of smart buildings has been changing and improving since the term is put forward in literature, as a result of continues developments in technology and changes in society. Youssef (2005) generated a table to aggregate various definitions which can be seen from Table 2.1.

Travi (2001) describes the difference between an IB and a conventional one by existence of central computer connected to an integrated network containing sensors, activators and all other installations. However, Himanen (2004) states that smart building concept is not same with integrated or automated buildings; but smart buildings is an umbrella concept for automated buildings.

The aspects which should be taken into consideration for intelligent buildings are stated by Himanen (2004) as being environment friendly, adaptable, flexible for long term, healthy, productive, service oriented, marketable, comfortable, safe, secure, convenient, high-tech and reliable while having operable elements, feasible life cycle cost, efficient space organization within its culture.

2.2.2 Historical background of smart buildings

Sinapoli (2010) states that smart building concept was started to be discussed in the early 1980s. The author refers to a New York Times article, published in 1984, which mentions intelligent buildings as a new generation which is nearly able to think. The author notes those buildings were combination of just building management and telecommunications.

In 1981, United Technology Building Systems Corporation (UTBS) propounded idea of intelligent building. The idea became a reality in 1983 with City Place building constructed in Hartford, Connecticut, USA.

Before 1980, single device or apparatus had been applied for the automation of building systems (Wang, 2010). The born of IBs depends on intelligent control of building services, processes and communication devices but IB technologies have became more advance and integration level has improved increasingly with the rapid development of technology in electronic, computer and information (Wang, 2010).

The intelligent building pyramid which was created during European Intelligent Building Study by researchers is given in Figure 2.8 below.

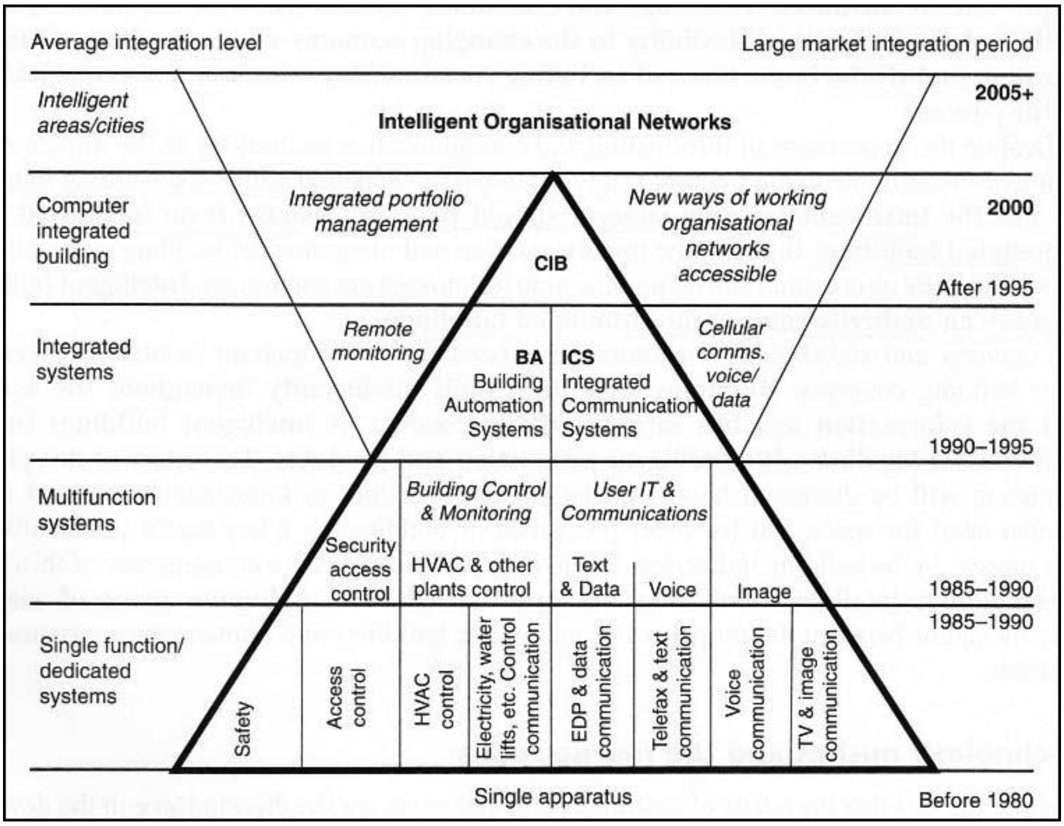

Figure 2.8: The intelligent building pyramid (Harrison, 1999)

As Clements-Croome (2004) mentions this pyramid is not intended to define intelligent buildings, but it defines integrated and automated building- the type of intelligent buildings which highlights the utilization of information and communication technology. The author also notes the pyramid has turned out to be a notable landmark in the short history of progress in smart building concepts. The pyramid divides smart building system after 1980 into 5 stages as follows:

- Single function dedicated systems (1980-1985)
- Multi function systems (1985-1990)
- Integrated systems (1990-1995)
- Computer integrated building (after 1995)
- Intelligent areas (2005+)

On the other hand, Harrison, *et al.* (1988) divide smart buildings into three distinct periods as can be seen in Figure 2.9.

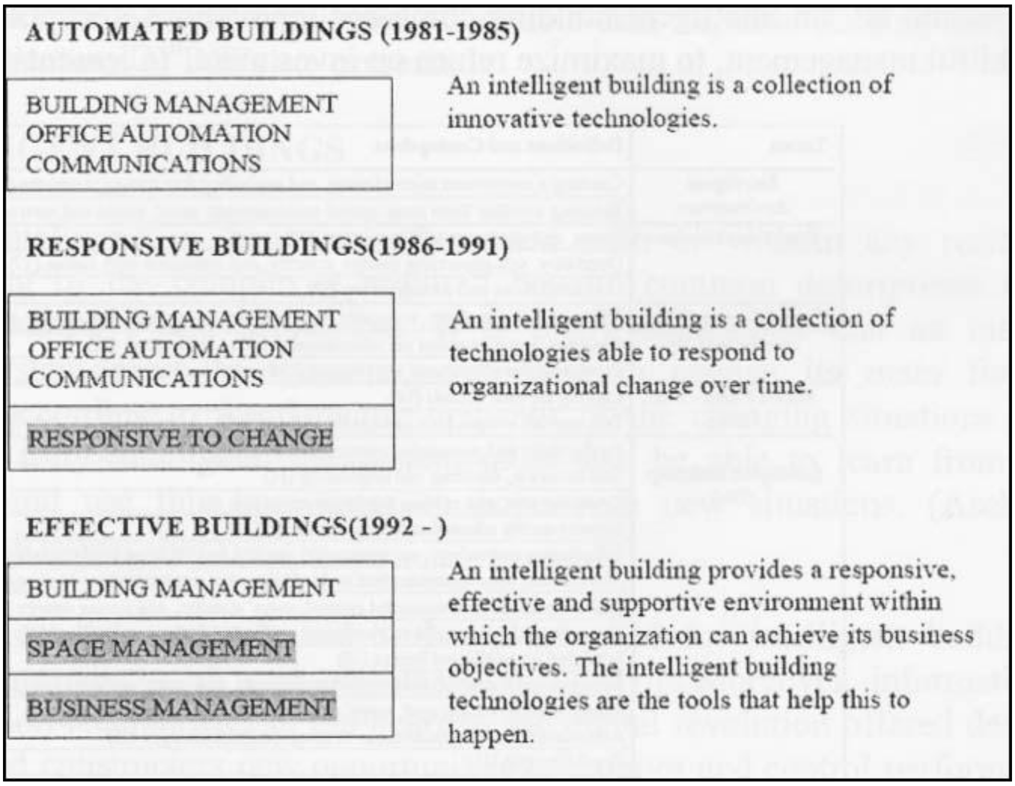

Figure 2.9: Progress of intelligence in buildings (Harrison, *et al.*, 1998)

When developers saw the advantages of building intelligence, automated office buildings emerged in 1980s (Harrison, *et al*, 1998). The authors note that there was a concern about security and integrity of shared telecommunications and data networking systems in that time. They refer to orbit research studies, conducted by DEGW architects, which showed that smart buildings should be able to respond to changing needs of occupants and be adaptable to developments in information technologies. As a result of this study responsive building period started and definition of smart building were revised by adding a new criterion: responsiveness to changes (Harrison, *et al*, 1998).

Harrison, *et al.* (1998) mention the 1992 DEGW/ Tekinibank research project, related with the Intelligent Building in Europe (IBE), which is defined as a smart building since it supports the organization that occupy it to succeed business objectives by providing a responsive, efficient and assistive smart space.

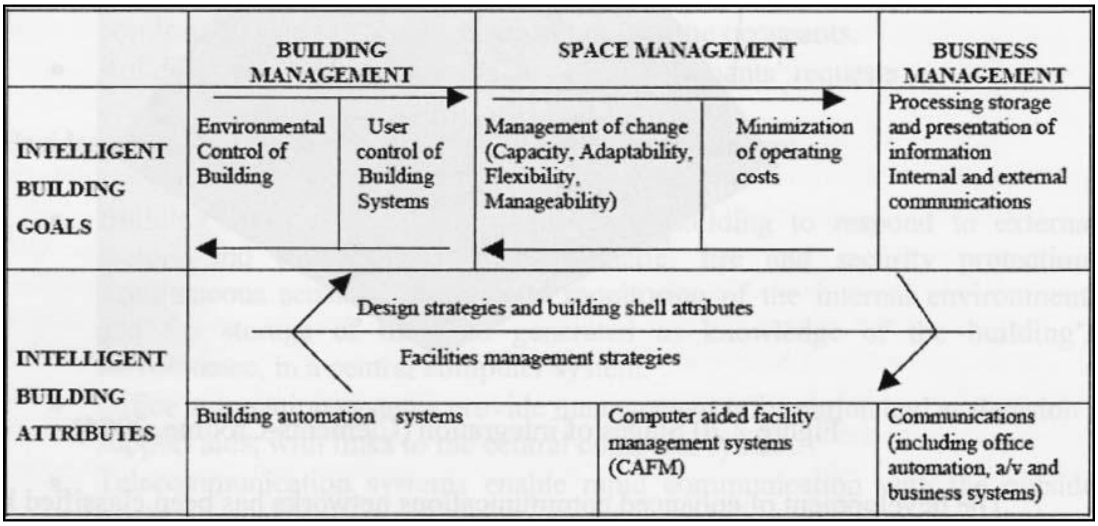

Figure 2.10: The IBE model of building intelligence (Harrison, *et al.,* 1998)

Harrison, *et al*. (1998) note IBE model focuses on the building's occupants and their tasks instead of computer systems. The author states information technology was acknowledged as one of the ways in which the building can help or hinder the occupants, but it is not the reason for the building's existence.

As can be seen from the Figure 2.9 and Figure 2.10, there are three main aims of an organization occupying a building presented in IBE model which are give as follows (Harrison, et al., 1998):

- Building management is management of building's physical environment using both facilities management and building automation systems.

- Space management is the management of the building's internal spaces over time.
- Business management is the management of the organization's core business activities.

2.3 Integrated systems in smart buildings

Himanen (2004) draws a parallel between the smart building concept and the human being with a metaphor of the building systems and the human senses by referring to Huhtanen's (2000) graphic representation of the types of integrated systems shown in Figure 2.11.

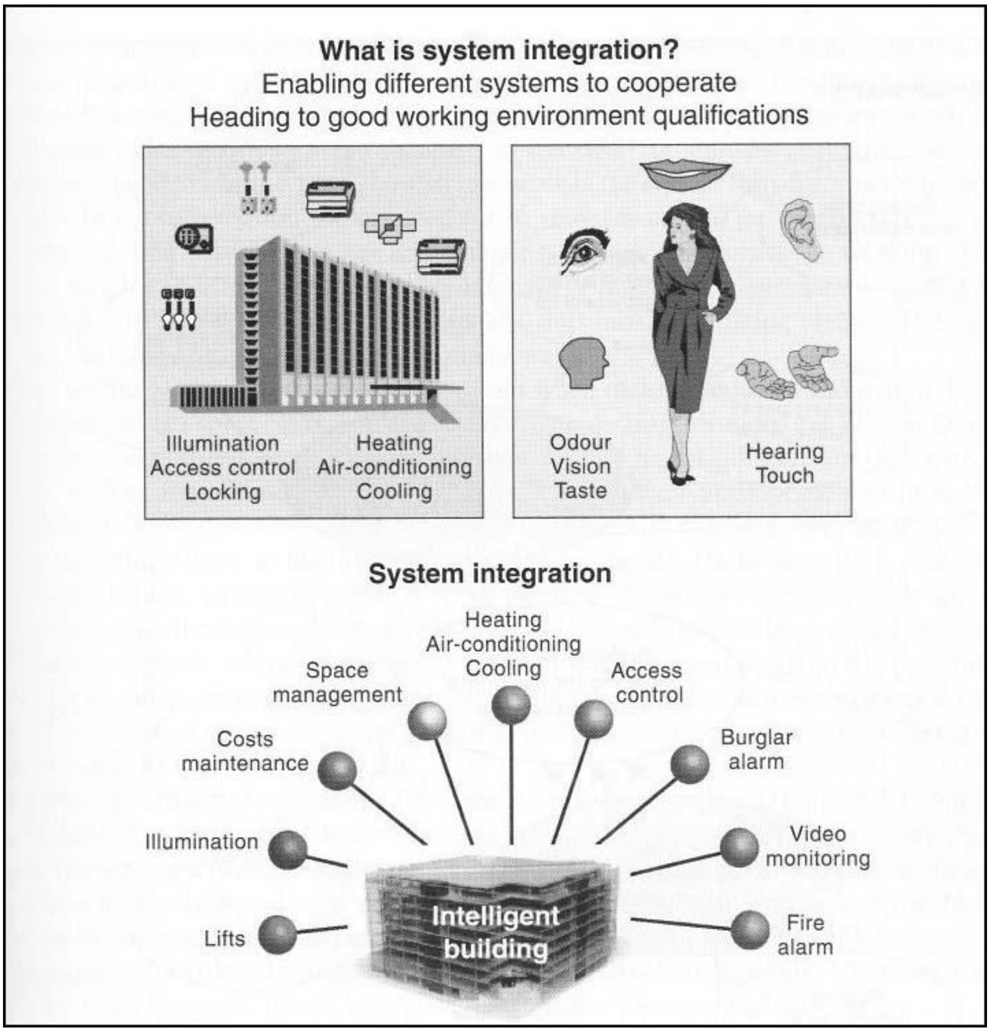

Figure 2.11: The metaphor between the working environment and human senses and senses of a smart building (Huhtanen, 2000).

Clements-Croome (2004) refers to Gann, Barlow & Venables (1999) for classification of enhanced communications networks' development as :

- Human flows: supervision and private entryways and spaces.
- Energy and water flow: monitoring and management of networks and calculation of energy and water.
- Information flow: managing the transmission and reception of data.

While IBs are responsible for different functions, Fletcher's (2003) pyramid (Figure 2.12) which focuses on building services and communications identifies integration stages.

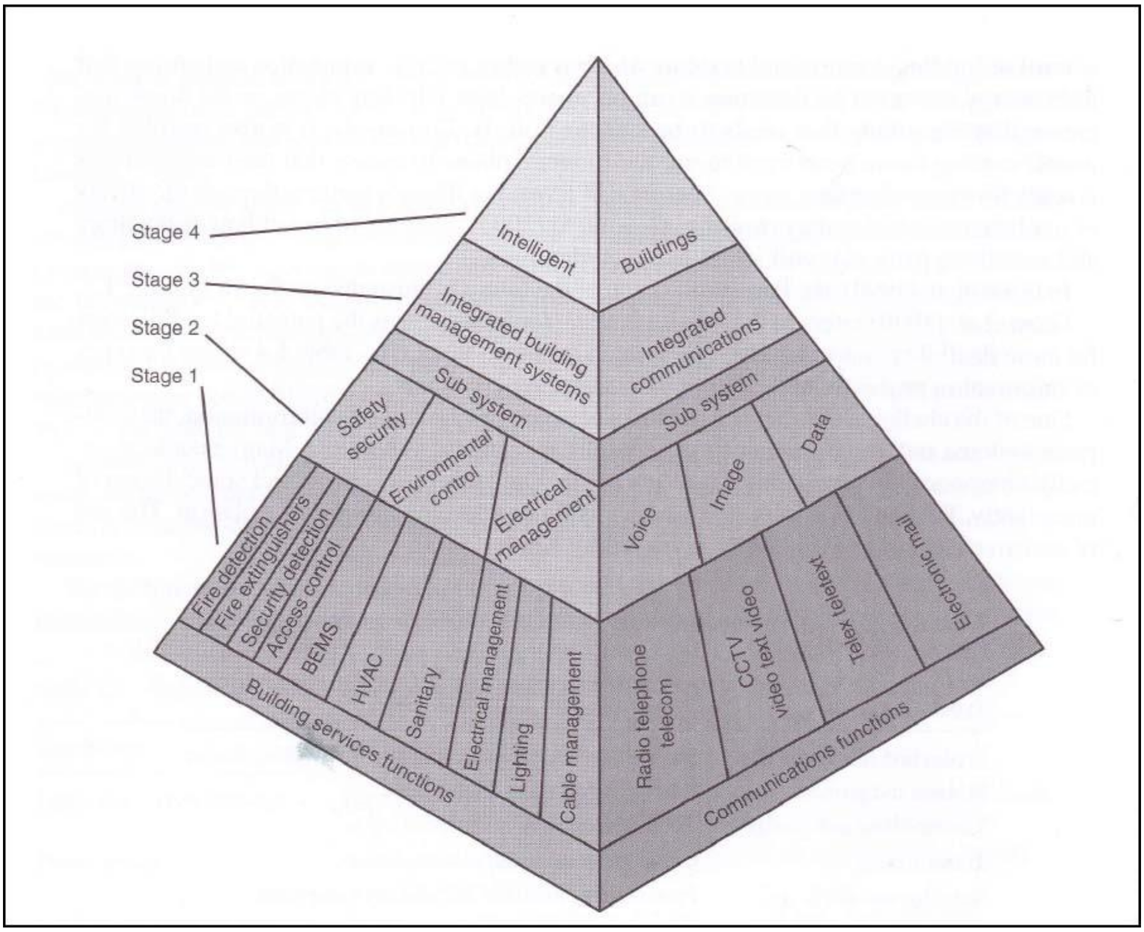

Figure 2.12: Stages of integration (Fletcher, 2003)

Coggan (1999) divides smart building systems into four categories in terms of recognition of the electronic aspects:

- Energy efficiency: Reducing energy consumption to minimum by using computer based technologies comprehensively is what intelligence by means of energy in IBs refers to. Some of well known computer systems used in IBs related with energy performance are; Building Automation System (BAS), Energy Management System (EMS), Energy Management and Control System (EMCS), Central Control and Monitoring System (CCMS) and Facilities Management System (FMS).
- Life safety: Integrating high technology in order to ensure maximum performance for safety and security with minimum cost is what intelligence by means of life safety in IBs refers to.
- Telecommunication: Availability of various complex telecommunication services with low cost is what intelligence by means of telecommunications in IBs where many users will share the equipments refers to.
- Workplace automation: Integrating high technology office automation systems which will be shared by many users in order to ensure efficient operation and needs of business with low cost is intelligence by means of workplace automation in an IBs refers to.

Another classification which is done by Travi (2001) agrees with Coggan's (1999) classification. Travi (2001) identifies categories of integrated systems in four parts:

- Area of system management: energy (HVAC, lighting, energy management); technical system (vertical transportation, public services)
- Area of control and security: security (access control, presence detectors, anti-intrusion, anti-burglary, video surveillance); safety (fire prevention, gas and water detection, electric safety, earthquake detection, evacuation management)
- Area of information: office automation (word-processing, electronic filling, e-mail, desktop publishing); specific services (CAD/CAM, administration, records); electronic data processing (network connection, back-up and archives)
- Area of Communication: audio-phonic (word-processing, telephones, intercommunications, telex, facsimile, data-base access, message distribution,

internet); images (entrance video phone, slow-scan video, video conferencing, closed circuit video control)

Travi (2001) notes the importance of central control computer which acts like human brain for connection in between all integrated systems according to needs of occupants and requirement of business.

Table 2.2: Integrated elements (Ochoa & Capeluto, 2008)

Class	Category	Design variable	Sub-variable	Common values
A. Sensor elements	A.1 Sensors	No sensor		none
		Light	illuminance, luminance	internal, zoned
		Temprature		internal, external
		Glare		external
		Solar radiation		external
		Humidity		internal, external
	A.2 User interfaces	termostats		on/off, variable control
		swithches		on/off, variable control
B. Control processing elements	B.1 Individual process	Light controls		Always on On/Off Dimmer Stepped Lighting
		Shading Controls	Blind types	Non (always off or retracted) Always on, fixed slat angle On if radiation level is high, fixed slat angle on if glare level is high, fixed slat angle
		Thermal comfort Controls	Temprature level policy	Cooling on if temprature lower than limit Heating on if temprature higher than limit
		Ventilation control		
		Energy controls		Grid-connected only
	B.2 Schedules			For non sensor operation
	B.3 BMS			Electronic brain
	B.4 Sycronized controls			One element turns on/off another
	B.5 Passive building			static elements fullfil all functions
	B.6 User only			user perform operative routines
C. Actuating elements	C.1 Daylight systems	Sunshading elements	No shading element Horizontal External blinds/louvers/shutters internal blinds, curtains, shades	none opaque opaque opaque
		Daylight redirection elements	No elements lightshelves automatic reflective blinds	none fixed, external external
	C.2 Fenestration systems	Glazing elements	Conventional glazing	Double glazing clear (gas=air) Double glazing low-E (gas=air)
	C.3 Ventilation system	Window operator	fixed manual mechanic	no opening different opening conbinations different opening conbinations
		Fan ventilation elements		no fan electric fan
	C.4 Cooling and heating syste	Passive	Orientation sunshade sunspace	north,south, east,west north,south, east,west north,south, east,west
		Active	conventional	HVAC system

Ochoa & Capeluto (2008), summarizes the elements of sensing, deciding and responding process for energy efficiency by focusing on hot climates with an open-ended list which can be seen from Table 2.2.

2.3.1 Appropriate use of intelligent technologies in smart buildings

To quote Himanen (2004), ‘’buildings have been built smartly throughout the ages, but the information age has introduced the concept of smart buildings in a new context together with smart production and products.’’ Also Wang (2010) agrees that there are buildings which provide quite smart functions even they were constructed long time ago so technology by oneself does not mean intelligence.

Associating IBs with high-tech devices and computer systems is not false but it should be noted that implementation of building systems, rather than a goal, is a tool for meeting requirements. (Harrison, Loe & Read, 1998). So; technology single-handedly does not bring intelligence to a building (Yang & Peng, 2001). According to Cansever (2007), considering the technology as independent power is fetish of technology which do not take coherence into account. The author states that relation in between climate and building should be considered in unity of architectural design. To quote Ochoa & Capeluto (2008); "a building is a direct product of the entire process that created it."

According to Himanen (2004) a long list of equipments and systems is not guarantee of intelligence, it is better to describe smart building concept by listing criteria of qualities than by a list of high-tech equipments. So the aim should be defined at first and then strategies and technologies should be selected accordingly.

The sole objective of SBs should not be the implementation of technologies, although main feature of smart buildings is the successful use of advanced technologies (Wang, 2010). The author agrees a key objective of SBs is definitely performance and that SBs cannot be discussed separately from the architectural design, building façades and materials.

Sinapoli (2010) states SBs, rather than an exhibition for implementation and operation of technology, are simply enablers to an aim. According to the author;

operating building more efficiently, constructing building in more efficient manner, providing productive, healthy, safe and sustainable environment for users, providing energy efficiency, and improving marketability of the building are objectives which are required from SBs.

While arguing that being highly fixed up with technology may not enough to achieve a smart building, Wang (2010) notes it is obvious that smart buildings cannot exist without technological systems in modern building context, especially information technology (IT) systems. The author states that smart buildings which are also related to economic and cultural aspects are interdisciplinary and involve multi-industrial system engineering while requiring the right combination of architecture, structure, environment, building services, information technology, automation and facility management.

Wan & Woo (2004) mention that design decision become more complicated by multi-criteria and multi-dimensional aspects of IBs such as ensuring needs of business, being user friend, being compatible with international standard protocols, being energy efficiency, inter-coordinating systems, having ITs and being flexible. Aygün (2000) and Pati, Park & Augenbroe (2006) are agreed that a balance should be maintained in these perspectives by designers in order to make buildings responsive to the changing conditions.

On the other hand, Wang (2010) explains the need for a right combination with an example which mentions that the most appropriate air conditioning strategy for a building may be thermal mass and night time free cooling instead of high-tech air conditioning system, in areas where people want operable windows for electricity saving.

In addition to appropriate combination of intelligent technologies and strategies in design, implementation part also requires care. Wang (2010) states buildings which are fully equipped with technology system may not be smart in reality if those systems are not coordinated or they are not functioning properly. The author also mentions any failure in operation may create problems for occupants instead of being intelligent.

Although implementing intelligent technologies is becoming more and more popular, the main issue is designing optimum configuration of intelligent building systems (IBSs) among a vast variety of available alternatives and associating them faultlessly in order to meet with expectations of developers and occupants (Wong *et al*, 2008). Professional's effort and care is needed while designing and implementing appropriate intelligent building systems (Pati, Park & Augenbroe, 2006).

2.3.2 Media network in smart buildings

All SB technologies are part of networks actually since they communicate with each other or control elements which are used for monitoring, managing, and providing services (Sinapoli, 2010). On the other hand, media network systems which society is very familiar with, include television casting, radio casting, telephone line, internet, video conference, audio-visual entertainment, various services based on internet, fax, word processing, data base access, entrance videophone, computers, cameras, speakers, media players, monitoring devices *etc.* (Travi, 2001).

It can be said that those media network systems are widely prevalent even in conventional buildings since computer usage and network connection in between computers and other digital devices are indispensable for not only workspace but also daily life in modern context. Furthermore, media network systems do not make a building smart but those are a part of SBs. Basically, all networks include an administrative workstation in order to provide management, monitoring and reporting (Sinapoli, 2010). Connection between network devices may be via cable or wireless transmitter/receiver, while communications between the devices depend on a set of rules or protocols (Sinapoli, 2010).

Audio-visual network includes various equipments and materials, multiple technical standards, and rapidly changing technologies such as computer, video player, projector, sound system, radio, camera, lighting system, tablet and derivatives, remote network via internet *etc.* (Sinapoli, 2010). Also the author notes SBs are benefit from data network technologies for controlling and managing audio visual systems. In other words, it is possible to access, monitor and manage audio-visual devices remotely with cell phone, notebook or tablet even far from building with telecommunication or internet connection.

Sinapoli (2010) categorizes the main constituents of audio visual systems as:

- Audio and visual sources
- Processing and management
- Destinations (speakers and displays)
- System control

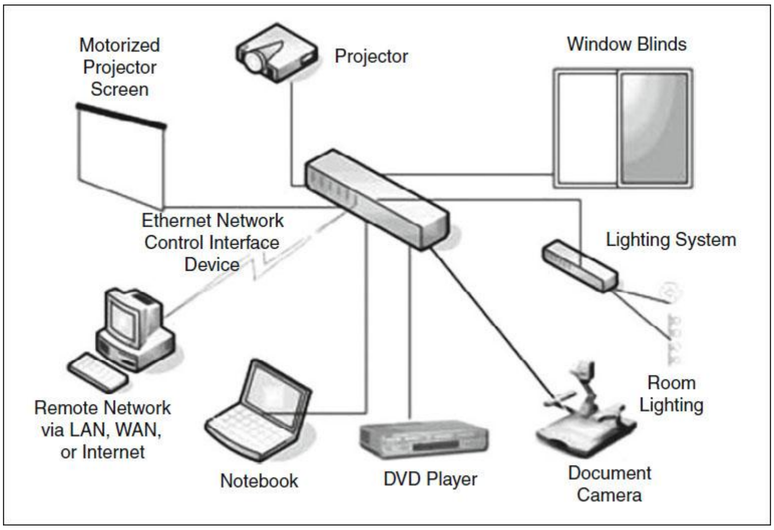

Figure 2.13: Audio visual systems with Ethernet interface (Sinapoli, 2010).

Data network which commonly includes primarily of switches, servers, industry-standard operating systems, network and client software applications, peripheral devices and user devices, is responsible for sharing resources and exchanging information with other networks and in between network users (Sinapoli, 2010). According to the author; the technical hearth of a SB is formed by data network technologies and infrastructure. Although technology is rapidly changing; personal computers, mobile phones including smart phones, tablets or other similar devices are commonly in use today for connecting to a data network and also other devices such as printers, scanners, fax machines can be added as a part of this network via cable or wireless point as seen in Figure 2.13. Data networks with included devices can be established in a building or in between many buildings as campus network to access and manage as seen in Figure 2.14.

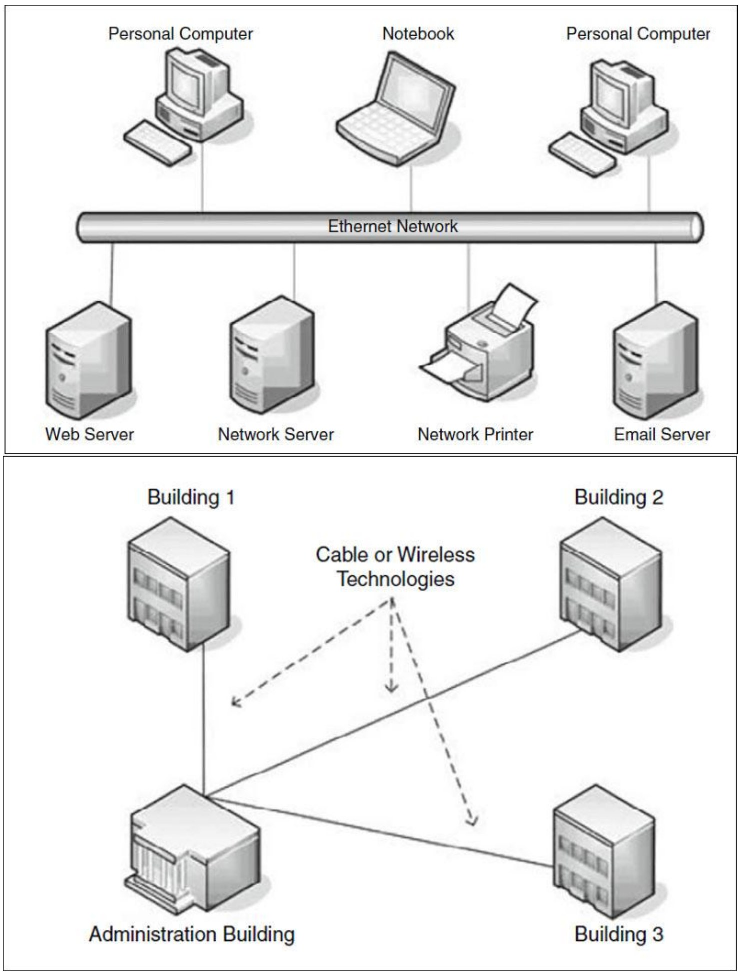

Figure 2.14: Local area network (LAN) and campus network (Sinapoli, 2010).

2.3.3 Security and safety in smart buildings

Wang (2010) states security and safety systems present for resisting against fire, damage, unauthorized entry, theft and any other dishonest, illegal or criminal acts in order to protect the property, life, materials and facilities.

Safety systems, according to Travi (2001), include; fire prevention**,** evacuation management, earthquake detection, gas and water detection, and electric safety.

Fire prevention is managed mostly by fire alarm systems whose function detecting the existence of undesirable fire in protected zones by being aware of changes in environment with combustion test; however, despite being essential and helpful they are not the unique criterion to achieve fire safety in buildings according to not only regulations but also reality (Wang, 2010). The author states that fire alarm systems may inform fire station for emergency assist and launch related systems for controlling spread of fire and smoke while notifying the danger of fire or other emergency to people to evacuate. In addition, Sinapoli (2010) agrees that it is important to link all systems with each other to minimize the effect of fire. The author explains the relationship between fire detection system and other building systems by listing the tasks which will be put into practice in a fire event by SB as follows:

- Fire alarm system signals HVAC in order to restrain heat, smoke and fire through dampers and fans.
- Fire alarm system activates access control system and opens doors, unlocks fire doors and automated exterior doors in order to prepare an open path for evacuation.
- Fire alarm system works with the access control system and closes interior doors when necessary in order to restrain the spread of fire and smoke.
- Fire alarm system triggers emergency power for not only itself but also related systems such as exit signs, lighting for emergency exit corridors *etc.*
- Fire alarm system shuts down the elevators.

Sinapoli (2010) states three types of fire suspension systems including; wet sprinkler systems (that is composed of not only different switches but also flow-detection elements), dry sprinkler systems (that consist of pressure switches) and fire suppression systems as seen in Figure 2.15. The author mentions that all types and their equipments can be monitored and managed. Wang (2010) categorizes type of detectors as heat detectors, smoke detectors and flame detectors. In addition; some of the sensing elements of fire alarms that are generally placed in ceilings or technical spaces are listed by Sinapoli (2010) as;

- Pull stations: for manually activating fire alarm when a person detects fire
- Thermal detectors: for sensing temperature risings or unusual high temperature caused from fire
- Smoke detectors: for sensing smoke which includes carbon content caused from the burn.

- Flame detectors: for sensing radiation of fire
- Sprinkler flow sensors:
- Fire-gas detectors: for sensing toxic gases.
- Air-sampling fire detectors: the system which is almost a micro-laboratory is able to sense a pre-combustion phase of fire by taking air samples continuously to analyze in a high delicate detector. Those are the most delicate fire sensors so generally preferred in important and critical spaces such as churches, clean rooms, hospitals, museums and network equipment rooms.

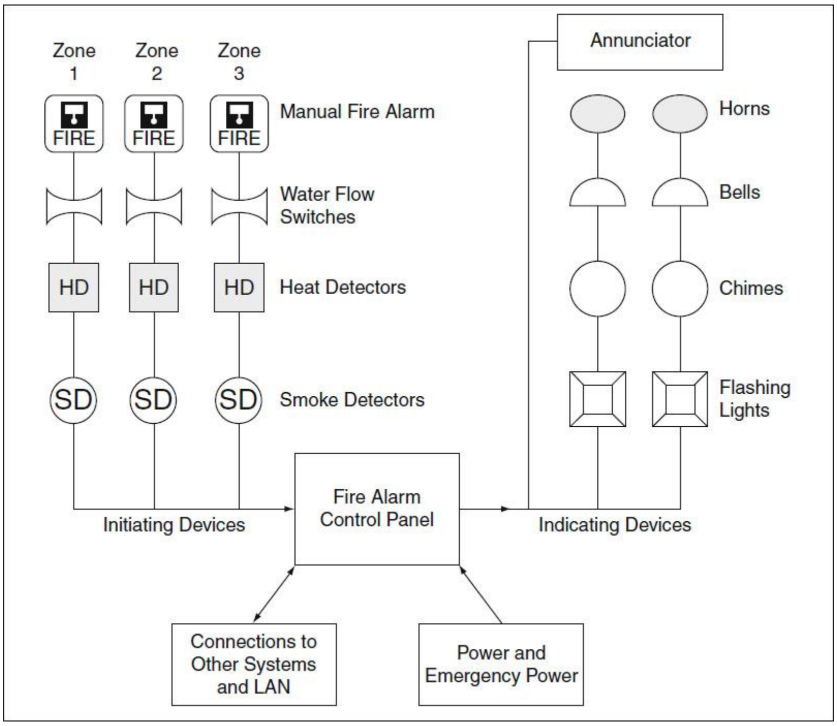

Figure 2.15: Basic fire alarm system (Sinapoli, 2010).

Earthquake detection follows similar process with fire prevention. Stump (2004) mentions proactive systems which detect non-destructive primary earthquake waves (P-waves) trigger not only an alarm system but also building automation system in order to take possible precautions by warning the occupants with audio and visual alarm before an earthquake. The author explains that this system activates emergency power system which turns emergency lights on and opens access doors for evacuation management; turns off gas to prevent fires; turns off water; stops hazardous activities such as cooking and keeps water/gas detection on in order to respond any gas leakage to prevent poisoning. At the same time, the system not only puts all equipments, machines and engines including elevators in safe mode, but also save work in progress, IT data and computers (Stump, 2004).

Reactive earthquake systems which are mostly related with structural engineering are also another supportive option depending on active systems and structure's flexibility. Kobori (2008) mentions that the building itself is able to resist actively to earthquakes in reactive concept which is called dynamical intelligent building (DIB).

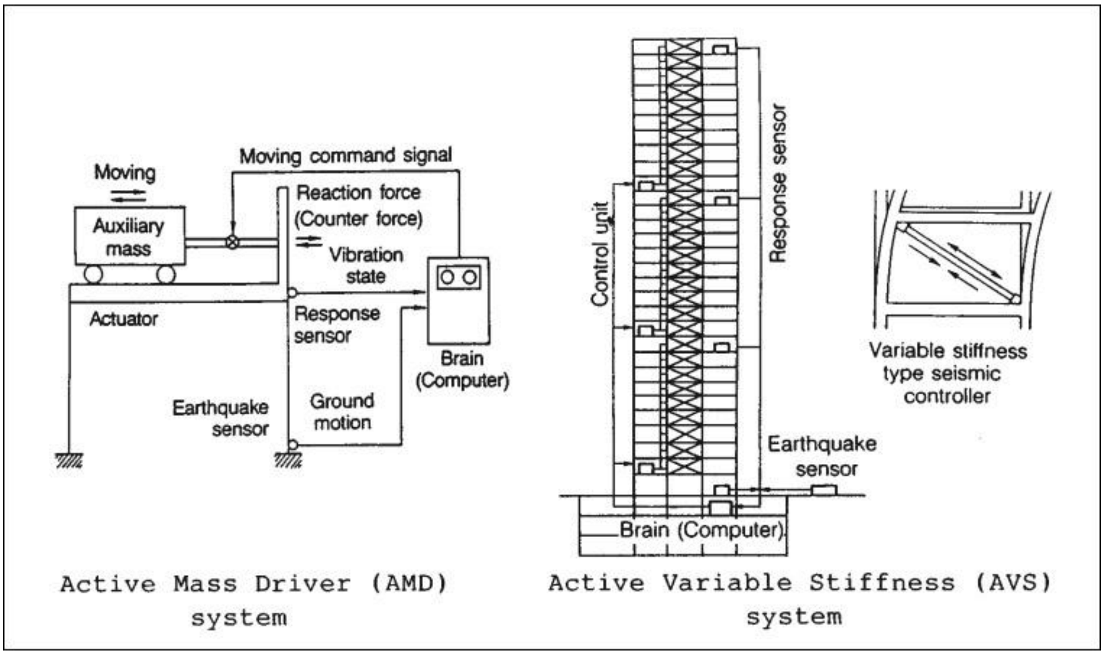

Figure 2.16: Applications of dynamic intelligent building (Kobori, 2008).

Seismic waves observation sensors or ground motion sensors which are connected to a central computer, *i.e.* building automation network, are in coordination with active control systems which help building to adjust its physical property such as stiffness, natural frequency and damping capacity instantly in accordance with information from response sensors placed in strategic parts of building (Kobori, 2008). The author states that central computer works as a brain and artificial intelligence manages the situation by analyzing information supplied by both ground motion sensors and response sensors, deciding what should be done with control algorithm and operating active control systems.

Figure 2.16 shows not only components of reactive concept but also its two main types. Active variable stiffness system adjusts its own vibration characteristics moment by moment in order to prevent becoming resonant, while active mass driver system employs a mass to control vibration of building in order to restore the deformation of structure caused by earthquake (Kobori, 2008).

Security is activating some precautions after predicting a crime danger in order to prevent it or decrease its effects; regarding this, the security systems in a building are mainly composed of closed circuit television (CCTV), access control system and anti-burglary system (So & Chan, 1999).

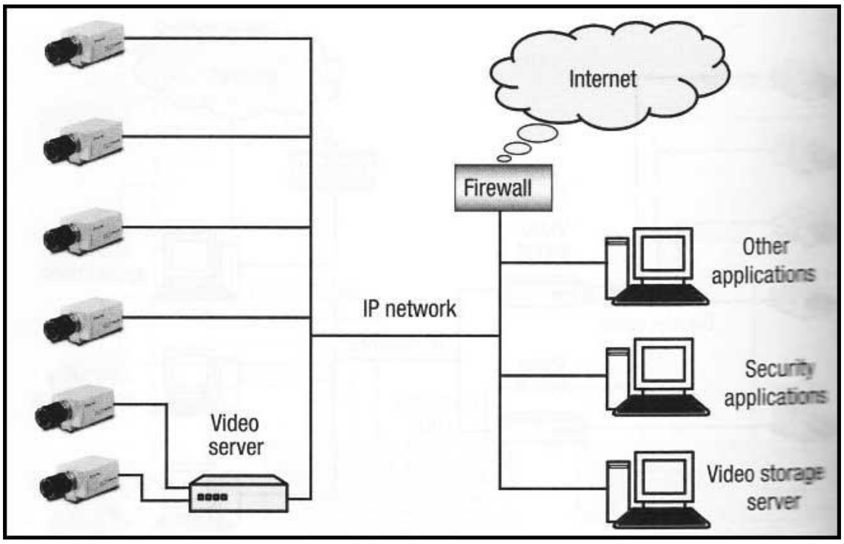

Figure 2.17: IP surveillance system with analogue/digital IP cameras (Wang, 2010).

CCTV which aims to prevent theft rather than to record thieves has been in use for decades as a cost effective way to extend security (Wang, 2010). The author defines CCTV as ‘remote eyes’ for security operators since they provide live-action displays and to record the spaces under monitoring from a distance as seen from Figure 2.17. Although it is widely accepted that CCTV is very helpful for security operations, there is a debate based on privacy. This discussion may be issue of another study but it is obvious that privacy issue should be considered while designing and integrating this kind of systems.

Access control systems defined by Wang (2010) as "the ability to permit or deny the use of a particular resource by a particular entity". As the author mentioned, physical access by a person which is related with authorization, payment *etc.* can be controlled by the help of mechanical or technological systems.

Access-control locks which are also designed in various formats for different purposes such as public transportation, car parks *etc.* are often connected to an access-control system rather than being standalone (Wang, 2010).

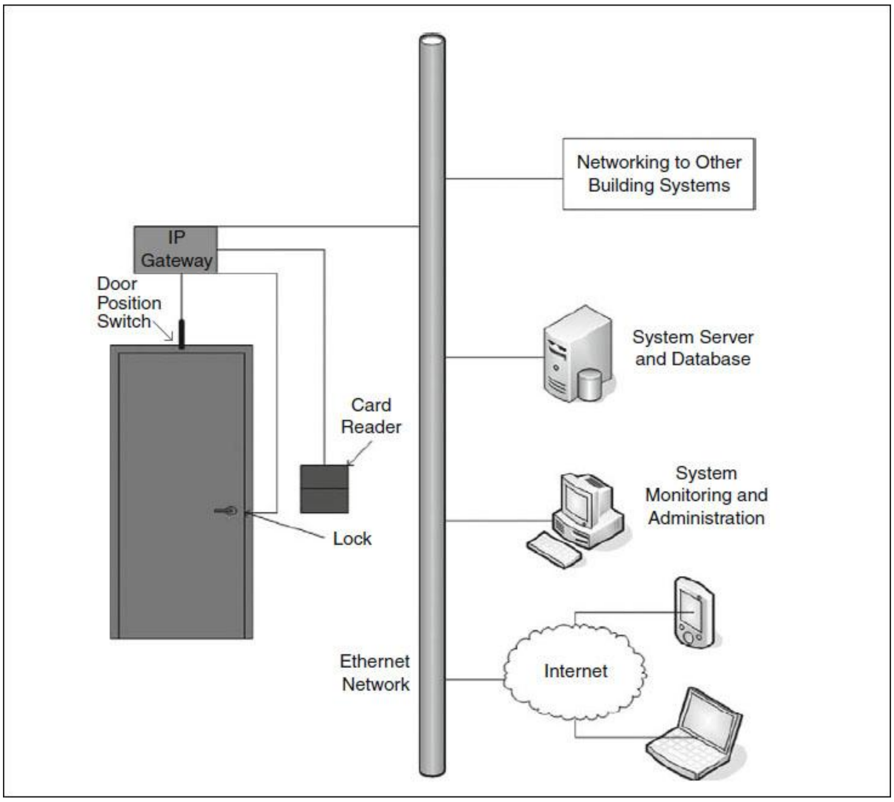

Figure 2.18: IP card reader access control (Sinapoli, 2010).

According to Sinapoli (2010), the basic or typical access system seen in Figure 2.18 is card access in which card reader identify the information on the card and allow or refuse the access to a space or a facility. In addition to this, as Wang (2010) mentions there are three types of access control according to method;

- PIN access control (depends on code entering)
- Card access control (depends on card such as magnetic cards, wiegand cards, proximity cards, smart cards)
- Biometric access control (depends on person's unique biometric features)

Anti-burglary systems aim to detect unwanted attempts in accessing a space or object (Wang, 2010). The author analyzes the types of burglar alarm systems in three categories including perimeter protection, area/space protection and object/spot protection.

Perimeter protection which protects only the openings with simple design is achieved by mounting sensors (including door contact, electric field fence sensor, infrared beam sensor and glass break detectors) on doors, windows, vents, skylights or any openings to space (Wang, 2010).

Area/space protection which protects the interior spaces of a facility and effective against intruders can be achieved by sensors (including passive infrared detector (PIR), photoelectric beams, ultrasonic detector and pressure-sensitive mats for audio, pressure, electronic vibration and motion detection. (Wang, 2010). Moreover, the author states that area protection system, as a backup to the perimeter protection, provides delicate and invisible detection; while frequent false alarms may be seen as a result of incorrect application and installation in it.

Object/spot protection which is the last phase of a comprehensive protection system, directly protect specific items by the help of sensors including capacitance/proximity detectors and electronic vibration detectors (Wang, 2010).

2.3.4 Energy performance in smart buildings

While energy performance in buildings are already related with the terms green, sustainable, high-performance and many others; smart technologies comes with adaptive and responsive abilities to enhance and extend the concerns mentioned in those terms.

According to Barnett & Browning (2007), criteria that sustainable building should follow can be described as;

- using the land appropriately
- using water, energy, lumber, and other resources efficiently;
- enhancing human health and productivity;
- strengthening local economies and communities;
- conserving plants, animals, endangered species, and natural habitats;
- protecting agricultural, cultural, and archaeological resources;
- being nice to live in; and being economical to build and operate

In the light of definitions by Yudelson (2008), Zigenfus (2008), EPA (2010) and CIWMB (2000); green building concept can be described as a structure which follows resource-efficient way throughout a building's life-cycle in order to reduce overall impact on environment while protecting occupant health and improving productivity even in design, construction, operation, renovation or reuse period. In other words, green building which expands economy, utility, durability, and comfort concerns is a structure that uses site, energy, water, and other resources efficiently in a sustainable manner during design, construction, operation, maintenance, renovation and deconstruction stages in order to bring healthy and productive space for occupants with environmental responsibility.

According to U.S. Energy Independence and Security Act of 2007 (EISA 2007), the term high-performance building is the one that all main high performance attributes such as energy efficiency, environment, safety, security, durability, accessibility, cost-benefit, productivity, sustainability, functionality, and operational considerations, life-cycle performance are integrated and optimized in it.

As Crosbie (2000) mentioned, a high-performance building and a green building specifically aim to be energy efficient, while green building definition includes description of a high-performance building.

On the other hand, Sinopoli (2010) remarks the common characteristics between smart buildings and sustainable or green building, as can be seen from Figure 2.19. The author also note that smart buildings with smart technologies, as a part of green building concept, greatly support green building success. According to the author, marriage of smart technologies and green buildings results more energy saving and financial benefits with energy management.

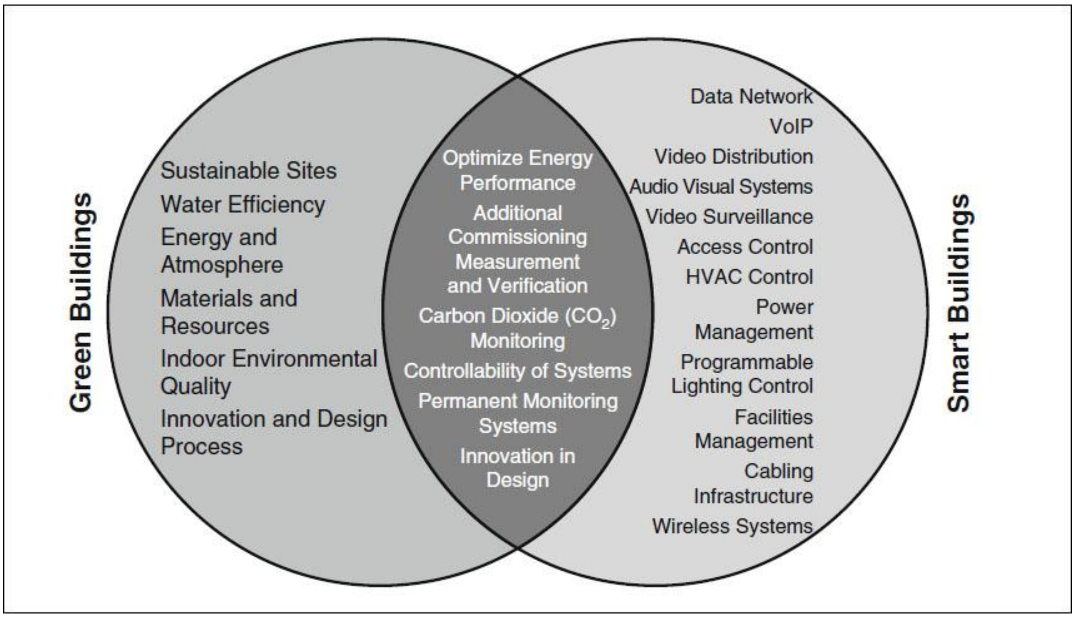

Figure 2.19: Commonality of smart and green buildings (Sinapoli, 2010)

In addition, Sinapoli (2010) states that in order to achieve sustainability, computerized systems such as Buildings Automation System (BAS), Energy Management System (EMS), Energy Management and Control System (EMCS), Central Control and Monitoring System (CCMS) and Facility Management System (FMS) are helpful for reducing energy use to minimum while supplying comfort for occupants.

According to Crosbie (2000), high-performance buildings and their design are an "all-inclusive philosophy" and requires interdisciplinary team approach while designing the whole building structure and systems by considering interaction in between them. Furthermore, Sinopoli (2010) claims that SBs which greatly support energy saving require coordination in between different disciplines.

Architectural design is required to deal with passive design strategies and active systems in order to achieve energy performance in buildings. Passive strategies depend on building physics, while active systems are mechanical devices which integrated in the design and requires energy.

2.4 Active systems for energy performance of smart buildings

In the light of descriptions by Wigginton & Harris (2002) and Lee *et al*. (2002); it can be said that intelligent active systems are building elements which able to adjust itself due to internal or external changes in order to achieve required comfort level. Active systems which are mostly mechanical and electronic devices, generally requires energy but ideally it is desired that intelligent active technologies with minimum energy use has impacts on reducing energy consumption in a building.

2.4.1 Building Automation

Building automation system (BAS) which is also known as Building Management System (BMS), is one of the major smart building systems (Wang, 2010). Travi (2001) explains building automation in a metaphoric way by mentioning intelligent building and human beings. According to the author the central computer is similar to human brain and integrated network is equivalent to nervous system. Wang (2010) states BAS which is actually product of computing and IT technologies refers to combination of various computerized building control systems including a wide range from control elements with specific objective to independent remote terminals or even to complicated systems with central computer terminals.

BAS is more than existence of different systems, main logic behind it is artificial intelligence and analysis/response algorithm. As Wang (2010) mentions, BAS functions for monitoring, controlling and managing all services including HVAC, electrical systems, lighting systems, fire systems, security systems, lift systems and water systems as seen from Figure 2.20. It is possible to say, building automation is a cover which integrates various separate building systems and facilities by help of IT and computer technologies in order to generate productive, healthy and energy efficient space.

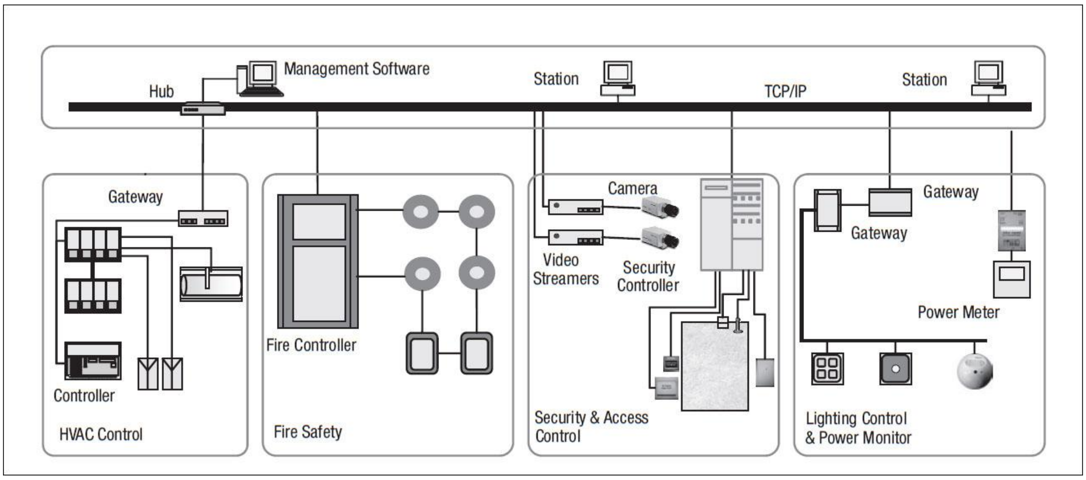

Figure 2.20: Example of integrated building system (Wang, 2010)

Wang (2010) describes typical functions provided by building automation systems as installation-management and control functions, energy-management functions (supervisory control), risk-management functions, information-process functions, facility management functions, performance monitoring and diagnosis, maintenance management.

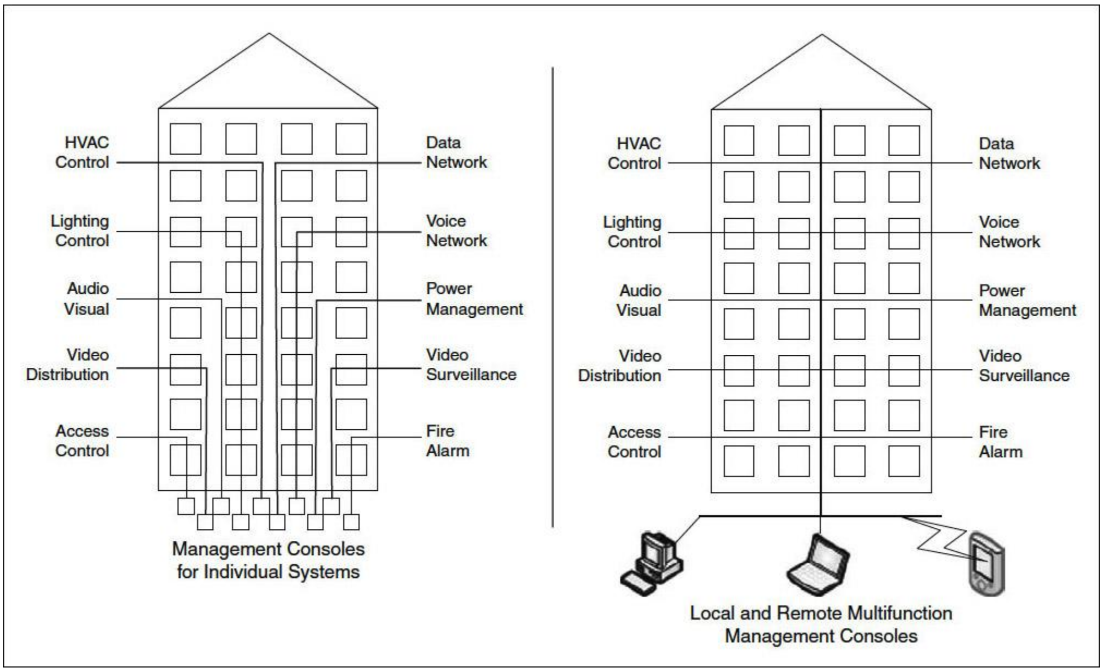

Figure 2.21: Difference between individual controls and BAS (Sinapoli, 2010)

So & Chan (1999) referred to Carlson (1991) who describes BAS as ‘’a tool in the hands of building operations personnel to provide more effective and efficient control over all building systems’’. Also Wang (2010) agrees that BAS as a high-technology tool or platform comes with not only solutions but also new possibilities for building operators.

Improving occupants productivity and health, protecting people and equipments, reducing operating cost, increasing reliability of plants and services are some of benefits from BAS while managing the building (Wang, 2010). As the author mentions as well, BAS with all these benefits is available online so BAS integration and information can be accessed, monitored and managed via internet as seen from Figure 2.21. Connection between BAS and internet also generates base of smart cities.

HVAC control, lighting control, power management and metering are some critical components of building automation systems in terms of energy performance of building the operation period (Sinapoli, 2010). In addition, heating, air-conditioning and illuminating the space constitutes one of the major expenditures in building operation (Wang, 2010). The author declares that BAS with abilities such as programmed start/stop, duty cycling, set-point reset and chiller optimization mainly aims to reduce the energy consumption and the related costs as much as possible.

Sinapoli (2010) suggests developing a matrix of all systems as seen in Figure 2.22 in order to determine which systems should be integrated with each other by means of BAS after the building systems in project are specified. The author describes integration levels as physical level (cable, equipment, room, *etc*.), logical level (*i.e*., similar protocols), and functional level.

Sinapoli (2010) explains the function of integration by mentioning the relation in between the fire detection system and access control system which have been mentioned in previous sections. In addition, examples can be multiplied by specifying that video surveillance and audio visual systems is coordinated with lighting control elements in order to turn off lights when a movie starts (Sinapoli, 2010). Another example can be given as gas detection and temperature sensors will be integrated with automated windows in order operate natural ventilation when needed.

Smart Building Integration Matrix©	Data Network	Structured Cable	Grounding System	VoIP	UPS System	Video Distribution System	Audio Visual System	Access Control System	Video Surveilance System	Intrusion Detections System	Wireless System	HVAC Management Control System	Electric Power Management Control System	Lighting Control System	Fire Alarm System	Elevator Systems Controls	Facility Management System	Integration of Business System
Data Network		•	•	•	•	•	•	•	•		•	•	•	•			•	•
Structured Cable	•			•	•	•	•	•	•		•	•	•	•	•		•	•
Grounding System	•			•		•	•	•	•	•	•	•	•	•	•	•	•	•
VoIP	•	•	•		•		•	•				•		•	•	•		
UPS System	•			•		•	•	•	•	•	•	•	•	•	•	•	•	•
Video Distribution System	•	•	•		•		•								•	•		
Audio Visual System	•		•	•	•	•						•		•				
Access Control System	•	•	•	•	•				•	•		•		•		•		•
Video Surveilance System	•	•	•		•			•		•					•	•		
Intrusion Detections System			•		•			•	•									
Wireless System	•	•	•	•	•		•			•								
HVAC Management Control System	•	•	•		•		•	•			•			•	•		•	•
Electric Power Management Control System	•		•		•												•	•
Programmable Lighting Control System	•	•	•	•	•		•	•	•	•		•			•		•	
Fire Alarm System		•	•	•	•			•	•			•		•		•		
Elevator Systems Controls			•	•	•	•		•	•			•		•	•			
Facility Management System	•						•	•	•	•	•	•	•	•	•	•		•
Integration of Business System	•							•									•	

Figure 2.22: Integration matrix (Sinapoli, 2010)

Wang (2010) states the BAS is cost effective way to manage the building and it is able to respond quickly and efficiently to the changes in space or functions, while performing monitor and control functions over situations and services at the desired level always.

According to Coggan (1999), some attributes to increase energy performance in SBs are;

- Programmed start/stop
- Optimal start/stop
- Duty cycling

- Set point reset
- Electric demand limiting
- Adaptive control
- Chiller optimization
- Boiler optimization
- Optimal energy sourcing

2.4.2 Material and structures

Smart materials refer to materials which are responsive to the changes in spaces while interacting with its environment (Beaven & Vincent, 2004). The authors mention photo-chromic glass as an example of smart materials with property of darkening response to the sunlight. In consideration of the term smart which is ability to get knowledge, to decide with logical judgment and to response quickly to the changes in environment; smart materials can be described as materials that are responsive with their build-in or inherent structure to the changes in environments (Addington & Schodek, 2005).

Addington & Schodek (2005) get involved in the discussion about technology for smartness, is it obligatory or not, within the context of smart materials. According to the authors, smartness in materials should be evaluated with their behaviors, so advanced technologies and systems are not obligatory requirement. The authors describe the characteristics of smart materials and technologies which refer to whether a molecule, a material, a composite, an assembly or a system as:

- Immediacy: ability to respond in real-time.
- Transiency: ability to respond to multiple environmental situations at the same time.
- Self-actuation: ability to respond with embedded intelligence.
- Selectivity: capability to respond in a predictable and discrete manner.
- Directness: ability to respond locally to activating event.

TYPE OF SMART MATERIAL	INPUT	OUTPUT
Type 1 Property-changing		
Thermomochromics	Temperature difference	Color change
Photochromics	Radiation (Light)	Color change
Mechanochromics	Deformation	Color change
Chemochromics	Chemical concentration	Color change
Electrochromics	Electric potential difference	Color change
Liquid crystals	Electric potential difference	Color change
Suspended particle	Electric potential difference	Color change
Electrorheological	Electric potential difference	Stiffness/viscosity change
Magnetorheological	Electric potential difference	Stiffness/viscosity change
Type 2 Energy-exchanging		
Electroluminescents	Electric potential difference	Light
Photoluminescents	Radiation	Light
Chemoluminescents	Chemical concentration	Light
Thermoluminescents	Temperature difference	Light
Light-emitting diodes	Electric potential difference	Light
Photovoltaics	Radiation (Light)	Electric potential difference
Type 2 Energy-exchanging (reversible)		
Piezoelectric	Deformation	↔ Electric potential difference
Pyroelectric	Temperature difference	↔ Electric potential difference
Thermoelectric	Temperature difference	↔ Electric potential difference
Electrorestrictive	Electric potential difference	↔ Deformation
Magnetorestrictive	Magnetic field	↔ Deformation

Figure 2.23: Sampling of different types (Addington & Schodek, 2005).

On the other hand, there are many interesting and useful materials with different features; for instance, composites from carbon fiber or a range from new radiant mirror films but those materials are high-performance materials rather than smart because their selected, designed and optimized properties such as high strength, stiffness, particular reflective properties *etc.* are static (Addington & Schodek, 2005). The authors state that smart materials should be able to change their -chemical, thermal, mechanical, magnetic, optical or electrical- properties or provide energy transfer functions. As can be seen from Figure 2.23, the former classified as type 1 and the latter as type 2 by the authors. Also, the authors mention that reversibility and discrete size/location are beneficial properties of smart materials.

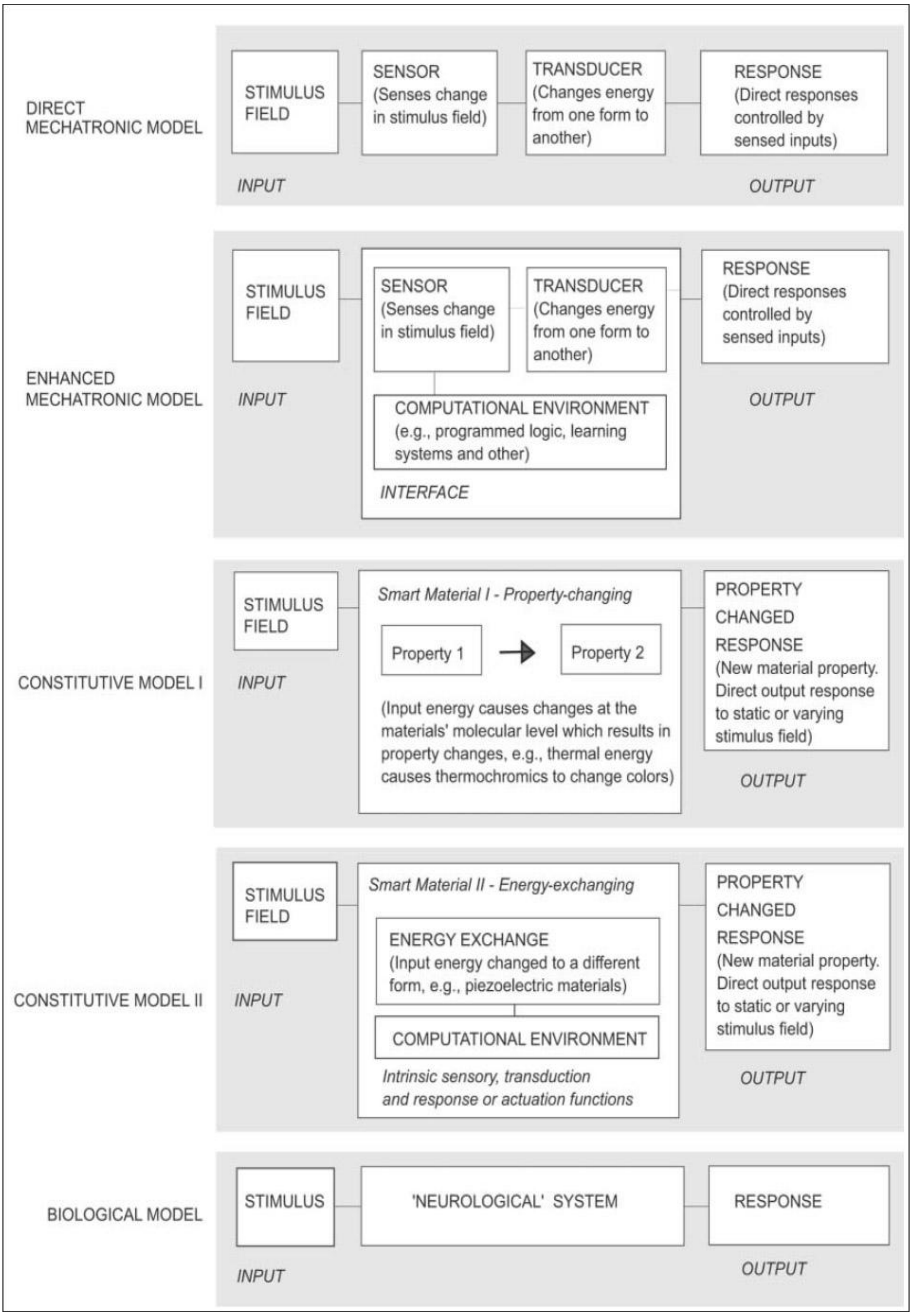

Figure 2.24: Different input/output models

Sensors and response devices have been mentioned as main elements of a smart building in different parts of this study, while energy converters/producers are highly effective for energy performance of buildings. Smart materials which may serve in different roles can be directly translated into roles as sensors, transducers or actuation devices (Addington & Schodek, 2005). As the authors mention, ability to change property in response to changes in environment can be used as a sensor, while energy exchanging materials may be used as sensors and transducers. In addition, the authors mention that some of them may be used as actuators. Light sensors, sound sensors, thermal sensors, humidity sensor, touch sensor, position sensor, proximity sensor, motion sensor, environmental sensors, biosensors, swarms (smart dust), chemical, magnetic and other basic sensors can be totally or partly artifact of smart materials. Moreover, the authors compare smart materials and mechanical electronic (mechatronic) systems in terms of response procedure in order to mention the advantage of smart materials with the possibility of reducing complexity in system since the actions occur internally within the materials as seen from Figure 2.24.

There are many different forms and technologies of smart products with various properties related with luminous environment (transparency, color change, light emission etc.), thermal environment (heat transfer, heat absorption etc.), acoustic environment (sound absorption etc.) and kinetic environment (energy production, energy absorption, shape change etc.) but in architectural terms, what can be done with these materials is more important (Addington & Schodek, 2005).

In order to give examples Addington & Schodek (2005) mention that various glasses with specific properties such as antireflective glass, brightness enhancing glass, glass with low-E coating for thermal performance can be achieved by coating with polymer films and in addition, electro-optical glass technology can be used to produce heated glass. Furthermore, the authors describe the relation in between architectural applications and smart materials with relevant characteristics as can be seen Figure 2.25.

Addington & Schodek (2005) states the important role of façade system including glazing in building energy performance, while the most embraced use of smart materials in architecture takes place in façade systems including thin film coated

BUILDING SYSTEM NEEDS	RELEVANT MATERIAL OR SYSTEM CHARACTERISTICS	REPRESENTATIVE APPLICABLE SMART MATERIALS*
Control of solar radiation transmitting through the building envelope	Spectral absorptvity/transmission of envelope materials	Suspended particle panels Liquid crystal panels Photochromics Electrochromics
	Relative position of envelope material	Louver or panel systems - exterior and exterior radiation (light) sensors -- photovoltaics, photoelectrics - controls/actuators -- shape memory alloys, electro- and magnetorestrictive
Control of conductive heat transfer through the building envelope	Thermal conductivity of envelope materials	Thermotropics, phase-change materials
Control of interior heat generation	Heat capacity of interior material	Phase-change materials
	Relative location of heat source	Thermoelectrics
	Lumen/watt energy conversion	Photoluminescents, electroluminescents, light-emitting diodes
Energy delivery	Conversion of ambient energy to electrical energy	Photovoltaics, micro- and meso energy systems (thermoelectrics, fuel cells)
Optimization of lighting systems	Daylight sensing Illuminance measurements Occupancy sensing	Photovoltaics, photoelectrics, pyroelectrics
	Relative size, location and color of source	Light-emitting diodes (LEDs), electroluminescents
Optimization of HVAC systems	Temperature sensing Humidity sensing Occupancy sensing CO_2 and chemical detection	Thermoelectrics, pyroelectrics, biosensors, chemical sensors, optical MEMS
	Relative location of source and/or sink	Thermoelectrics, phase-change materials, heat pipes
Control of structural systems	Stress and deformation monitoring Crack monitoring Stress and deformation control Vibration monitoring and control Euler buckling control	Fiber-optics, piezoelectrics, electrorheologicals (ERs), magnetorheologicals, shape memory alloys

Figure 2.25: Typical building system design needs and potential smart materials (Addington & Schodek, 2005).

glazing, automated louvers to reject excess solar radiation with energy management control system and double skin façades.

Addington & Schodek (2005) states the important role of façade system including glazing in building energy performance, while the most embraced use of smart materials in architecture takes place in façade systems including thin film coated glazing, automated louvers to reject excess solar radiation with energy management control system and double skin façades.

Smart facades are defined by Wigginton & Harris (2002) as a system including responsive and active elements which are able to provide optimum comfort by automatic self-adjustment with self regulated enhancement to its own building fabric to control the changing conditions between external and internal environments in order to minimize energy usage. To quote the author; "the intelligent fabric of the building envelope turns to a flexible, adaptive and dynamic membrane, rather than a statically inert envelope." Wigginton & Harris (2002) points out that the smart facade can perform up to 10 different functions which are identified as;

- The enhancement of daylight (*e.g.* with light shelves/reflectors)
- The maximization of daylight (*e.g.* full-height glazing/atria)
- Protection from the sun (*e.g.* louvers/blinds)
- Insulation (*e.g.* night-time shutters)
- Ventilation (*e.g.* automatic dampers)
- The collection of heat (*e.g.* solar collectors)
- The rejection of heat (*e.g.* overhangs/ *brise soleil*)
- The attenuation of sound (*e.g.* acoustic dampers)
- The generation of electricity (*e.g.* photovoltaic) and
- The exploitation of pressure differentials (*e.g.* ventilation chimneys).

Accordingly, Addington & Schodek (2005) states the functions of smart windows, which is interactive or switchable surfaces as control of optical transmittance, control of thermal transmittance, control of thermal absorption, control of view as seen from Figure 2.26.

SMART WINDOWS				
System type	Spectral response (bleached to colored)	Interior result visual	Interior result thermal	Input energy
Photochromic	Specular to specular transmission at high UV levels	Reduction in intensity but still transparent	Reduction in transmitted radiation	UV radiation
Thermochromic	Specular to specular transmission at high IR levels	Reduction in intensity but still transparent	Reduction in transmitted radiation	Heat (high surface temperature)
Thermotropic	Specular to diffuse transmission at high and low temperatures	Reduction in intensity and visibility, becomes diffuse	Reduction in transmitted radiation, emitted radiation, and conductivity	Heat (high and/or low surface temperature)
Electrochromic*	Specular to specular transmission toward short wavelength region (blue)	Reduction in intensity	Proportional reduction in transmitted radiation	Voltage or current pulse
Liquid crystal*	Specular to diffuse transmission	Minimal reduction in intensity, reduction in visibility, becomes diffuse	Minimal impact on transmitted radiation	Voltage
Suspended particle*	Specular to diffuse transmission	Reduction in intensity and visibility, becomes diffuse	Minimal impact on transmitted radiation	Current

Figure 2.26: Comparison of smart window features (Addington & Schodek, 2005).

In addition, Wigginton & Harris (2002) define the double skin as a system which can provide possibilities for maximizing daylight and improving energy performance of buildings by involving a second glazed envelope additionally and an example can be seen from Figure 2.27. As the authors mention; solar gains which increase cooling load for building can be minimized by the ventilated cavity as a feature of double façade in summer times, while the double façade can minimize heat loss and improve U-values in the winter times by acting as a buffer zone between the building and the outdoor environment. The authors states the intelligent control systems have been in use for most examples of double façade systems.

Since façade systems include mainly the glass, the structure and blinds, it can be said that smart materials and smart façade systems are directly related with each other. As an advantage of nanotechnology, extremely small sensors can be inserted easily into materials in order to give very advanced feedback and also to offer high-level of control (Clements-Croome, 2004). Some materials as a part of façade can react against to changes or can turn conditions to an advantage such as Active glass which can effectively clean itself when it rains. This kind of reaction not only reverses the effect of rain which naturally makes windows dirty but also brings advantage for operational cost and water saving since there is no need to clean windows anymore.

Figure 2.27: Double skin façade of GlaxoWellcome building (Wigginton & Harris, 2002).

2.4.3 HVAC systems

Heating, ventilation, and air conditioning (HVAC) systems is responsible to provide user comfort by controlling interior climatic condition, so; temperature, humidity, air flow, and overall air quality in the building are maintained by HVAC systems (Sinapoli, 2010). According to the author; boilers, chillers, air-handling units (AHUs), air thermal units (ATUs), and variable air volume equipment (VAV) are main components of HVAC which may become much more complicated by including wide range of components.

Sinapoli (2010) states HVAC systems which ensure user comfort, health, and livable climatic conditions in the building; is responsible for a significant part of energy consumption in the building. Also, the author argue that HVAC systems must be able to respond to different indoor and outdoor conditions such as weather, time of day, various kinds of spaces and occupancy in order to optimize building operation and energy performance simultaneously. The author notes that the rise in energy prices trigger to think about efficiency in HVAC system and technological developments made possible to increase efficiency in HVAC system steadily. Wigginton & Harris (2002) mentions smart technologies are employed to minimize the energy load resulting from the highly serviced elements of heating, ventilation and cooling.

Wigginton & Harris (2002) note attempts which provided with more precise motorized control, are put forward to reduce energy consumption caused from space and water heating by using passive solar strategies. The authors state control systems guarantee the optimized operation of low temperature hot water circuits and the sun is also utilized for water heating by the help of equipments which are able to track the sun automatically for maximum exposure. Sinapoli (2010) mentions the possibility to set an operating schedule for HVAC system in smart network and by the way reduce energy consumption. According to the author controlling with sensors are useful to maximize energy efficiency.

In order to increase effectiveness and achieve greater occupant control, ventilation can be automatically managed by movable elements of the envelope, such as retractable roofs, motorized windows and pneumatic dampers (Wigginton & Harris, 2002). Also, as the authors mention, the moving elements can respond to unfavorable conditions such as the inclement actions of wind and rain by closing themselves automatically, while some of inherent problems faced by natural ventilation, such as air and noise pollution can be overcome by the help of smart control mechanism.

Wigginton & Harris (2002) mention different concepts and elements for minimizing energy usage in ventilation:

- Mixed-mode approach: intelligent control systems are utilized and required to sense and decide to activate mechanical ventilation when it is needed. It is possible to maximize natural ventilation and minimize energy usage by using mechanical ventilation only in extreme conditions.
- Self-regulating vents: This vents supply constant airflow even in changing wind speeds.

- Air distribution system: This system goes through the building structure and can be compared with human circulation system. The system may be occupancy depended, with local fan units operated only when user presence is detected.

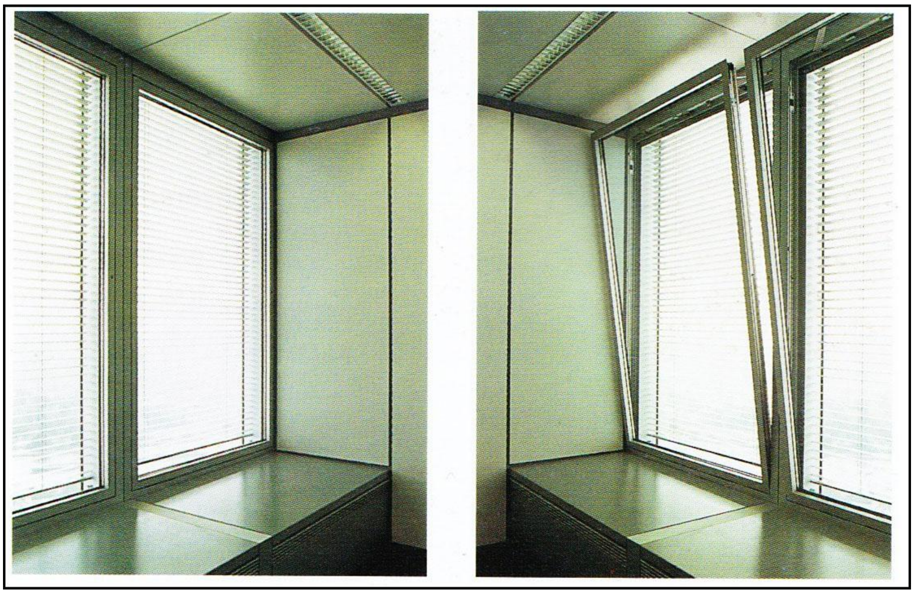

Figure 2.28: Computer controlled windows (Wigginton & Harris, 2002)

As an example, Wigginton & Harris (2002) mention some properties of Commerzbank building;

- Natural ventilation is employed for nearly 60% of total hours of usage and mechanically assisted air conditioning is used only under extreme conditions.
- Not only natural ventilation but also lighting is based on motorized bottom-hinged perimeter windows which can be controlled both by the occupants and the BMS.
- Two principal building management options which vary throughout the day as well as seasons are available: the artificial control of building's climate and low-energy option. The artificial control provide fully operational air conditioning and cooling provided by chilled ceilings, while low-energy

option involves the motorized openings of windows and deactivates air conditioning.

According to Wigginton & Harris (2002), employing night ventilation with computer controls in order to make pre-cooling for the thermal mass is beneficial in some cases as much as controlling passive cooling techniques with mechanical elements, such as earth heat exchanger, borehole water and ground water. Computer controlled ventilation system of Commerzbank building is given as an example in Figure 2.29.

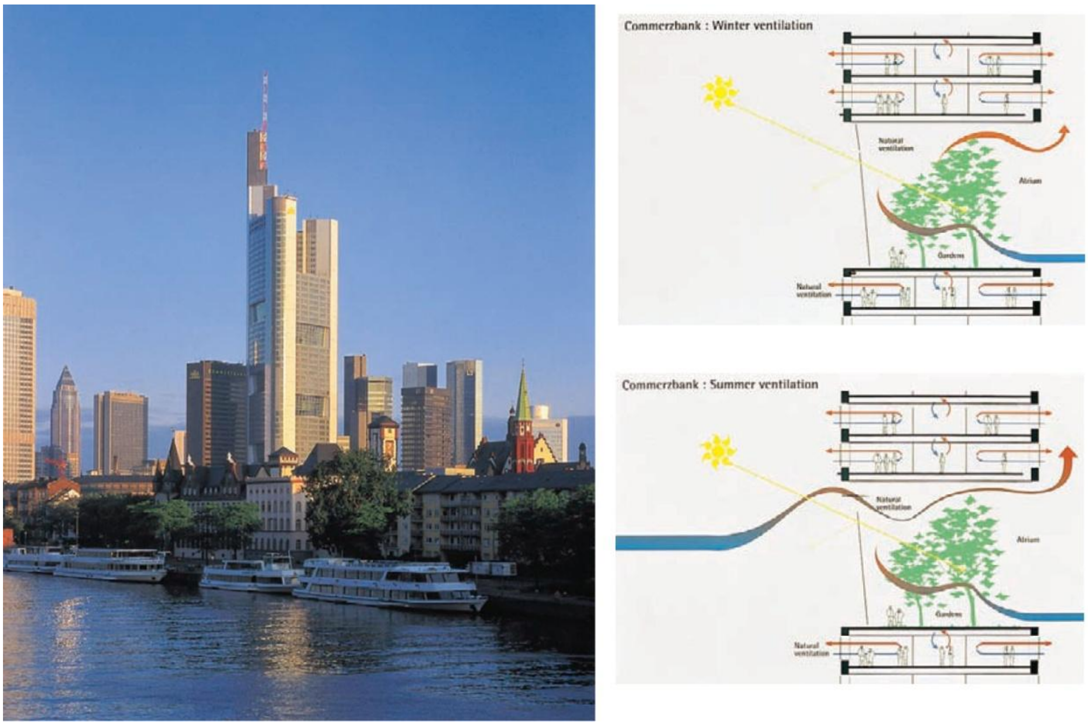

Figure 2.29: Computer controlled ventilation system- Commerzbank (Wigginton & Harris, 2002).

2.4.4 Electrical installations and lighting

So & Chan (1999) state that electricity is the most important energy source in modern buildings and operation of almost all building service systems is dependent on electricity; consequently, the second highest amount of energy consumption in modern building normally comes from lighting systems. In addition, Sinapoli (2010) states that lighting is responsible for 30 or 40% of total electricity consumption for typical buildings where facility lighting is used to ensure visibility for users, desirable ambiance in space and life safety.

Addington & Schodek (2005) mentions an intelligent technology with low energy consumption: inorganic light-emitting diodes (LEDs) which are self actuating, immediate and transient in addition to being discrete and direct. LEDs which are the only lighting technology that offers both dynamism and transiency may be used with the advantage of dynamic controls since transiency brings possibility for any color at any intensity at any time, at the size of a pixel to that of a large surface (Addington & Schodek, 2005). As the authors mention, those features make LEDs appropriate for mood lighting design and individualization possibility; hence, LEDs which aim higher utility, higher flux and lower cost may take place of incandescent and fluorescents. However, the authors state that the most inefficient process in a building is production of artificial (electrical) light, so only improving lamp efficiency may bring just limited energy saving in total.

Maximization of daylight is one of the actions to achieve low-energy design (Wigginton & Harris, 2002). This passive strategy in basic can be supported by active systems as well to control comfort levels. According to Sinapoli (2010), lighting control systems increases efficiency in lighting for users.

Wang (2010) defines the purposes that lighting control systems should meet even manually or automatically:

- Functional need and flexibility of the space
- Energy saving
- Visual comfort of occupants
- The requirements of legislation
- Creating a dynamic or dramatic environment

Although power distribution to the lighting fixtures in lighting control system is same with usual method, smart control is present in various controlling elements including circuit, breaker panel, wall switches, photo cells, occupancy sensors, backup power and lighting fixtures (Sinapoli, 2010). As Wigginton & Harris (2002) mention, various active systems not only provide optimum position for motorized light guiding, light reflecting, and light shading devices by ability to respond to solar angle, but also can help to achieve varying internal demand by adjusting light transmission.

Sinapoli (2010) who mentions the need for lighting in a building is variable according to building type, space organization, time of day, and occupancy, explains the controlling approaches and function of lighting controls as follows:

- Scheduling: operation of lights is controlled by pre-specified schedule with time intervals.
- Occupancy sensors: operation of lights is controlled by sensors with sensibility to occupancy for especially spaces where occupancy is not programmed or foreseeable.
- Daylight: operation of lights is controlled due to daylight levels coming in to space for reducing energy consumption and cost caused by space lighting by maximizing the use of daylight which is also known as day lighting or daylight harvesting.
- Window coatings: although, not being directly related with operation of lights; coatings allow daylight to come in space while preventing overheating caused from some frequencies by working as a filter and it is beneficial for especially for climates where cooling load is dominant.

Sinapoli (2010) notes that lighting has an effect on different building services such as space cooling since demand and cost for space cooling will increase while lighting causes internal heat gain or the inverse is possible for heating due to climate. Wigginton & Harris (2002) mention operation of active lighting control systems depends on the information provided by sensors which measure not only outside light level and solar intensity, but also inside levels and temperature.

Moreover, Sinapoli (2010) note lighting systems are also related with fire alarms, security elements and emergency generators because lighting is also needed in emergency situation to assist evacuation paths for ensuring life safety.

After mentioning importance of lighting control systems, Wang (2010) summarizes typical approaches to achieve efficient energy management and lighting control as:

- activate lighting only in spaces where it is necessary;
- activate lighting in time when it is necessary;
- activate lighting with just right amount;
- maximize day lighting.

In addition; linear control, linear/off control and stepped control are main types of lighting control systems. In linear control which is also known as continuous control, lights are controlled by dimming linearly and continuously due to availability of daylight luminance from minimum electric power where lights stay at the end -*i.e*: minimum light output- to maximum electric power -*i.e*: maximum light output- (Lighting Control, n.d.). Linear/off control which is also called as continuous/off control is same with linear one but lights will be switched off at minimum dimming point. Continuous controls provide idealized lighting control. (Lighting Control, n.d.) Stepped lighting control, on the other hand, switch lighting on/off due to natural light levels in discrete steps. (Lighting Control, n.d.)

2.4.5 Energy generators

Energy production is meaningful as much as overall energy reductions. Electricity generators which extend the concept of buildings with living capabilities are feasible for buildings to deal with electrical autonomy through self-generation; which can be achieved with the installation of photovoltaic panels, wind turbines, and/or combined heat and power systems. (Wigginton & Harris, 2002).

Energy generators such as PV panels and wind turbines are energy converters in fact because they convert energy from different sources such as sun and wind to usable forms of energy, *i.e* electricity. Expected energy production may vary according to the location, orientation, weather conditions, properties of energy producers, amount of solar insolation and design.

Wigginton & Harris (2002) state that photovoltaic (PV) panels greatly support energy efficiency in various examples. It should be noted that appropriate design and application is effective to reach expected energy production since it is related to sun angle and direction. PV panels may be placed not only roofs but also on building envelopes as can be seen from Figure 2.30.

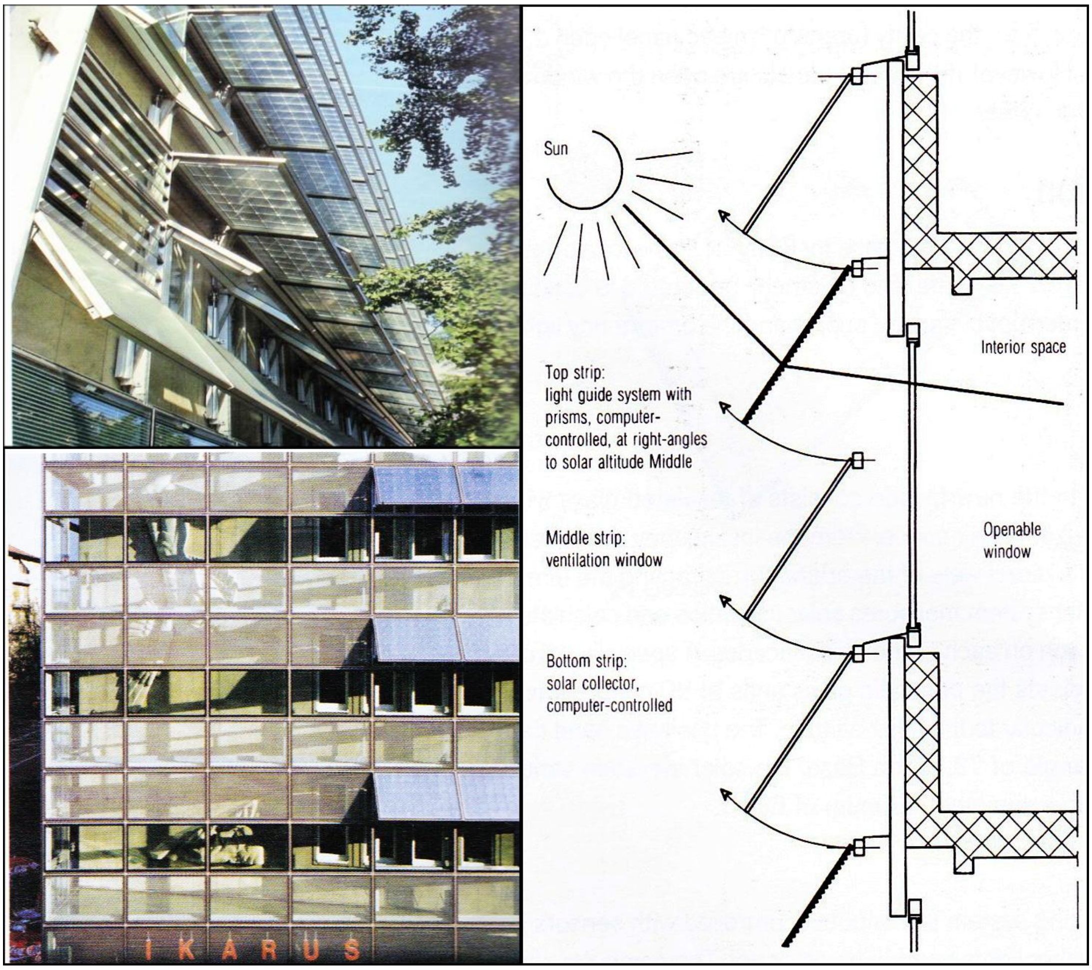

Figure 2.30: Suva insurance company façade section and use of panels (Wigginton & Harris, 2002).

Wind turbines, another energy producer which may be related with buildings, are classified by Günel, Ilgın & Sorguç (2007) into three types: building independent wind turbines, building mounted wind turbines and building integrated wind turbines. The first one will not be discussed in this study since it is not related with architectural design and building structure, while building mounted wind turbines which can be installed on the building after construction are dependent on the building structure even if they are part of architectural form or not (Günel, Ilgın & Sorguç, 2007).

According to Günel, Ilgın & Sorguç (2007) building integrated wind turbines are architecture dependent and can be grouped as structure independent and structure dependent: the former is supported by its own structure but benefits from the aerodynamics of the building form,while the latter influences both architectural and structural decisions. The authors list their advantages as reduction in CO_2 emissions direct energy supply; while the disadvantages are the need for increasing endurance in structural design to handle turbine and wind load and less than expected efficiency.

In future, there may be other smart possibilities to energy production since some studies focused on energy production with different sources, for example production from daylight to produce energy even in cloudy weathers. In addition, a study done by Guigon, Chaillout, Jager & Despesse (2008) focuses on harvesting energy from raindrops.

2.5 Passive design strategies

Passive design strategies have been mentioned in various studies related to green buildings, sustainable buildings, high-performance buildings etc, while passive strategies at urban scale are also effective on the energy performance of building but this section focuses on just building scale strategies for the sake of this study.

According to Brophy & Lewis (2011), bioclimatic heating, cooling, day lighting and energy strategies must be considered at early design stages with architect's other priorities for energy efficiency; since energy consumption can be reduced by as much as 20-35% at no cost with designing the right form in the right orientation. Although, some mechanical systems seem essential in buildings for energy efficiency; their use should be challenged and energy conservation should be the first option (Hestnes, 1997).

According to Hestnes (1997), designing energy efficient buildings require a multi-disciplinary design team. Lovell (2010) agrees with him that architects and engineers should work together from early design stages. In addition, Hestnes (1997) states that the building should be considered as a system in which different technologies are complementary parts of the whole.

Saxhof (1997) defines both passive strategies (such as super-insulation, high-performance windows, transparent insulation, sunspaces, thermal storage) and active systems (such as automation systems, integrated mechanical systems, photovoltaic system, ground coupled heat exchangers) as innovative technologies which have impacts on energy consumption reduction in buildings.

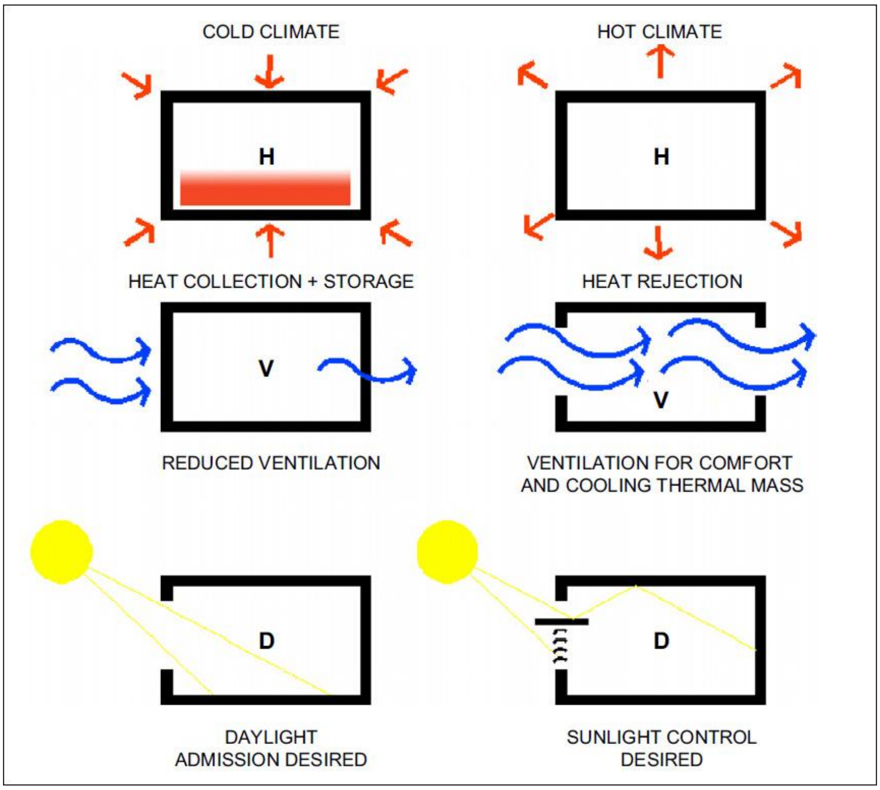

Figure 2.31: Some passive strategies for hot and cold climates (Ochoa & Capeluto, 2008).

Space heating, cooling, ventilation, lighting, water heating and devices used for daily needs are elements of energy consumption in a building. Similarly, Lovell (2010) evaluates the elements related with energy saving in a holistic approach under six titles as air, heat, water, materials, day lighting and energy. According to Balcomb (1997) some main strategies are space heating reduction, cooling load avoidance, water heating saving and electrical supply. To complete these, day lighting and natural ventilation can be mentioned as other main strategies as seen in Figure 2.31.

Space heating reduction can be achieved by reducing transmission loses, reducing infiltration and ventilation loads, recovering heat and using passive solar gain; while cooling load avoidance can be achieved by reducing summer solar gain, incorporating ventilation, using thermal storage and using other passive cooling techniques (Balcomb, 1997). Passive solar gains have great potential to contribute to space heating in all climates and do not lead to overheating if necessary solar protection is used (Hestnes, 1997). The author also mentions the positive effects of passive solar systems such as sunspaces and day lighting systems for energy saving. Lovell (2010) states that properly designed high performance glazing is advantageous for not only heat gain and thermal mass but also day lighting.

Lovell (2010) notes that operating windows should be correctly oriented, planned and sized; otherwise, some problems such as energy waste, noise, inconstant ventilation rates, or air leakage may occur. In addition, the author mentions mix-mode ventilation systems, which employ a combination of natural and mechanical systems with the help of sensors and BMS, and have beneficial potential for some cases.

Natural heating, cooling, ventilation and day lighting are related with each other and should be considered together. Basic strategies to reduce energy consumption can be evaluated simply under; site planning, building form, building envelope, passive solar systems, etc.

2.5.1 Site planning

Site planning which includes orientation, neighborhood density, topography and green spaces is able to bring energy saving by means of heating, cooling, ventilation and daylight (Brophy & Lewis, 2011). According to site situation and climate, orientation which is also related with building form and envelope should be properly considered.

As Brophy & Lewis (2011) mention, south facing façades and glazed areas are beneficial by employing passive solar heating for the buildings in which heating load is dominant. In addition, the authors state overheating can be prevented by shading if needed on south; while it is possible but difficult to shade east and west façades effectively because of sun angle.

On the other hand, Brophy & Lewis (2011) note wind may cause heat loss from building by infiltration and convection so it should be take into account during design while it is possible to modify wind speed and direction by land forms, vegetation, structures and building form.

For cooling, orienting building and designing glazed areas to minimize solar overheating is one of the strategies, while adequate daylight should be considered to minimize internal gains from electric lighting since glazing locations and sizes are important for daylight (Brophy & Lewis, 2011). The authors note that water features may be used for evaporative cooling and shading by vegetation or devices can be used for preventing overheating, while directing wind properly to reduce cooling load is also useful.

In addition, ventilation which can be provided naturally by properly oriented opening windows is not only a part of cooling but also a need for internal air quality in any climate (Brophy & Lewis, 2011).

2.5.2 Building form

Designing spatial organization and the form correctly at the beginning has important effect on energy saving, while changes are difficult or even impossible sometimes and both financially and environmentally costly after building is built (Brophy & Lewis, 2011). The authors state some strategies which are related with the form depends on controlling solar gain and wind to reduce energy consumption as;

- zoning and orienting spaces properly,
- finding optimum shape for building mass,
- designing sunspace, courtyard and atrium,
- adjusting surface to volume ratio and window wall ratio,
- taking ventilation and infiltration into consideration
- locating openings properly,

- adjusting surface areas at different directions according to climate conditions,
- using buffer zones and thermal mass,
- employing overhangs, arcades, shutters and canopies to shade the envelope.

2.5.3 Building envelope

Mediating the effects of climate on the occupants and the energy systems of building, collecting and storing heat, redirecting light, controlling air movement, and generating power are duties which are expected from building envelope in terms of energy, while any building enclosure is already responsible for keeping out wind, rain and damp, letting light in, conserving heat and proving security and privacy (Brophy & Lewis, 2011). The authors mention some strategies for envelope design which may include solid, translucent and transparent elements as;

- modify envelope according to different orientations for heating, cooling and daylight strategies
- design envelope to achieve thermal comfort by means of thermal mass and insulation
- avoid thermal bridge and infiltration
- provide controlled energy efficient ventilation with heat recovery
- integrate appropriate passive components to advance the efficiency by considering potential thermal collection and storage
- consider glazing ratio and position
- consider thermal solar and light transmission properties of materials

Brophy & Lewis (2011) advise the use of active technologies on envelope, for energy production with renewable energy sources. As the authors mention, green roofs, trombe walls, double skin façades, light re-directing and chromic glazing, high performance windows, shading devices are some components of building envelope.

Lovell (2010) mentions that U-value indicates the rate of heat flow lost through an element by conduction for a unit of temperature, while R-value is the resistance to heat flow by a building element. So higher U-value result in higher heat loss, while higher R-value results higher resistance to heat flow.

Daylighting issue should be considered with cooling and heating together, for example winter sun may bring undesired glare with heat and summer sun may bring undesired heat with light (Lovell, 2010). The author mentions daylighting variables are constantly changing according to season, day time and other conditions.

CHAPTER 3

MATERIAL AND METHOD

In this Chapter, the material used and the method of the study is presented. Descriptions and selection criteria of the subject material are given under the material section. The methodology and operational procedure that is used to assess the material is described under the method section.

3.1 Material

In the study, comparative impacts of active systems and passive strategies were investigated on a base-case building by adding various elements on it with computer based building energy simulations.

Function of the base-case building could be one of various types such as residential, commercial, governmental, educational or healthcare. However, type of the building used in this study is chosen as residential since literature review points out that residential buildings has not only highest amount of energy consumption but also highest energy saving potential among building types.

Building typology is effective on design decisions and priorities; one of the reasons is that responsibility of different indicators on energy consumption varies by building function. For example; space heating is responsible for 30.7% of total consumption in residential buildings and 14.2% in commercial ones, while lighting is responsible for 11% of total consumption in residential and 25.5% in commercial (EC, 2007). On the other hand, required interior temperature varies by type and operation systems are different.

The seventeen storey building was constructed in 2011 with reinforced concrete structure by using tunnel formwork system. It represents a good example for typical construction in Turkey over the last decade with arrangement of windows, spatial design and construction method with shear walls.

The building that was chosen as base case is situated on Eskisehir road in Ankara and part of a building complex which includes four identical residential towers. Location of the building is shown in Figure 3.1.

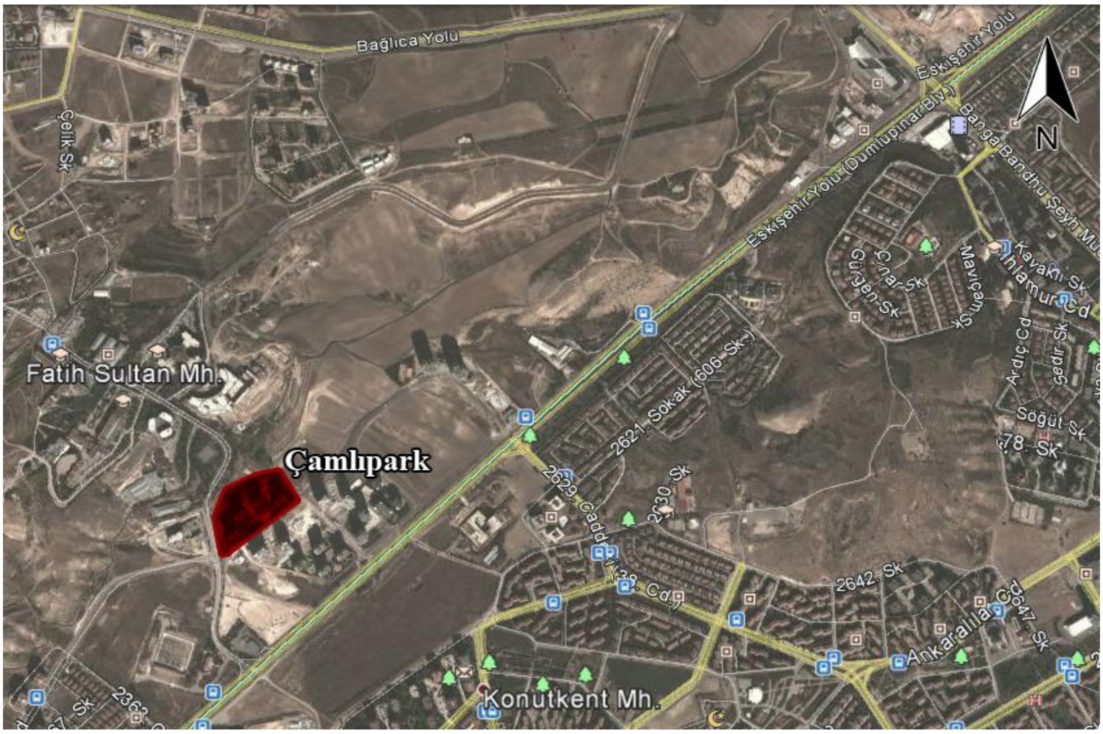

Figure 3.1: Location of the base case building (Google, 2013).

Coordinates is 39° 53'N, 32° 40'E and elevation is 938m for the existing building. Ankara is classified as cold semi arid climate (BSk) in Köppen scale (Lovell, 2010) and is located in the Greenwich Mean Time (GMT) +2 time zone.. Similarly, local climate is described as cold winters and hot summers in Trewartha climate classification; and as semi-arid, mesothermal and close to continental climate in Thornthwaite.

Weather data used for Ankara in this study is International Weather for Energy Calculations (IWEC) data in Energy Plus Weather (EPW) format. The data is average weather data which is generated from 30 years of weather records in order to be suitable for heating and cooling load calculation and it is supplemented by sky coverage, wind speed-direction and illumination, radiation ranges.

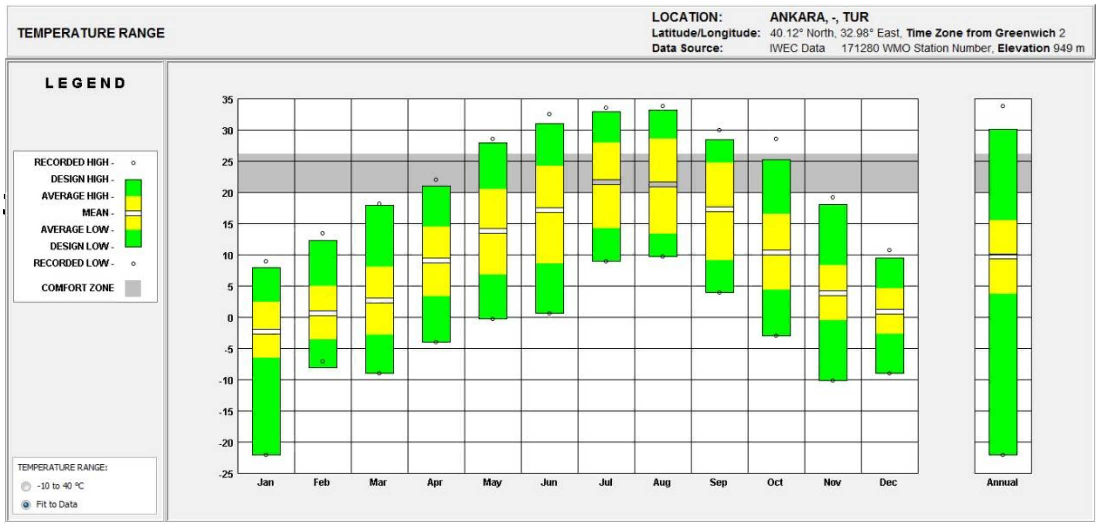

Figure 3.2: Annual temperature range for Ankara

Average annual precipitation in Ankara is 403.8mm for last 40 years and most of precipitation is in autumn time. Hottest months are July and August; coldest month is January. Figure 3.2 shows annual temperature and Figure 3.3 shows monthly diurnal averages for temperature and radiation. There are high differences in temperature between day and night, winter and summer. As can be seen from Figure 3.4, the variations in annual direct solar radiation has similar pattern with temperature values. The highest solar radiation is obtained in July and August, while the lowest values are in January and December. The similar pattern is also present for illumination range which is highest in August and lowest in December. On the other hand, sky coverage range shows an inverse pattern reasonably with highest value at December and lowest at August as seen in Figure 3.5.

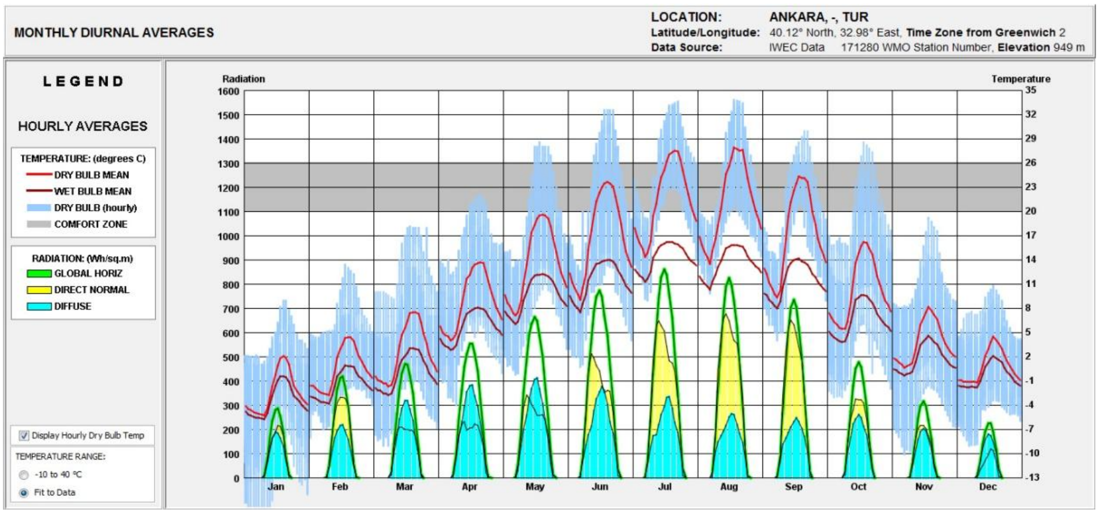

Figure 3.3: Monthly diurnal averages for Ankara.

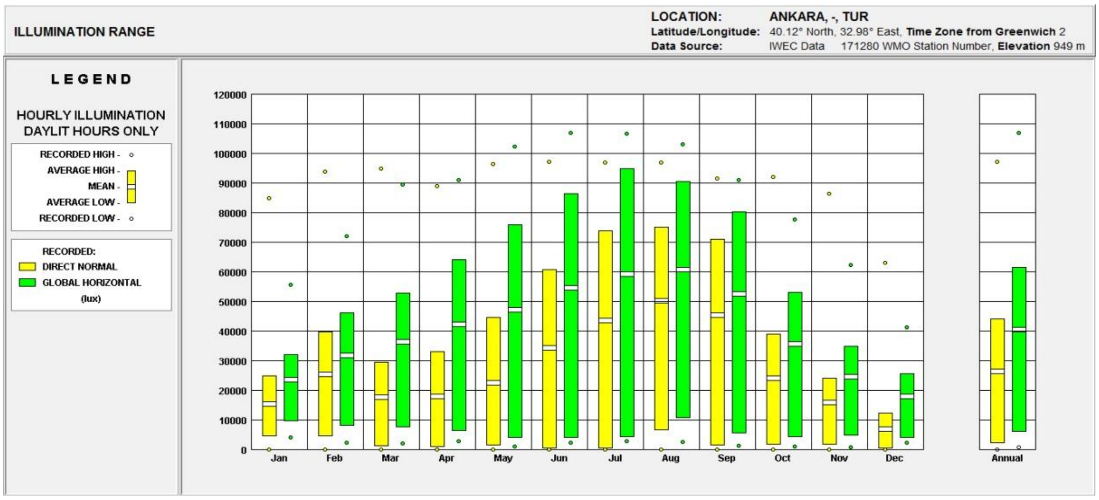

Figure 3.4: Annual illumination range for Ankara.

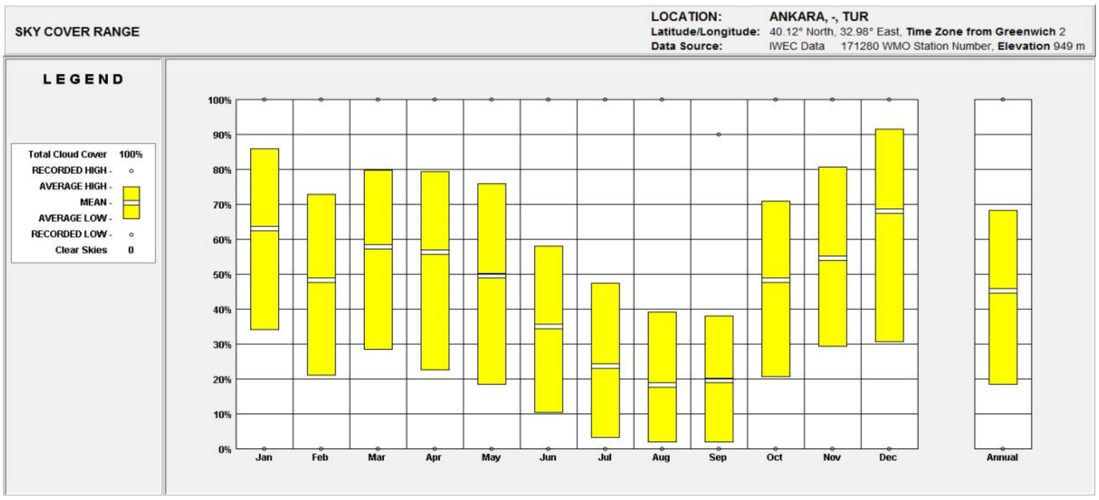

Figure 3.5: Annual sky cover range for Ankara.

As can be seen from Figure 3.6, prevailing wind direction is north-east and north from May to October for Ankara with a temperature range in between 0°C and 20°C. Figure 3.7 shows that winds from south-west shares total time with north-east from October to May, while winds north is present still.

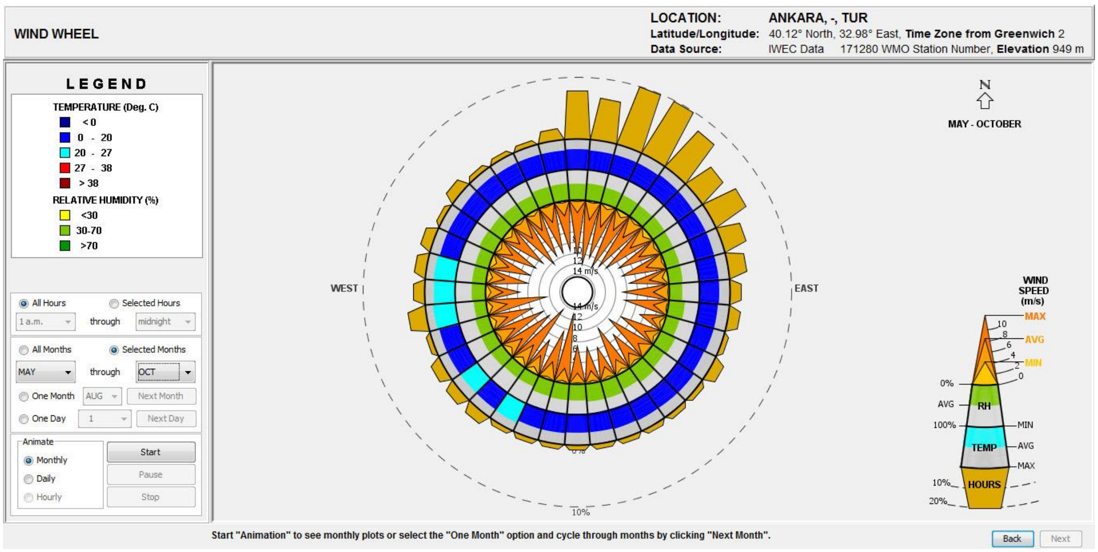

Figure 3.6: Wind wheel for Ankara, from May to October.

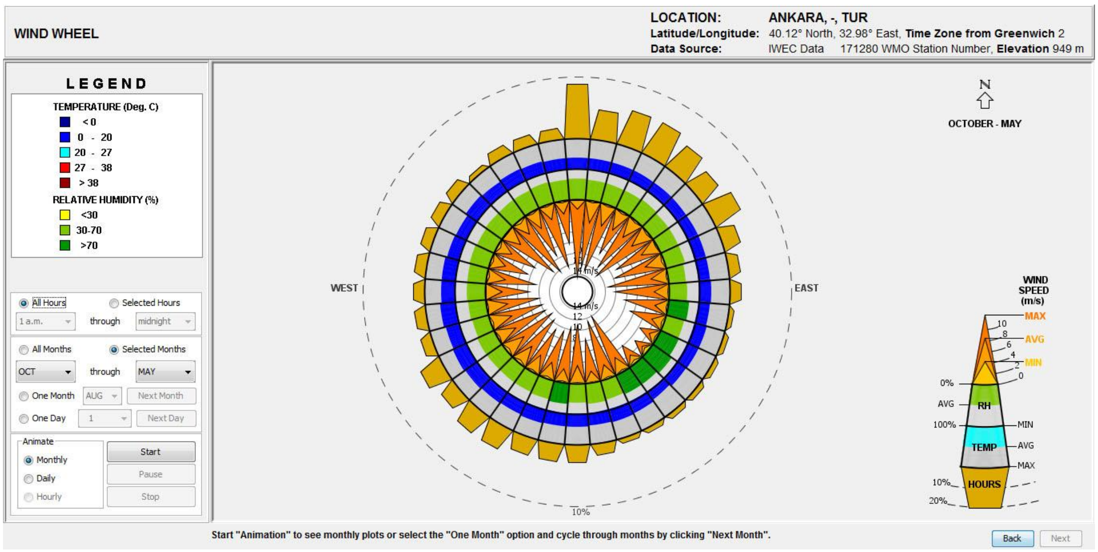

Figure 3.7: Wind wheel for Ankara, from October to May.

The base case residential module that has been evaluated is a part of an existing building and based on the existing building's form, plan, orientation and location. The existing building which carries typical design features for residential buildings in

Turkey is selected and then the materials used in the building is modified according to the minimum requirements of 'Turkish Building Regulations for Thermal Insulation' (TS 825) which is given in the Appendix A, in order to obtain a real base case. In the regulations, Turkey is evaluated in four zones in terms of their climatic conditions and Ankara is in the third zone, while the prescribed U-values are different for different zones. In third zone, maximum U-value is 0.50W/m^{2}K for walls (U_{wall}), 0.30W/m^{2}K for roofs (U_{roof}), 0.45W/m^{2}K for slabs (U_{slab}) and 2.4W/m^{2}K for windows (U_{win}).

Figure 3.8: Site plan of the existing building.

Selected building is noted as A1 in Figure 3.8. Base-case module is at 8th floor, and at north-east side of the building. Net area of the base case residential module is 144 m^2 and it is 156.35 m^2 with 12.35 m^2 balconies. Plan lay out of the module is shown in Figure 3.9. Natural gas based central heating system and panel radiator in modules are present in the existing building for heating. The module, in which floor to floor height is 3m, has view to south-east, south-west and north-west. Also, elevation can be seen from Figure 3.10.

Figure 3.9: Plan of the base case module.

Figure 3.10: Elevation of existing building.

Since active systems have changing reactions to changing conditions, they cannot be evaluated with conventional methods (Ochoa & Capeluto, 2008). Computer based simulations give reasonable and consistent results in comparison with the constructed building (Hestnes, 1997). On the other hand, accuracy of computer based energy/thermal simulations depends on input parameters which should be assigned appropriately and correctly. In other words, knowledge and understanding about both simulation software and building physics are very important to assess a building validly. DesignBuilder software which is an interface for EnergyPlus is used to evaluate active systems and passive strategies in terms of energy saving potential for buildings. DesignBuilder, which is able to use weather data from IWEC for Ankara, allows to assign and test various active and passive parameters for buildings by calculating building energy use on an hourly basis for 8760 hours per year.

3.2 Method

The study uses computer based energy simulations to assess the impact of active systems and passive strategies on energy saving for buildings. As stated before, a residential building which reflects typical residential design features in Turkey is selected and a module in it is used for simulations. While orientation, location, weather and site conditions, building form, window/wall ratio is taken as it is in existing module; building envelope is assigned according to minimum requirements in TS 825. The base-case module has south-east (SE), north-east (NE) and north-west (NW) façades with 50.4% - 19.5% - 22.6% window/wall ratio respectively. Heating set-points are assigned according to ASHRAE 55-2004 standards for the calculations. There is no shading device and no solar system included in design. Natural ventilation is employed by means of operable windows which are operated by user. It is assumed that the user will follow a certain routine and open windows at a specific time interval every day throughout the year. The specific time interval which is assigned according to occupancy period is 7:00am-8:00am and 8:00pm-9:00pm. This was based on the assumption the occupants will leave home at around 8:00 am in the morning to be at work at 9:00 am, and will return home around 7:30pm in the evening; it is also assumed that the occupants will not open windows as soon as they arrive home. Simulation number (SN) 1 deals with the base-case scenario with features given above. Since all neighbor units are same with base-case module, it is assumed that there is no heat transfer between neighbor units for all simulations; they are adiabatic zones. In addition to this, stairwell is also assumed as heated zone and considered as adiabatic in the simulations.

Before starting to test various active and passive building elements, the base-case module is simulated with worst-case orientation which has no view to south in SN2 in order to evaluate impact of orientation better in later parts.

Various active systems and passive strategies which have been chosen in the light of literature survey have been evaluated by adding on to the base-case residential module in three series described in the following paragraphs.

The first series of variation improves the module by addition of only active systems, as can be seen from Table 3.1. All sensor based operations for all systems can be limited by an operation schedule and also interrelated with other systems by means of BMS.

In the first series; sensor based and automatically operated windows for **natural ventilation** is one of the active systems. Sensors are sensitive to interior air temperature and temperature difference between inside and outside. Sensing environments and responding to the conditions according to requirements may bring more efficiency in natural ventilation, while uncontrolled ventilation increases heating load.

- SN3: Natural ventilation is active when air temperature in the zone is higher than 23.5 °C throughout the year.
- SN4: Natural ventilation is active when air temperature in the zone is higher than 23.5 °C and outside temperature is lower at least 2 °C than inside throughout the year.
- SN5: Natural ventilation is active when air temperature in the zone is higher than 23.5 °C in between 30 April and 30 September. Window operation is off during autumn and winter.
- SN6: Natural ventilation is active when air temperature in the zone is higher than 23.5 °C and outside temperature is lower at least 2 °C than inside in between 30 April and 30 September. Window operation is off during autumn and winter.

Another active system is lighting sensors and automated **lighting control** which is able to improve reduction in electricity usage in space lighting by evaluating daylight levels in zones. Required lighting levels for each is zone are assigned according to the standards reported by the Chamber of Electrical Engineer (EMO) in Turkey (see: Appendix B). It is assumed that occupants will also follow a sensor - reaction process and lighting will be active for just occupancy periods. Because of this, occupancy sensors are not used for residential buildings and base-case module is assigned with same occupant control.

- SN7: Linear (continuous) lighting control is used. The lights dim continuously from minimum light output to maximum output as day lighting illuminance decreases.
- SN8: Linear/off (continuous/off) lighting control is used. Reaction is same with linear control but the lights will be switched off at minimum dimming point.
- SN9: Stepped lighting control which turns lights on/off in discrete steps due to level of natural daylight. Control step number is assigned as three.

Table 3.1: Test focuses on base-case and the first series.

	Number	Orientation	Win/Wall Ratio	Envelope	Solar gain systems	Cooling/Ventilation	Shading	Lighting
basecase	**1**	SE-NE-NW	SE: %50.4 NE: %19.5 NW: %22.6	TSE 825	none	natural	none	occupancy
basecase+	**2**	E-N-W	E: 50.4% N:19.5% W:22.6%	TSE 825	none	natural	none	occupancy
Active only	**3**	SE-NE-NW	SE: %50.4 NE: %19.5 NW: %22.6	TSE 825	none	natural + temprature setpoint	none	occupancy
	4	SE-NE-NW	SE: %50.4 NE: %19.5 NW: %22.6	TSE 825	none	natural + temprature + delta t	none	occupancy
	5	SE-NE-NW	SE: %50.4 NE: %19.5 NW: %22.6	TSE 825	none	natural + temprature (summer)	none	occupancy
	6	SE-NE-NW	SE: %50.4 NE: %19.5 NW: %22.6	TSE 825	none	natural + temp + delta t (summer)	none	occupancy
	7	SE-NE-NW	SE: %50.4 NE: %19.5 NW: %22.6	TSE 825	none	natural	none	lineer
	8	SE-NE-NW	SE: %50.4 NE: %19.5 NW: %22.6	TSE 825	none	natural	none	lineer/off
	9	SE-NE-NW	SE: %50.4 NE: %19.5 NW: %22.6	TSE 825	none	natural	none	stepped
	10	SE-NE-NW	SE: %50.4 NE: %19.5 NW: %22.6	TSE 825	none	natural	Daylight (on) CLR	occupancy
	11	SE-NE-NW	SE: %50.4 NE: %19.5 NW: %22.6	TSE 825	none	natural	Daylight (summer) CLR	occupancy
	12	SE-NE-NW	SE: %50.4 NE: %19.5 NW: %22.6	TSE 825	none	natural	Outside air temp (summer) CLR	occupancy
	13	SE-NE-NW	SE: %50.4 NE: %19.5 NW: %22.6	TSE 825	none	natural	Cooling (on) CLR	occupancy
	14	SE-NE-NW	SE: %50.4 NE: %19.5 NW: %22.6	TSE 825	none	natural	NightOutside (winter) HLR	occupancy
	15	SE-NE-NW	SE: %50.4 NE: %19.5 NW: %22.6	TSE 825	none	natural	NightInside (on) HLR	occupancy
	16	SE-NE-NW	SE: %50.4 NE: %19.5 NW: %22.6	TSE 825	none	natural	NightHeating (on) HLR	occupancy
	17	SE-NE-NW	SE: %50.4 NE: %19.5 NW: %22.6	TSE 825	none	natural	NightHeating + DayCooling	occupancy
	18	SE-NE-NW	SE: %50.4 NE: %19.5 NW: %22.6	TSE 825	none	natural	NightOutside + DayCooling	occupancy
	19	SE-NE-NW	SE: %50.4 NE: %19.5 NW: %22.6	TSE 825	none	natural	OutsideTemp (s) + night outside (w)	occupancy
	20	SE-NE-NW	SE: %50.4 NE: %19.5 NW: %22.6	TSE 825	none	natural + temprature (summer)	NightOutside + DayCooling	lineer/off

Table 3.2: Test focuses on the second and the third series.

	Number	Orientation	Win/Wall Ratio	Envelope	Solar gain systems	Cooling/Ventilation	Shading	Lighting
basecase	**1**	SE-NE-NW	SE: %50.4 NE: %19.5 NW: %22.6	TSE 825	none	natural	none	occupancy
basecase+	**2**	E-N-W	E: 50.4% N:19.5% W:22.6%	TSE 825	none	natural	none	occupancy
Passive only	**21**	S-E-N	S: %50.4 E: %19.5 N: %22.6	TSE 825	none	natural	none	occupancy
	22	SW-SE-NE	SW: %50.4 SE: %19.5 NE: %22.6	TSE 825	none	natural	none	occupancy
	23	W-S-E	W: %50.4 S: %19.5 E: %22.6	TSE 825	none	natural	none	occupancy
	24	SW-SE-NE	SW: %56 SE: %47 NE: %22.6	TSE 825	none	natural	none	occupancy
	25	SW-SE-NE	SW: %86 SE: %60 NE: %22.6	TSE 825	none	natural	none	occupancy
	26	SW-SE-NE	SW: %30 SE: %14 NE: %22.6	TSE 825	none	natural	none	occupancy
	27	SE-NE-NW	SE: %50.4 NE: %19.5 NW: %22.6	wall	none	natural	none	occupancy
	28	SE-NE-NW	SE: %50.4 NE: %19.5 NW: %22.6	glazing	none	natural	none	occupancy
	29	SE-NE-NW	SE: %50.4 NE: %19.5 NW: %22.6	infiltration	none	natural	none	occupancy
	30	SE-NE-NW	SE: %50.4 NE: %19.5 NW: %22.6	all	none	natural	none	occupancy
	31	SE-NE-NW	SE: %50.4 NE: %19.5 NW: %22.6	TSE 825	none	natural	external, fixed	occupancy
	32	SE-NE-NW	SE: %50.4 NE: %19.5 NW: %22.6	TSE 825	none	natural+user knowledge	none	occupancy
	33	SE-NE-NW	SE: %50.4 NE: %19.5 NW: %22.6	TSE 825	sunspace	natural	none	occupancy
	34	SE-NE-NW	SE: %50.4 NE: %19.5 NW: %22.6	TSE 825	trombe wall	natural	none	occupancy
	35	SW-SE-NE	SW: %56 SE: %47 NE: %22.6	all	none	natural	none	occupancy
	36	SW-SE-NE	SW: %56 SE: %47 NE: %22.6	all	sunspace	natural	none	occupancy
	37	SW-SE-NE	SW: %56 SE: %47 NE: %22.6	all	sunspace	natural	external, fixed	occupancy
	38	SW-SE-NE	SW: %56 SE: %47 NE: %22.6	wall flazing	sunspace	natural	none	occupancy
Hybrid	**39**	SW-SE-NE	SW: %56 SE: %47 NE: %22.6	all	sunspace	natural + temprature (summer)	NightOutside + DayCooling	lineer/off
	40	SW-SE-NE	SW: %56 SE: %47 NE: %22.6	all	none	natural + temprature (summer)	NightOutside + DayCooling	lineer/off
	41	SW-SE-NE	SW: %56 SE: %47 NE: %22.7	wall glazing	sunpace	natural + temprature (summer)	NightOutside + DayCooling	lineer/off
	42	SW-SE-NE	SW: %56 SE: %47 NE: %22.7	TSE 825	none	natural	none	lineer/off

Another active system is **shading devices** with sensor based operation control. Active shading devices can reduce cooling or heating load while optimizing day lighting by not only daylight sensor, outside / inside air temperature sensors and BMS which coordinates different systems but also smart materials. Shading elements are located outside for all cases.

- SN10: Daylight sensors and photo-chromic glass shading which do not allow daylight more than required lighting levels for zones by getting darker are active throughout the year for cooling load reduction.
- SN11: Daylight sensors and photo-chromic glass shading are active in between 30 April and 30 September. Shading is off for all other days.
- SN12: Blinds with high reflective slats are active when outside temperature exceeds 23 °C in between 30 April and 30 September for cooling load reduction. Shading is off for all other days.
- SN13: Blinds with high reflective slats are on when cooling load is not zero in previous time step throughout the year for cooling load reduction.
- SN14: Transparent insulation is active at night when outside air temperature is less than 21 °C from 30 September to 30 April for heating load reduction. Shading is off for all other days and day time.
- SN15: Transparent insulation is active at night when inside air temperature is less than 21.5 °C throughout the year for heating load reduction. Shading is off during day time.
- SN16: Transparent insulation is active at night when heating load is not zero in previous time step throughout the year for heating load reduction. Shading is off during day time to maximize solar gain.
- SN17: Night heating and day cooling controls are applied together. Transparent insulation is active at night when heating load is not zero in previous time step throughout the year for heating load reduction and shading are active in day time when cooling load is not zero in previous time step throughout the year for cooling load reduction. This type of control helps to cope with temperature differences between day and night.

- SN18: Transparent insulation is active at night when inside air temperature is less than 21.5 °C throughout the year and shading is active at day time when cooling load is not zero in previous time step throughout the year.
- SN19: Shading is active when outside temperature exceeds 23 °C in between 30 April and 30 September for cooling load reduction and it is also active at night when outside air temperature is below 21 °C from 30 September to 30 April for heating load reduction.

The last case for the first series of variation is SN20 which brings together the best of active systems tested including shading, lighting and ventilation controls.

The second series of variation improves the module by addition of only passive strategies, as can be seen from Table 3.2. The strategies which are concern of early design stage are fixed after construction. The first passive strategy in the second series of variation is **orientation** which is directly related with solar gain, daylight, wind exposure and more.

- SN21: Building is tested with South(S), East (E) and North (N) facing position.
- SN22: Building is tested with South-West(SW), South-East (SE) and North-East (NE) facing position.
- SN23: Building is tested with West (W), South(S) and East (E) facing position.

Window/wall ratio is another passive strategy. Since window/wall ratio is dependent to orientation, impact of the ratio is designed and tested with best orientation. Otherwise optimum window/wall ratio for base-case orientation may not bring desirable results for best orientation at the end. In other words, window wall ratio cannot be tested separate from orientation.

- SN24: Window/wall ratio is designed as SW: 56%, SE: 47% and NE:22.6%.
- SN25: Window/wall ratio is designed as SW: 86%, SE: 60% and NE:22.6%.
- SN26: Window/wall ratio is designed as SW: 30%, SE: 14% and NE:22.6%.

Improving envelope is another passive strategy. Building envelope which separates interior and exterior environment is responsible for many functions such as rain control, air control, heat control, daylight control, sound control, vapor control etc.

- SN27: Envelope is improved by changing exterior walls. U_{wall}: 0.15 W/m^2K
- SN28: Envelope is improved by changing windows with a triple glazing window which is available in Turkish market. low-e coatings are applied at second and fifth surfaces. 4(#) +16 air +4 +16 air +(#)4. U_{win}: 0.74 W/m^2K
- SN29: Envelope is improved by reducing air infiltration with extra little insulation. Infiltration rate is assigned as 0.35 ac/h which is the limit for mechanical ventilation necessity.
- SN30: This case bring all improvements together. Infiltration rate: 0.35 ac/h, U_{win}: 0.74 W/m^2K, U_{wall}: 0.15 W/m^2K.

SN31 tests **fixed shading** which is another passive strategy. Fixed overhangs with 0.5m projection are used for south facing windows in order to prevent overheating during summer time and allowing solar gain at winter time by using sun angle. Side fins which are vertical shading elements with 0.5m projection are used for east and west facing windows.

SN32 tests natural ventilation with an optimized schedule. Schedule is optimized by analyzing the weather data and this case assume that the occupant will act as sensor and s/he has already been educated about passive strategies and follows weather forecasts. In between 30April and 30September windows will be opened at specific time interval; 8:00am-8:30am and 8:00pm-00.00am. This optimized user control will not be a part of final evaluation for passive strategies but tries to find out the limit of user impact with an optimistic approach.

Passive solar systems are another strategy in order to reduce heating load. SN33 tests **sunspace** with is located at the same location with the balcony. It can be assume that balcony is closed with glazing. Exterior windows of sunspace will be open between 30 April and 30 September in order to prevent over heating during summer time. For heating season, in between 30 September and 30 April, exterior windows will be operated and interior window will be open every day at specific time interval;

01:00pm-04:00pm. On the other hand, SN34 tests **trombe wall** which is located in between two windows at SE façade of base-case module and contributes living room zone.

Before conclude passive strategies, SN35 brings best orientation, window wall ratio and envelope properties together. SN 36 adds sunspace to SN35 and represents the best of all passive strategies. SN37 adds fixed shading devices to SN36 and analyzes impact of it. SN38 repeats SN36 without infiltration treatment.

The third series of variation improves the module by addition of both passive strategies active systems together, as can be seen from Table 3.2. SN39 designed after evaluating results and composed of the best active or passive elements for each category. So SN39 will reflect energy saving potential of hybrid design. SN40 contain best of active and passive systems except solar systems. SN41 repeats SN39 without infiltration treatment. At the end, SN42 tests best orientation and window wall ratio with best lighting control in order to point out impact of changes in orientation and façades to daylight and saving on electricity.

On the other hand, constant parameters of all simulations are occupancy schedule and density, room electricity, efficiency of machines and electronics, required lighting levels for zones, required minimum fresh air level, DHW usage, heating system and efficiency, lighting sources and their efficiency.

CHAPTER 4

RESULTS AND DISCUSSION

At the beginning, it should be noted that building automation which is the key element of intelligent buildings automatically account for passive strategies while integrating and controlling active systems, which are its main objectives. In other words, building automation enables the following of changes in space with sensors and helps decides what should be done according to space condition. Since passive strategies are effective on space conditions, this kind of awareness makes possible to adjust active systems in coordination with passive strategies in building management level so energy consumption will additionally be reduced by efficient use of active systems.

Before starting to evaluate various scenarios, sections of results should be explained. Comfort analysis section shows discomfort hours for all the year in occupancy period by comparing combination of humidity ratio and operative temperatures with ASHRAE 55-2004 in summer or winter clothes region. Fabric and ventilation section represents heat gains/losses from walls, glazing, external ventilation and infiltration. Gains or losses from floors and ceilings are ignored since neighboring units are defined as adiabatic and so there is no heat transfer occuring in between the units. Interior gain section shows annual total exterior solar gain and it is sensible to glass transparency, shading and solar systems. Gains from general lighting and sensible zone heating are parallel with lighting and heating consumptions and impacts of this parallelism will be mentioned in evaluations. Catering, occupancy, computer and equipment gains and energy consumption will be constant since no input related with them is changed so they will be evaluated separately. Energy consumption caused by lighting and heat generation is given separately. Since evaluating DHW heating, system miscellaneous and room electricity is not within the context of this study, their properties and so consumptions are constant for all cases but their constant consumption is presented in total electricity and gas consumption in addition to lighting and zone heating consumptions, in order to measure energy saving percentage in total. On the other hand, CO_2 production section points out to the amount of CO_2 emissions for the residential unit.

The base-case module which is represented in SN1 will be used for comparison and SN2 which represents worse orientation will be helpful while evaluating impact of orientation in different cases.

The first series, which only tests active systems, starts with improvements on natural ventilation. **Sensor supported, automated windows** do not affect daylight, solar gain and electricity consumption so those data are same for all four cases. SN3, SN4, SN5 and SN6 contributed to comfort hours, energy savings in heat generation and CO_2 emissions reduction in similar ratio but SN6 presented better improvement as can be seen from Table 4.1 in which the best results are shown in bold.

Table 4.1: Impact of natural ventilation with sensors.

	SN1	SN3	SN4	SN5	**SN6**
EXT. VENT. (kWh)	-4498.96	-3821.19	-3815.35	-3643.23	**-3636.27**
HEAT GEN. (kWh)	20787.67	15520.13	15520.60	15428.32	**15427.95**
DISCOMFORT HOURS	2425.51	1935.95	1932.97	1926.44	**1923.30**
C02 (kg)	7016.47	5989.30	5989.40	5971.40	**5971.33**
TOTAL GAS (kWh)	22149.46	16881.92	16882.39	16790.11	**16789.74**
TOTAL ELECTR. (kWh)	3937.71	3937.71	3937.71	3937.71	3937.71

In the light of results, **interior temperature sensor and automation** with set point has notable impact and it may be improved effectively by an operation schedule which does not allow ventilation during winter. On the other hand, it appears that using a delta-T sensor (which measures inside and outside temperature differences) for regulating natural ventilation by opening the windows has very little impact on energy saving, emission reduction and comfort levels. It should be noted that the impact of natural ventilation is more visible in cooling load calculation, but since there is no cooling system installed in the case study building, the contribution of this sensor cannot be seen from heating loads or discomfort hours only. At the end, SN6 which is better than other operation control types brings 5359.72 kWh (≈25% improvement) energy reduction for heat generation and 1045.15 kg emission reduction (≈15% improvement). Also 502 hours are added to the comfort zone.

Another improvement focus in the first series is lighting system which is improved by **lighting control sensors and automated lighting** for electricity saving. Lighting controls do not affects daylight, solar gain, ventilation and infiltration. However, it is affected by daylight and it idealizes electricity consumption for lighting. SN7, SN8 and SN9 contributed to electricity saving for lighting and CO_2 emissions reduction in similar ratio but SN8 presented better improvement as can be seen from Table 4.2 in which the best results are shown in bold.

Table 4.2: Impact of lighting sensors and control systems.

	SN1	SN7	**SN8**	SN9
LIGHTING ELECTR.(kWh)	1395,33	1115,40	**1086,65**	1096,91
HEAT GEN. (GAS) (kWh)	**20787,67**	20952,16	20968,83	20962,31
DISCOMFORT HOURS	2425,51	2418,38	**2417,43**	2418,08
C02 (kg)	7016,47	6856,80	**6840,36**	6846,11
TOTAL GAS (kWh)	**22149,46**	22313,95	22330,62	22324,10
TOTAL ELECTR. (kWh)	3937,71	3657,78	**3629,03**	3639,29

According to these results, it can be said that linear/off control (SN8) which switches the lights off at minimum dimming point is more efficient than linear control (SN7). Although saving by stepped control (SN9) is very close to linear/off control, user comfort in terms of lighting levels will be provided in a better way by linear/off control which is based on continuous dimming instead of stepped response. Since comfort hours given in Table 4.2 is related with thermal comfort, these hours are not a measure for lighting comfort.

On the other hand, it should be noted that heating load may increase while lighting need decreases since internal gain from lighting will decrease by reduction in artificial lighting use. An increase is seen in gas consumption for heat generation and also correspondingly in total gas consumption but this increase is acceptable when it is compared with saving from electricity. Therefore, CO_2 emission stepped down in total.

Finally, SN8 which is better than other lighting control types brings 308.68 kWh (≈22% improvement) energy reduction for lighting and 176.12 kg emission reduction (≈3% improvement). However, SN8 results 181.16 kWh (≈1%) more gas use for heat generation. Relatively, energy saving potential in lighting is limited as a result.

The last improvement focus in the first series is **shading devices** which is movable and improved by sensors and automated control for various purposes. SN10, SN11, SN12 and SN13 mainly serve for cooling load reduction, while S14, SN15 and SN16 serve for heating load reduction. In addition, SN17, SN18 and SN19 employs systems for both heating and cooling load reduction together.

All systems which aim to reduce cooling load and prevent overheating result in an increase in heating load as can be seen from Table 4.3. SN10 and SN11 tests daylight sensors and photo-chromic glass shading. Heat loss from glazing and external infiltration in decreased in SN10 and SN11 because photo-chromic glass shading exists as an additional layer at the outside surface of windows. Since photo-chromic glass just allows required amount of daylight inside, solar gain dramatically falls down. Decrease in heat loss is not enough to balance decrease in solar gain. Results for SN10 in which operation depends only on sensor measurements can be cured by limiting operation with summer times as seen in SN11. Even if this improvement is not enough to bring a desirable result for heating load with 1027.40 kWh increase in consumption, it affects comfort hours positively and adds 417 more hours to comfort zone by preventing overheating. Since daylight sensor for photo-chromic glass is also related with lighting control system, SN10 and SN11 results electricity saving from lighting. There is not much difference in between base-case and SN11 for CO_2 production. Photo-chromic glass shading with daylight sensors are beneficial for thermal comfort when operation is only active during spring and summer (SN11); although, it has not positive effect for energy saving and CO_2 production since there is no cooling system employed in this residential module. For cases which employ cooling systems such as office buildings, SN11 is expected to have a remarkable impact for not only comfort levels but also energy saving and CO_2 production.

Table 4.3: Impact of active shading devices for cooling load reduction.

	SN1	SN10	SN11	SN12	SN13
SOLAR GAIN	**11863.17**	1995.21	6119.45	9281.77	10532.25
H. FLOW - GLZ. (kWh)	-8339.23	**-4551.78**	-5511.51	-7201.35	-7586.51
EXT. INFILT. (kWh)	-11428.77	**-9616.58**	-9932.61	-10638.94	-11068.69
HEAT GEN. (kWh)	20787.67	25521.06	21815.07	21385.16	21345.17
DISCOMFORT HOURS	2425.51	2172.52	**2008.82**	2172.84	2401.96
C02 (kg)	7016.47	7751.10	7028.44	7105.83	7098.03
TOTAL GAS (kWh)	22149.46	26882.85	23176.86	22746.95	22706.96
TOTAL ELCTR. (kWh)	3937.71	**3662.70**	**3662.70**	3937.71	3937.71

On the other hand; SN12 which activates shading when outside air temperature is higher than assigned limit during spring and summer, is effective than SN13 which activates shading when cooling demand is not zero at previous time step throughout the year . Contribution by SN13 to comfort hours is inconsiderable, while SN12 adds 253 hours to comfort zone. Also, SN12 causes less increase in heating load than SN11 but more increase in CO_2 production. As a result, SN11 and SN12 are prominent for cooling load reduction.

On the other hand, systems which aim at heating load reduction as another part of improvements with shading, work at night time so their effect on solar gain is same and not much more, as can be seen from Table 4.4. It can be said that reduction in heat loss from glazing and external infiltration balances the reduction in solar gain for SN14 and SN15 but heat loss reduction is inadequate to balance in SN16. Although, their effects are not so significant; SN 14 and SN15 which work for heating load reduction have similar amount of positive effect on energy saving and CO_2 emissions reduction.

Table 4.4: Impact of active shading devices for heating load reduction.

	SN1	SN14	SN15	SN16
SOLAR GAIN	**11863.17**	10532.25	10532.25	10532.25
H. FLOW - GLAZING (kWh)	-8339.23	-6948.37	-6929.48	-7206.47
EXT. INFILTRATION (kWh)	-11428.77	-11112.08	-11117.44	-11082.83
HEAT GEN. (GAS) (kWh)	20787.67	20512.26	20497.18	20828.03
DISCOMFORT HOURS	2425.51	2378.60	2375.05	2396.75
C02 (kg)	7016.47	6935.62	6932.68	6997.19
TOTAL GAS (kWh)	22149.46	21874.05	21858.97	22189.81
TOTAL ELECTR. (kWh)	3937.71	3937.71	3937.71	3937.71

After testing shading devices for heating and cooling load reduction separately, SN17, SN18 and SN19 employs systems for both heating and cooling load reduction together. As can be seen from Table 4.5; SN17 causes a little increase in gas consumption for heat generation instead of a decrease. SN18 which employs night insulation with shading when outside air temperature is lower than assigned limit at night time and solar shading when interior temperature is higher than assigned limit at day time, represents best energy saving among all shading tests with 330.41 kWh decrease (≈1% improvement) in heat generation and best CO_2 production reduction with 91.58 kg decrease (≈1% improvement).

Table 4.5: Impact of active shading devices for both heating and cooling reduction.

	SN1	SN17	SN18	SN19
SOLAR GAIN	**11863.17**	10532.25	10532.25	9271.06
H. FLOW - GLAZING (kWh)	-8339.23	-7206.47	-6711.32	-6562.63
EXT. INFILTRATION (kWh)	-11428.77	-11082.83	-11218.94	-10679.90
HEAT GEN. (GAS) (kWh)	20787.67	20828.03	**20457.27**	20566.41
DISCOMFORT HOURS	2425.51	2396.75	2406.57	2143.44
C02 (kg)	7016.47	6997.19	**6924.89**	6970.73
TOTAL GAS (kWh)	22149.46	22189.81	**21819.05**	21846.69
TOTAL ELECTR. (kWh)	3937.71	3937.71	3937.71	3937.71

It should be noted that SN18 is not best case for comfort hours. As a result; impact of night insulation with properties assigned in this study is not impressive for energy saving. In addition, solar shading is effective for preventing overheating and increasing comfort hours but energy saving potential has not been tested since there is no cooling system in the case study residential module.

At the end of the first series of simulation variations; SN5, SN8, SN18 come together in SN20, which tests the best active systems used together. SN5 is preferred instead of SN6 because inside and outside temperature difference sensor has very little effect for energy saving, emission reduction and comfort so adding one more sensor is unnecessary.

Table 4.6: Impact of the best active systems together.

	SN1	SN20
SOLAR GAIN	**11863.17**	**11863.17**
H. FLOW - GLAZING (kWh)	-8339.23	**-6404.34**
EXT. INFILTRATION (kWh)	-11428.77	**-10453.85**
EXTERNAL VENT. (kWh)	-4498.96	**-3730.75**
LIGHTING ELECTR.(kWh)	1395.33	**1086.65**
HEAT GEN. (GAS) (kWh)	20787.67	**14734.89**
DISCOMFORT HOURS	2425.51	**1903.83**
C02 (kg)	7016.47	**5624.74**
TOTAL GAS (kWh)	22149.46	**16096.67**
TOTAL ELECTR. (kWh)	3937.71	**3629.03**

As can be seen from Table 4.6, heat losses are reduced by1934,89 kWh for heat flow from glazing, 974.92 kWh for external infiltration and 768.21 kWh for external ventilation by active systems that are tested in the study. In addition, CO_2 emissions are reduced by 1391.74 kg (≈20% improvement) for a year and 522 hours are added to comfort zone. Energy savings that come up with active systems are 308.68 kWh (≈22% improvement) from lighting electricity and 6052.78 kWh (≈29% improvement) from heat generation. In other words, active systems provide approximately 27% improvement for total gas consumption which includes DHW and space heating, and about 8% improvement for total electricity consumption which includes room electricity, system miscellaneous and lighting electricity.

The second series, which tests passive strategies only, starts with improvements on **orientation** which has effect on many outputs. SN21, SN22 and SN23 test building energy performance for various orientations.

Table 4.7: Impact of orientation.

	SN1	*SN2*	SN21	SN22	SN23
SOLAR GAIN	11863.17	11391.75	11694.72	12714.65	**12745.24**
H. FLOW - GLZNG (kWh)	-8339.23	-8268.71	**-8022.35**	-8205.05	-8232.17
H.FLOW - WALL (kWh)	-5033.19	-5043.95	**-4881.27**	-5000.14	-5003.72
EXT. INFILT. (kWh)	-11428.77	-11411.20	**-11183.00**	-11572.22	-11746.97
EXTERNAL VENT. (kWh)	-4498.96	-4541.39	**-4401.88**	-4522.36	-4596.19
LIGHTING ELECT.(kWh)	1395.33	1395.33	1395.33	1395.33	1395.33
HEAT GEN. (GAS) (kWh)	20787.67	21502.53	19837.26	**19554.45**	19903.47
DISCOMFORT HOURS	2425.51	2470.51	**2297.06**	2396.08	2464.21
C02 (kg)	7016.47	7155.87	6831.14	**6776.00**	6844.06
TOTAL GAS (kWh)	22149.46	22864.32	21199.04	**20916.24**	21265.26
TOTAL ELECTR. (kWh)	3937.71	3937.71	3937.71	3937.71	3937.71

As seen from Table 4.7, SN22 presents best results for energy saving and CO_2 emission reduction. When wind direction, speed and temperature are considered for separate seasons, SN21 has the best orientation and reduces heat losses but this orientation is not good for solar gain. SN23 is exact opposite of SN21, that is, good for solar gain but not good for wind. SN22 achieve the balance in between losses (wind) and gains (sun). As a result, SN22 provides 1233.22 kWh saving (≈6% improvement) from heat generation and 240.48 kg reduction (≈3% improvement) in CO_2 production in comparison with base-case (SN1). Also, it adds 30 more hours to comfort zone. Since no lighting sensor is employed in this case, impact of orientation on daylight use is not measured. In order to evaluate impact of orientation much better, SN22 should be compared with the worst orientation because base-case orientation is not the worst one. SN2 tests an orientation which has no view to south. If SN22 compared with SN2, it can be said that SN22 provide 1948 kWh saving

(≈9% improvement) from heat generation and 379.88 kg reduction (≈5% improvement) in CO_2 production. Also, it adds 75 hours to comfort zone.

Another improvement focus in the second series is **window-wall ratio**. Window wall ratio is tested on best orientation (SN22) because window size consideration is dependent to orientation.

Table 4.8: Impact of window-wall ratio.

	SN1	SN24	SN25	SN26
SOLAR GAIN	11863.17	18497.81	**23110.50**	8495.34
H. FLOW - GLAZING (kWh)	-8339.23	-12603.56	-17260.10	**-5427.36**
H.FLOW - WALL (kWh)	-5033.19	-4658.17	**-3765.41**	-5011.17
EXT. INFILTRATION (kWh)	-11428.77	-12352.28	-12585.32	**-10850.47**
EXTERNAL VENT. (kWh)	-4498.96	-4664.93	-4688.92	**-4377.34**
LIGHTING ELECTR.(kWh)	1395.33	1395.33	1395.33	1395.33
HEAT GEN. (GAS) (kWh)	20787.67	**19102.28**	19611.05	20357.01
DISCOMFORT HOURS	2425.51	2459.33	2472.49	**2348.13**
C02 (kg)	7016.47	**6687.82**	6787.03	6932.49
TOTAL GAS (kWh)	22149.46	**20464.07**	20972.84	21718.80
TOTAL ELECTR. (kWh)	3937.71	3937.71	3937.71	3937.71

An optimum for window-wall ratio should be found because enlarging window area increases not only solar gain but also heat loss and making window area smaller decreases not only heat loss but also solar gain. As can be seen from Table 4.8; SN24 which provides the best improvement, put 452.17 kWh more saving for heat generation and 88.17 kg more reduction for CO_2 emissions on SN22. In other words, SN24 provide 1685.39 kWh saving (≈8% improvement) from heat generation and 328.65 kg reduction (≈5% improvement) from CO_2 emissions.

Envelope is another improvement focus in the second series. Cases tested for envelope improvements aims to point out impact of wall, glazing and infiltration. While exterior walls of base-case module is assigned with U value: 0.50Wm^{2}K according to TS825, exterior walls are upgraded in SN27 to 0.15 Wm^{2}K with extra insulation and changing materials used. Also, wall thickness is increased from 33.6cm to 37.6cm. As a result, this upgrade provides 3053 kWh gas saving (≈15% improvement) from heating generation and 595.38 kg reduction (≈8% improvement) in CO_2 production by 3362.61kWh reduction from heat loss from wall as can be seen from Table 4.9.

Table 4.9: Impact of envelope improvements.

	SN1	SN27	SN28	SN29	SN30
SOLAR GAIN	11863.17	11863.17	6270.34	11863.17	6270.34
H. FLOW - GLZNG (kWh)	-8339.23	-8982.04	-662.90	-9182.56	-1452.39
H.FLOW - WALL (kWh)	-5033.19	-1670.58	-4992.19	-5440.62	-1908.52
EXT. INFILT. (kWh)	-11428.77	-11974.86	-11375.02	-6209.38	-6940.25
EXTERNAL VENT. (kWh)	-4498.96	-4599.99	-4467.04	-4671.78	-4952.09
LIGHTING ELECT.(kWh)	1395.33	1395.33	1395.33	1395.33	1395.33
HEAT GEN. (GAS) (kWh)	20787.67	17734.46	17601.11	15161.73	8542.11
DISCOMFORT HOURS	2425.51	2443.22	2364.09	2454.09	2354.92
C02 (kg)	7016.47	6421.10	6395.09	5919.42	4628.59
TOTAL GAS (kWh)	22149.46	19096.24	18962.89	16523.52	9903.90
TOTAL ELECTR. (kWh)	3937.71	3937.71	3937.71	3937.71	3937.71

Improvements on **glazing** is tested in SN28 and double glazing windows are upgraded to triple glazing window with low-E coatings. According to results seen in Table 4.9, this upgrade provides 3186.56 kWh saving (≈15% improvement) from heat generation and 621.38 kg reduction (≈9% improvement) from CO_2 production. It should be noted that there is 5592.83 kWh decrease in solar gains since solar transmittance of glazing is changed but decrease in heat losses from glazing is higher with 7676.33 kWh so saving is achieved. While it is known that change in glazing will affect daylight which is not test in SN28 since no lighting sensor is installed.

Another case, SN29, tested impact of **infiltration**. While infiltration is assumed as 0.70 ach for base-case, target is 0.35 ach with extra little insulation for improved case. As a result, this strategy provide 5625.94 kWh saving (≈27% improvement) from heat generation and 1097.06 kg reduction (≈16% improvement) in CO_2 production by reducing external infiltration 5219.39 kWh as can be seen from Table 4.9.

At the end, SN 30 tested improvements in SN27, SN28 and SN29 together to point out impact of envelope. Results in Table 4.9 shows that high level improvements on envelope provide 12245.56 kWh saving (≈59% improvement) from heat generation and 2387.89 kg reduction (≈34% improvement) for CO_2 production. In other words, ≈55% improvement is achieved for total gas consumption.

Shading with **fixed external shadings** is another improvement focus in the second series. Overhangs at south facing facades and side-fins at east-west facing facades are tested together in SN31. As can be seen from Table 4.10, fixed shadings causes extra consumption instead of saving and extra emission accordingly as a result of decrease in solar gain during winter and autumn times. It should be noted that fixed shadings is beneficial to increase comfort hours in summer and spring times. Movable but not automated shading devices which are controlled by occupants can be an alternative but occupants plays role of sensor and central computer in this case.

Table 4.10: Impact of external fixed shading.

	SN1	SN31
SOLAR GAIN	11863.17	9710.86
H. FLOW - GLAZING (kWh)	-8339.23	-7827.00
H.FLOW - WALL (kWh)	-5033.19	-4708.79
EXT. INFILTRATION (kWh)	-11428.77	-10858.73
EXTERNAL VENT. (kWh)	-4498.96	-4382.04
LIGHTING ELECTR.(kWh)	1395.33	1395.33
HEAT GEN. (GAS) (kWh)	20787.67	21690.68
DISCOMFORT HOURS	2425.51	2369.98
C02 (kg)	7016.47	7192.56
TOTAL GAS (kWh)	22149.46	23052.46
TOTAL ELECTR. (kWh)	3937.71	3937.71

The role of **occupants** is issue of another debate which requires further research and user knowledge cannot be tested with computer simulation but SN32 aims to test limits on natural ventilation and discuss similarities in between human being and smart buildings in terms of sensing, deciding and responding process. 4873.93 kWh saving from heat generation and 950.42 kg reduction in CO_2 emission are achieved in SN32 as can be seen from Table 4.11. These results are close to results in SN5 which employs active control systems. Since user control schedule is assigned according to annual hourly weather data, user reaction is assumed as precise as sensors and automation in this scenario. SN32 which does not aim to put human being and machines in a competition, but tries to draw attention to the logic behind building automation which is programmed by occupants themselves. Occupants may control all systems manually according to their instant need and knowledge on environment-building relation may increase success to achieve comfort with energy saving but this means extra work and need for an effort. Active systems, on the other hand, make the same in a precise way and liberates the occupants to think about the issue. Occupants can feel an increase in temperature, so sensors measures temperature. Occupants decide to open windows when they decide that space is hot, so central computer can decide to open windows according to limits which are assigned by occupants. Occupants respond by opening window and so building automation can open automated window. Also, each occupant may react differently and assessment of user impact may be concern of another study.

Table 4.11: Impact of user control with knowledge.

	SN1	SN32
SOLAR GAIN	11863.17	11863.17
H. FLOW - GLAZING (kWh)	-8339.23	-8065.00
H.FLOW - WALL (kWh)	-5033.19	-4893.32
EXT. INFILTRATION (kWh)	-11428.77	-11109.77
EXTERNAL VENT. (kWh)	-4498.96	-2110.98
LIGHTING ELECTR.(kWh)	1395.33	1395.33
HEAT GEN. (GAS) (kWh)	20787.67	15913.74
DISCOMFORT HOURS	2425.51	2314.23
C02 (kg)	7016.47	6066.06
TOTAL GAS (kWh)	22149.46	17275.52
TOTAL ELECTR. (kWh)	3937.71	3937.71

Solar systems are another improvement focus in the second series. SN33 tests impact of sunspace, while SN34 tests impact of trombe wall. **Sunspace** provides 978.50 kWh saving (≈5% improvement) from heat generation and 166.86 kg reduction (≈2% improvement) in CO_2 emission by increasing solar gain 5302.97 kWh according to results seen in Table 4.12. In other words, sunspace provides ≈4% improvement for total gas consumption. Since closed balconies which are very popular in Turkey as a trend among occupants, may be designed as sunspaces. As can be seen from Table 4.12, **trombe wall** which is added to south facing facade of living room provide limited improvement since trombe wall is shaded by balcony and area is limited in facade design of existing building to add a trombe wall. Therefore; trombe wall may be more effective for another design. It should be noted that exterior wall of living is expanded into the space and niches take place as a result of trombe wall.

Table 4.12: Impact of solar systems.

	SN1	SN33	SN34
SOLAR GAIN	11863.17	17166.14	11976.68
H. FLOW - GLAZING (kWh)	-8339.23	-10136.82	-8546.34
H.FLOW - WALL (kWh)	-5033.19	-4597.45	-4834.26
EXT. INFILTRATION (kWh)	-11428.77	-12322.02	-11554.91
EXTERNAL VENT. (kWh)	-4498.96	-5623.07	-4526.23
LIGHTING ELECTR.(kWh)	1395.33	1395.33	1395.33
HEAT GEN. (GAS) (kWh)	20787.67	19809.17	20692.54
DISCOMFORT HOURS	2425.51	2291.43	2443.18
C02 (kg)	7016.47	6849.61	6994.17
TOTAL GAS (kWh)	22149.46	21174.28	22052.48
TOTAL ELECTR. (kWh)	3937.71	3937.71	3937.71

Before concluding the second series of variations, collective effect of passive strategies is tested. SN35 which brings the best orientation, window-wall ratio and envelope together, provide 13891.05 kWh saving (≈67% improvement) from heat generation and 2708.76 kg reduction (≈39% improvement) from CO_2 emissions as seen in Table 4.13. This means approximately 63% improvement in total gas consumption for the occupants who prefer balcony as it is instead of sunspace.

SN36, which also adds sunspace to SN35 and presents all best passive strategies together, provide 14022.56 kWh saving (≈67% improvement) from heat generation and 2710.45 kg reduction (≈39% improvement) from CO_2 emissions as can be seen from Table 4.13. This means approximately 63% improvement in total gas consumption. It should be noted that daylight improvements have not seen in the results for passive strategies since no daylight sensor is employed for the second series but the impact will be evaluated in the third series.

Table 4.13: Impact of passive strategies together.

	SN1	SN35	SN36	SN37	SN38
SOLAR GAIN	11863.17	9765.80	12379.51	11146.37	12379.51
H. FLOW - GLZING (kWh)	-8339.23	-2246.06	-2135.57	-2158.03	-1093.48
H.FLOW - WALL (kWh)	-5033.19	-1825.81	-1622.97	-1537.68	-1395.74
EXT. INFILT. (kWh)	-11428.77	-7862.41	-8375.52	-7944.18	-14234.91
EXTERNAL VENT. (kWh)	-4498.96	-5350.22	-6722.04	-6402.44	-6060.73
LIGHTING ELECT.(kWh)	1395.33	1395.33	1395.33	1395.33	1395.33
HEAT GEN. (GAS) (kWh)	20787.67	6896.62	6765.12	7193.30	12259.15
DISCOMFORT HOURS	2425.51	2373.25	2245.63	2209.50	2237.84
C02 (kg)	7016.47	4307.72	4306.02	4389.52	5377.36
TOTAL GAS (kWh)	22149.46	8258.41	8130.22	8558.41	13624.26
TOTAL ELECTR. (kWh)	3937.71	3937.71	3937.71	3937.71	3937.71

SN37 adds fixed **shading devices** which increase energy consumption and comfort hours at the same time to SN36. SN37 provides 13594.37 kWh saving (≈65% improvement) from heat generation and 2626.96 kg reduction (≈37% improvement) from CO_2 emissions. This means approximately 61% improvement in total gas consumption. Also SN37 adds 216 more hours to comfort zone in comparison with base-case.

SN38 withdraws infiltration improvements from SN36 by taking poor workmanship into consideration for some cases, while poor workmanship is inevitable or not is another debate. SN38 provides 8528.52 kWh saving (≈41% improvement) from heat generation and 1639.12 kg reduction (≈23% improvement) from CO_2 emissions. This means 38% improvement in total gas consumption.

The third series tests active systems and passive strategies together. As a result, SN39, which puts best improvements together, provide 18436.82 kWh saving (≈89% improvement) from heat generation, 310.38 kWh saving (≈22% improvement) from lighting electricity and 3786.17 kg reduction (≈54% improvement) from CO_2 emissions according to results seen from Table 4.14. This means approximately 83% improvement for total gas consumption and 9% improvement for total electricity consumption. Also, 1007 hours are added to comfort zone. On the other hand; if sunspace is not preferred (SN40), saving will be 18326.32 for heat generation because of the decrease in solar gain and comfort hours are effected badly as can be seen from Table 4.14.

Table 4.14: Impact of the best active systems and passive strategies together.

	SN1	*SN2*	SN39	SN40
SOLAR GAIN	11863.17	11391.75	12379.51	9765.80
H. FLOW - GLZING (kWh)	-8339.23	-8268.71	-628.48	-1822.77
H.FLOW - WALL (kWh)	-5033.19	-5043.95	-1326.47	-1799.39
EXT. INFILT. (kWh)	-11428.77	-11411.20	-6823.35	-7731.95
EXTERNAL VENT. (kWh)	-4498.96	-4541.39	-7568.61	-2976.24
LIGHTING ELECTR.(kWh)	1395.33	1395.33	1084.95	1084.79
HEAT GEN. (GAS) (kWh)	20787.67	21502.53	2350.85	2461.35
DISCOMFORT HOURS	2425.51	2470.51	1418.88	2299.12
C02 (kg)	7016.47	7155.87	3230.30	3230.13
TOTAL GAS (kWh)	22149.46	22864.32	3715.95	3823.14
TOTAL ELECTR. (kWh)	3937.71	3937.71	3657.94	3627.17

Since poor workmanship is taken into consideration for some cases, SN41 withdraws infiltration improvements from SN39 which is the best combination of active systems and passive strategies. As can be seen from Table 4.15, SN41 provides 13506.18kWh saving (65% improvement) from heat generation and 2824.70 kg reduction (40% improvement) from CO_2 emissions. Lighting electricity saving is same since infiltration is not related with electricity.

Table 4.15: Impact of various components.

	SN1	SN41	SN42
SOLAR GAIN	11863.17	12379.51	18497.81
H. FLOW - GLAZING (kWh)	-8339.23	-27.40	-12524.78
H.FLOW - WALL (kWh)	-5033.19	-1200.49	-4628.53
EXT. INFILTRATION (kWh)	-11428.77	-12276.13	-12293.06
EXTERNAL VENT. (kWh)	-4498.96	-6045.98	-4649.06
LIGHTING ELECTR.(kWh)	1395.33	1084.95	1080.24
HEAT GEN. (GAS) (kWh)	20787.67	7281.49	19264.21
DISCOMFORT HOURS	2425.51	1574.59	2452.61
C02 (kg)	7016.47	4191.77	6503.56
TOTAL GAS (kWh)	22149.46	8646.60	20626.00
TOTAL ELECTR. (kWh)	3937.71	3657.94	3622.61

Finally, SN42 tests the impact of orientation and window-wall ratio to daylight. SN42 provide 315kWh saving from lighting electricity as can be seen from Table 4.15. This result is better than SN8 which employs lighting control sensors on base-case orientation with just 6.42 kWh annually. For existing module and tested scenario, impact of window-wall ratio on daylight is not impressive since window-wall ratio is not changed extremely. However, it should be mentioned that every little saving for each module will have great impact for energy saving in wide scale when the state is considered. Also, results for different scenarios are given together in figures, from Figure 4.1 to Figure 4.8.

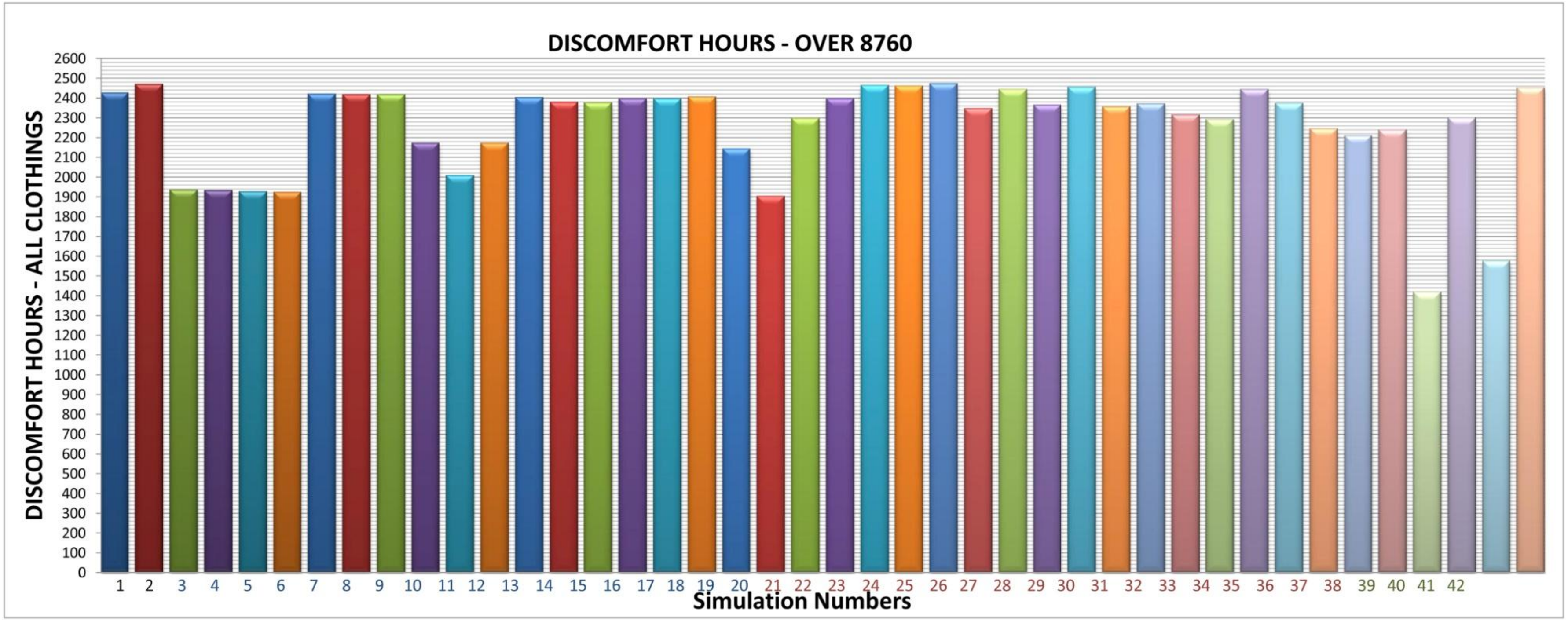

Figure 4.1: Annual discomfort hours for scenarios.

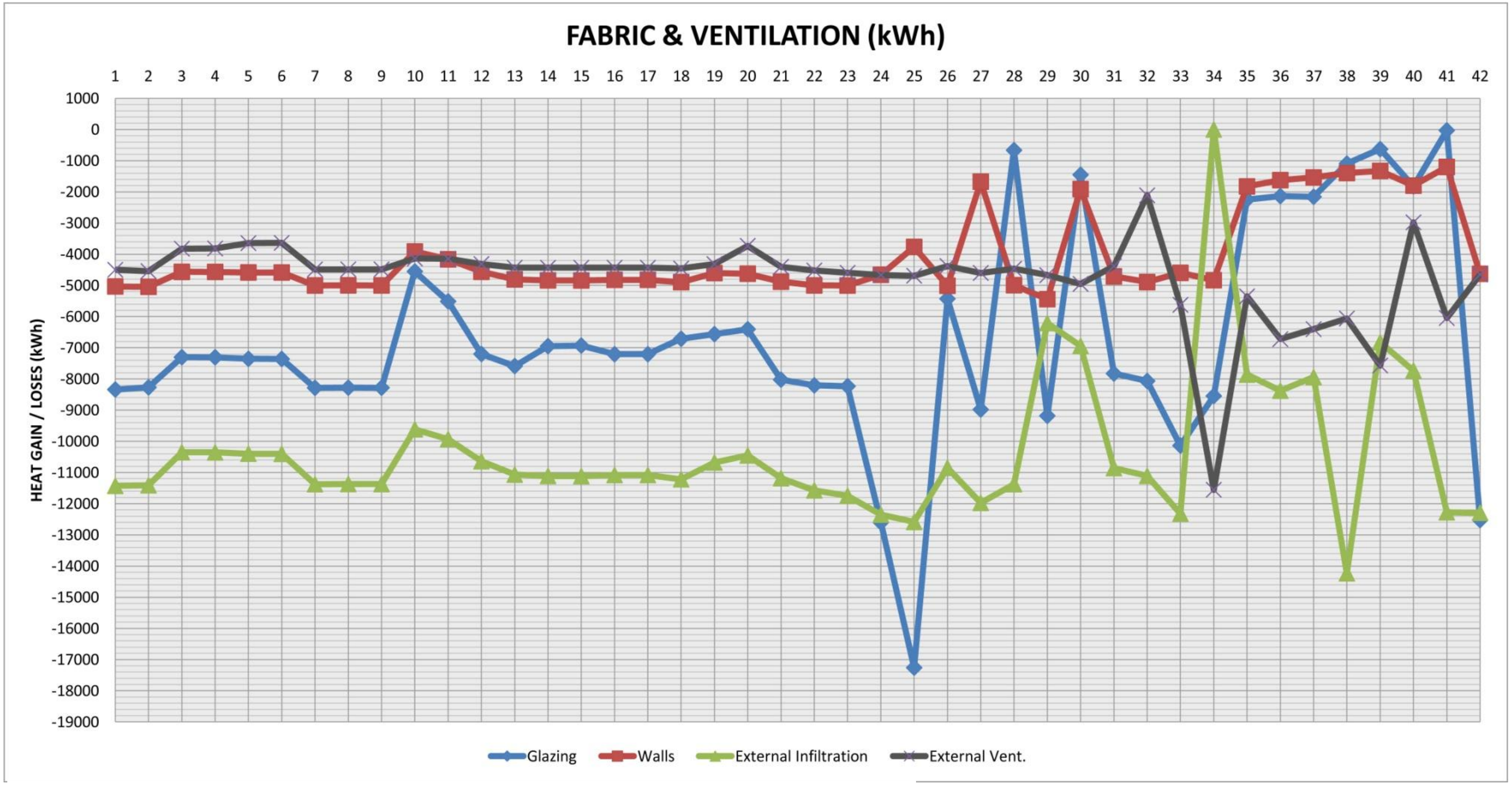

Figure 4.2: Annual heat losses for scenarios.

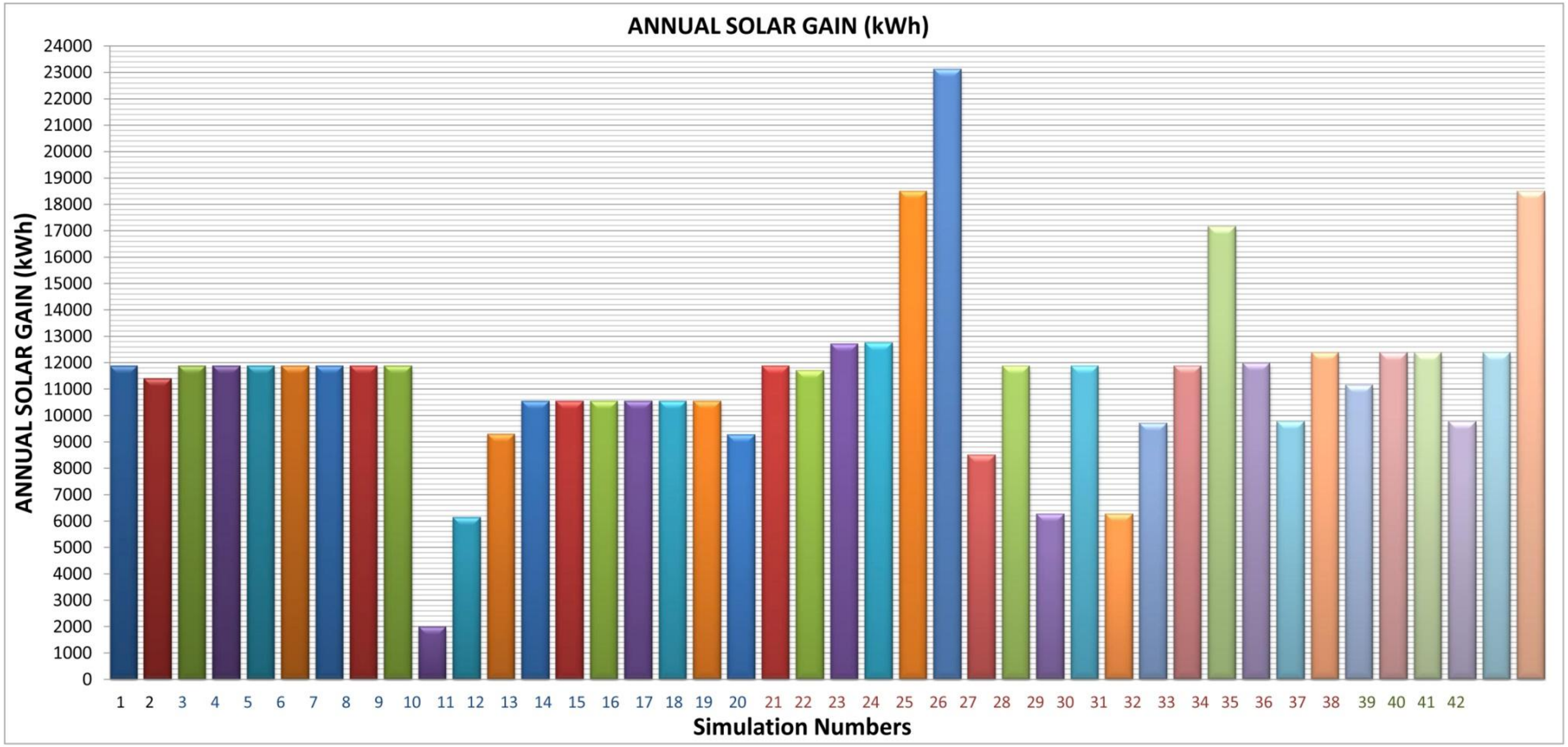

Figure 4.3: Annual solar gain for scenarios.

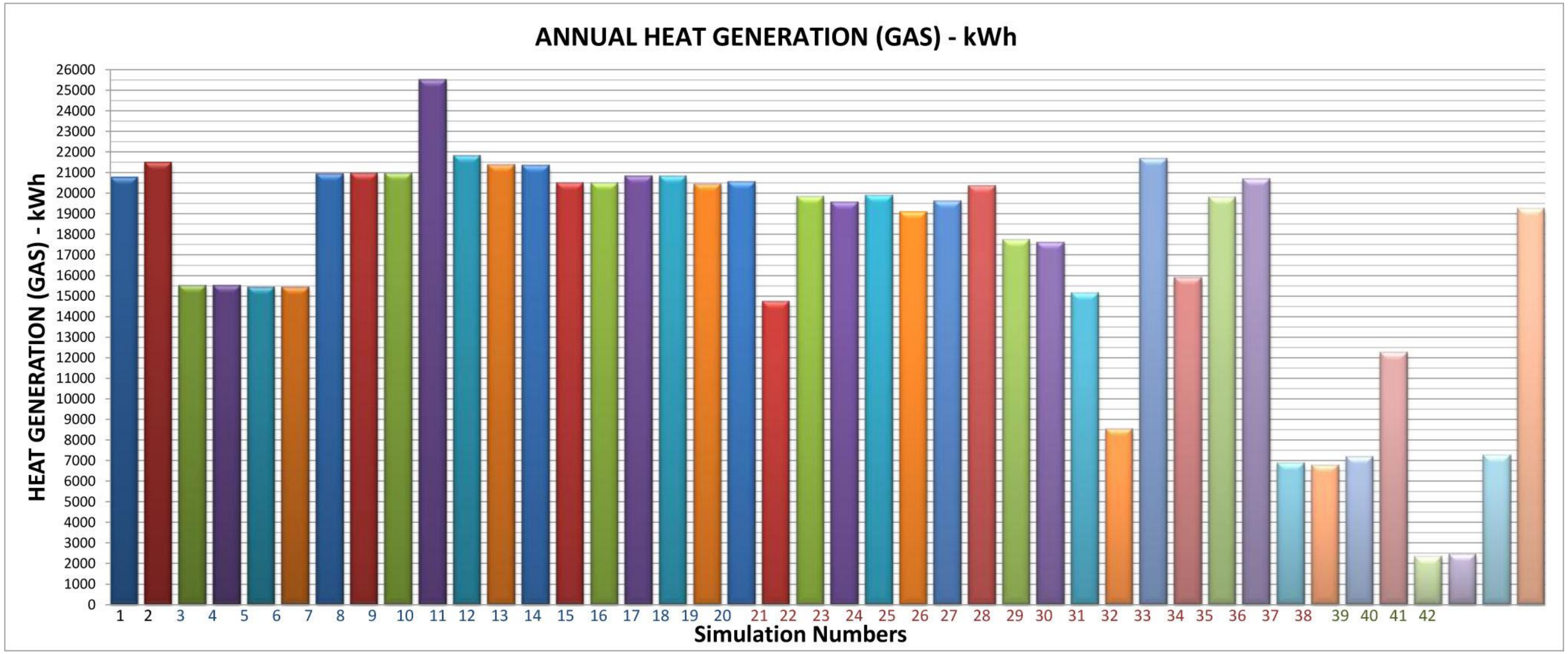

Figure 4.4: Annual gas consumption by heat generation for scenarios.

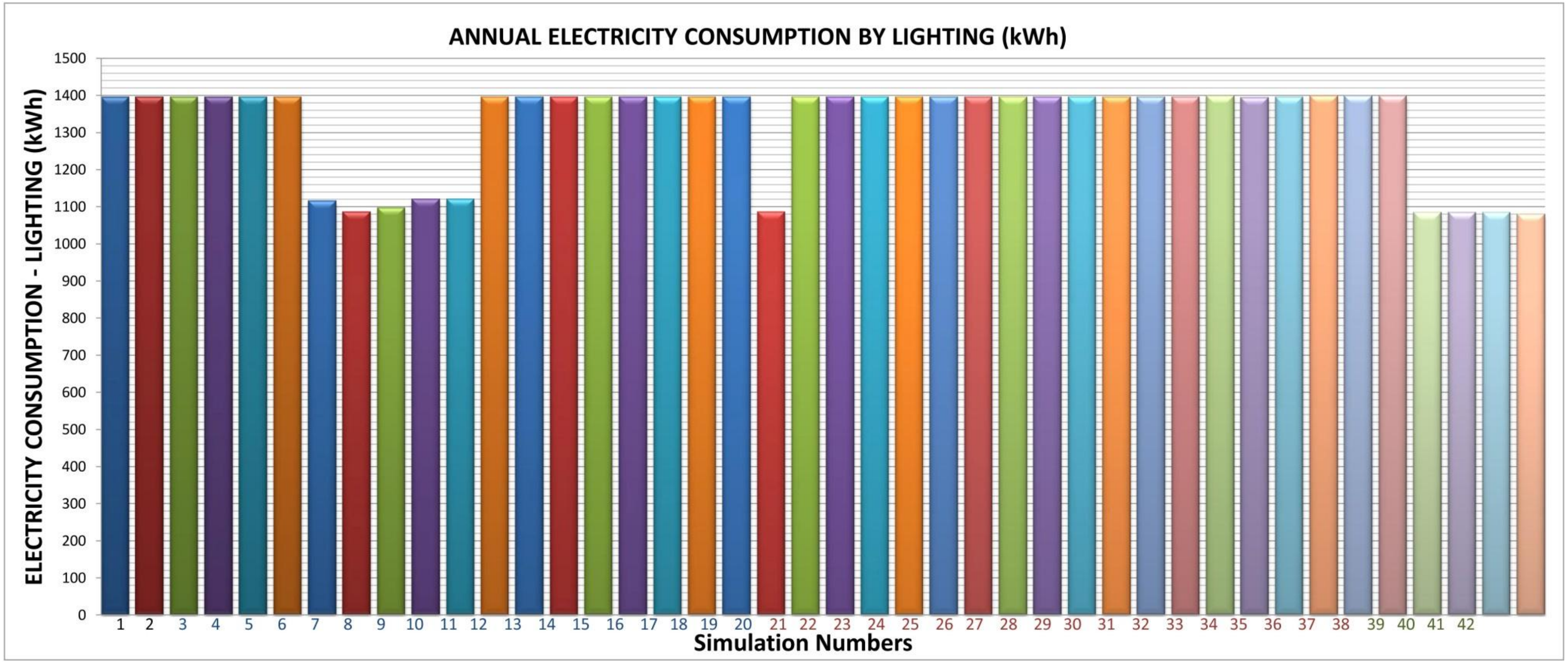

Figure 4.5: Annual electricity consumption by lighting for scenarios.

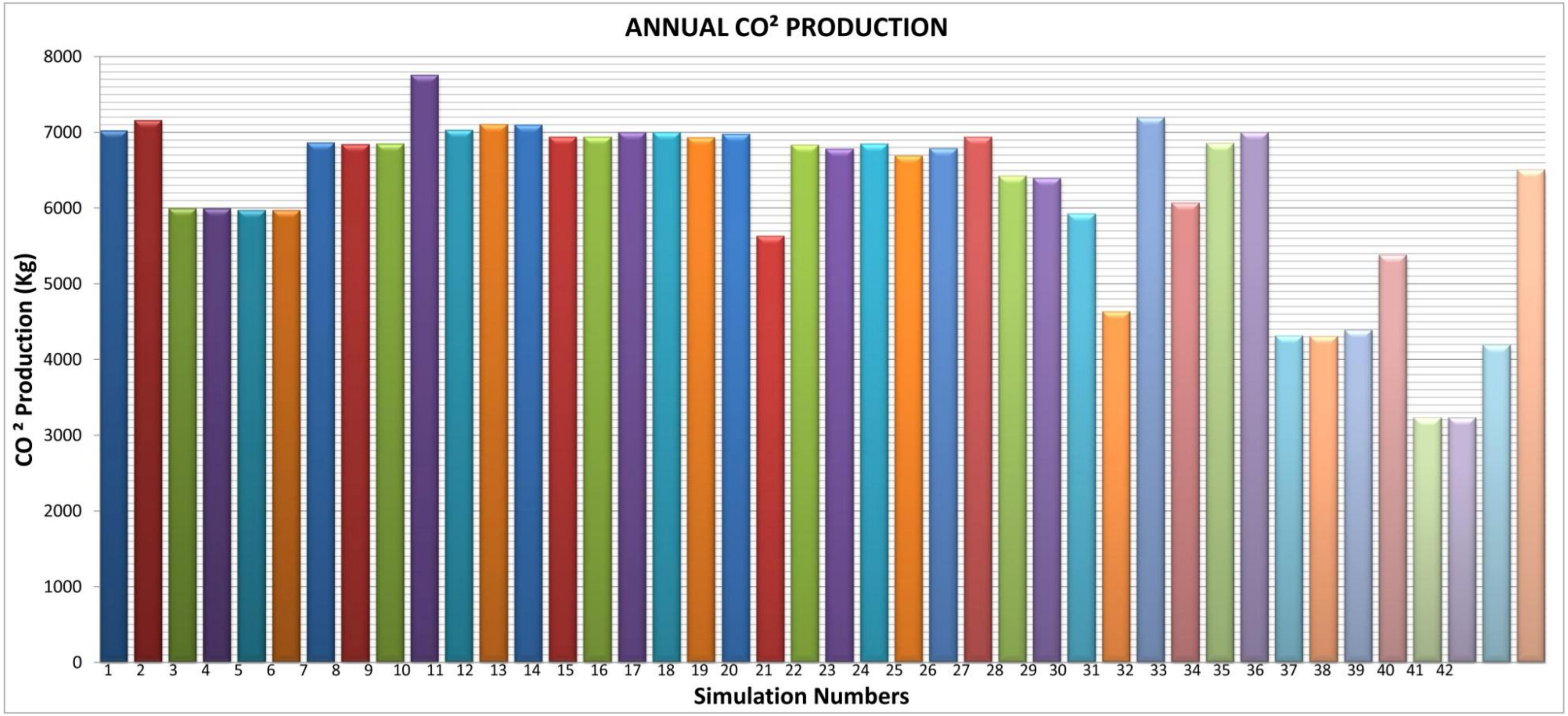

Figure 4.6: Annual CO2 production for scenarios.

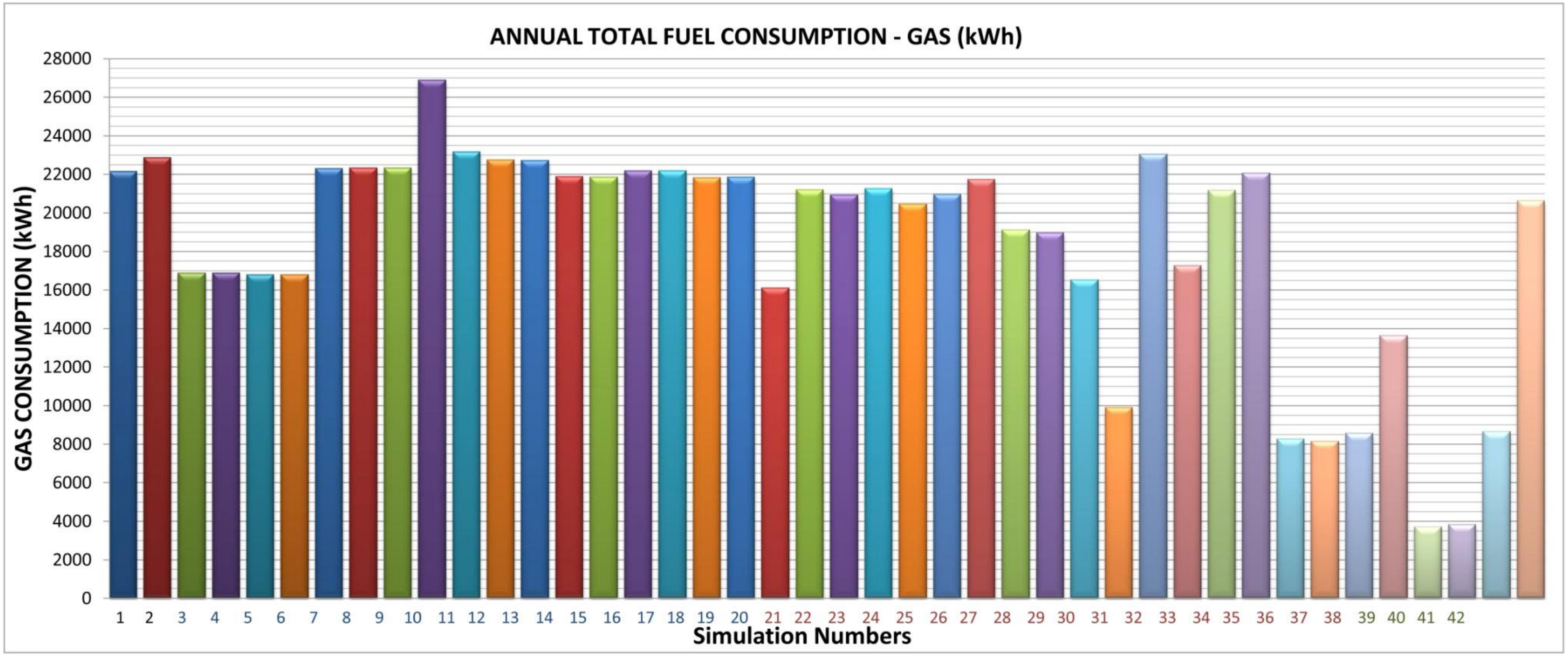

Figure 4.7: Annual total gas consumption for scenarios.

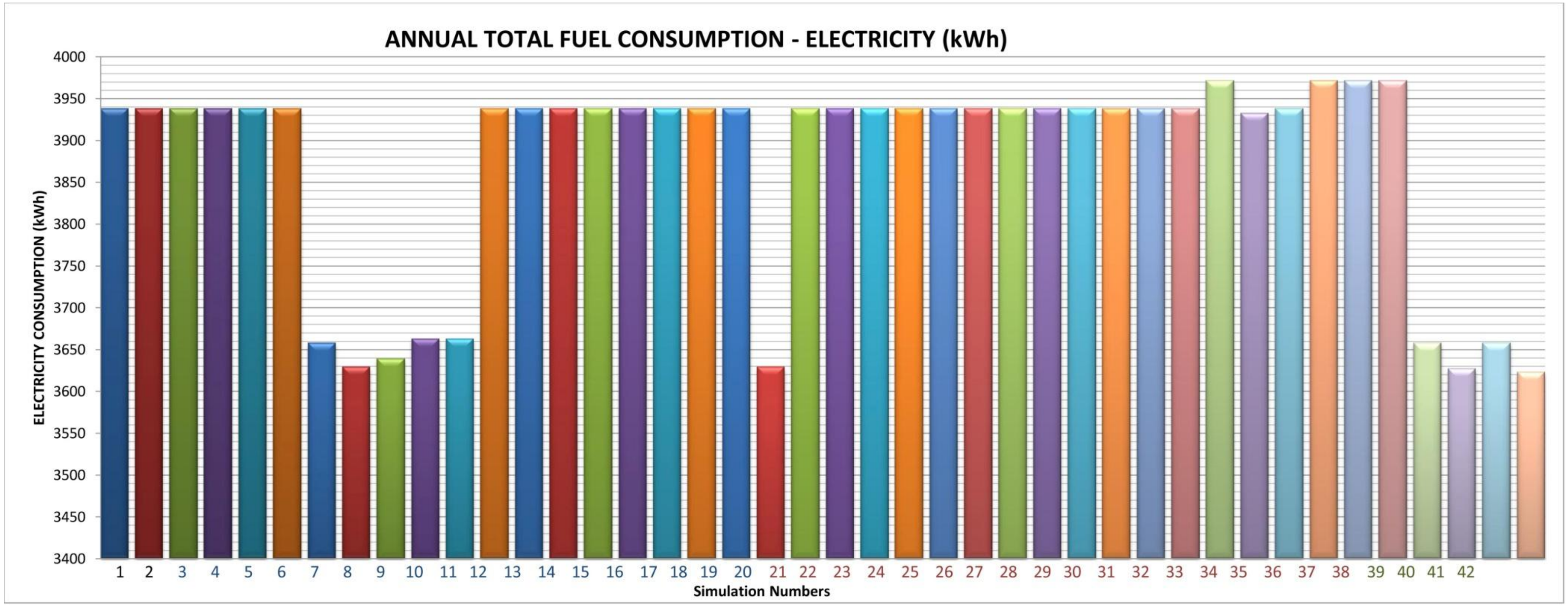

Figure 4.8: Annual total electricity consumption for scenarios.

CHAPTER 5

CONCLUSION

Importance of energy is obvious because of its economical, developmental, environmental and even political aspects. While buildings constitutes approximately 40% of total energy consumption in the world (UNEP, 2009); construction industry, building design teams, occupants and even the state cannot stand idly by neglecting energy efficiency in architecture.

While smart buildings which become more popular day by day, present technological solutions for energy saving; some architectural decisions have been used throughout the history to balance relation in between buildings and environment by employing free energy sources such as sun, wind etc.

This study focused on not only comparative impact of technological devices and traditional methods, but also energy saving potential of them. The study was conducted for residential type since residential sector not only constitutes highest share for energy consumption among building types but also has highest energy saving potential. Energy consumed for space heating is main focus of the study since it is the most important consumption indicator with approximately one-third of total consumption in residential sector. Also, lighting electricity is secondary focus since daylight and direct solar gain is related with each other. Various active systems and passive strategies are selected in the light of literature. There are two main selection criteria; the first is testability with computer simulations and the second is wide availability in current market. A residential module which is a unit in an existing residential tower in Ankara is used as base-case module and selected active systems and passive strategies are tested on it. The base-case module is also used for comparison. Ankara with its climate is an appropriate location to focus on energy saving from space heating.

During the process, three series of simulation variations including forty-two different scenarios are tested. Only active systems were tested in the first series, only passive strategies in the second series and, finally, combinations of both active and passive strategies were simulated and evaluated in the third series.

As a result; it is seen that using only active systems provide approximately 27% improvement for total gas consumption which includes DHW and space heating, and approximately 8% improvement for total electricity consumption which includes room electricity, system misc and lighting electricity. In other words; use of only active systems results in saving 6052.78 kWh from heat generation, and 308.68 kWh from lighting electricity. Also CO_2 emissions are reduced by 1391.74 kg, or it can be said that improved by approximately 20%. Figure 5.2 shows selection path for active systems and interdependence matrix at the top of the figure shows relation in between systems/strategies and main energy performance points.

The study points out that use of only passive strategies provide 14022.56 kWh saving from heat generation In other words; approximately 63% improvement in total gas consumption is achieved by passive strategies. Also CO_2 emissions are reduced by 2710.45 kg; *i.e.* improved by approximately 39%. Figure 5.1 shows selection path for passive systems.

It should be noted that the difference between impact of active systems and passive strategies is mainly caused by envelope improvements which in turn are passive strategies. There is no equivalent improvement result in tested active systems to envelope strategies. In addition; solar gain systems are tested in passive series but energy production by using PV panels which can be assumed as their equivalent in active systems are not tested.

Also another important point is building type to evaluate. While tested passive strategies have higher impact for energy performance in residential type, active systems may have higher impact then passive strategies in commercial type since energy consumption indicators are different for types. Since lighting electricity constitutes the biggest share in energy use of commercial buildings, lighting control systems probably may bring higher amount of saving.

On the other hand; cooling loads were not a concern in this study since active system for cooling is not employed for residential buildings in Turkey generally. Results may be different and active systems may bring more energy saving for commercial buildings which have active cooling systems.

At the final stage, the research shows that combining active systems and passive strategies has great potential for energy saving since using them together provides 18436.82 kWh saving from heat generation, and 310.38 kWh saving from lighting electricity. In other words; approximately 83% improvement for total gas consumption and 9% improvement for total electricity consumption is achieved. Also, CO_2 emissions are reduced by 3786.17 kg, or it can be said that improved by approximately 54%.

In the light of these results; both active systems and passive strategies have significant potentials for energy saving but it is obvious that hybrid usage of them consolidates the success with impressive saving potential.

While buildings constitutes with 35.4% of total energy consumption in Turkey where 73% of energy consumption is supplied through imports, Turkey paid 54 billion dollars for energy import in 2011. When the results are recovered by this perspective, economical saving for just a residential module which is approximately 150 meter square will be seen clearly. Using active systems and passive strategies save 1,850 Turkish Liras (including taxes) due to 18,436.82 kWh saving from heat generation; and 110TL (including taxes) due to 310.38 kWh reduction in lighting loads every year. These figures have been taken from the current energy rates at the time the study was conducted. 1 TL is approximately equal to 0.5 $ for the date.

Occupant behaviors and preferences are ignored in the study and they may be subject of another study. Also impacts for different zones are not examined, the residential module is considered as a whole and results have been evaluated with this logic for the sake of clarity since the study aims to compare impact of various systems and strategies. Evaluating each zone in a residential module separately is subject of another study and in need of further research.

Finally, it can be said that energy performance of smart buildings cannot be left to just technological active systems. Although they have a noteworthy impact on energy savings; as seen from results, passive strategies have a higher potential for savings. Using active systems and passive strategies together bring more desirable results. It is advised that smart buildings with smart technologies should be combined with smart passive techniques and be a product of smart design by an interdisciplinary team.

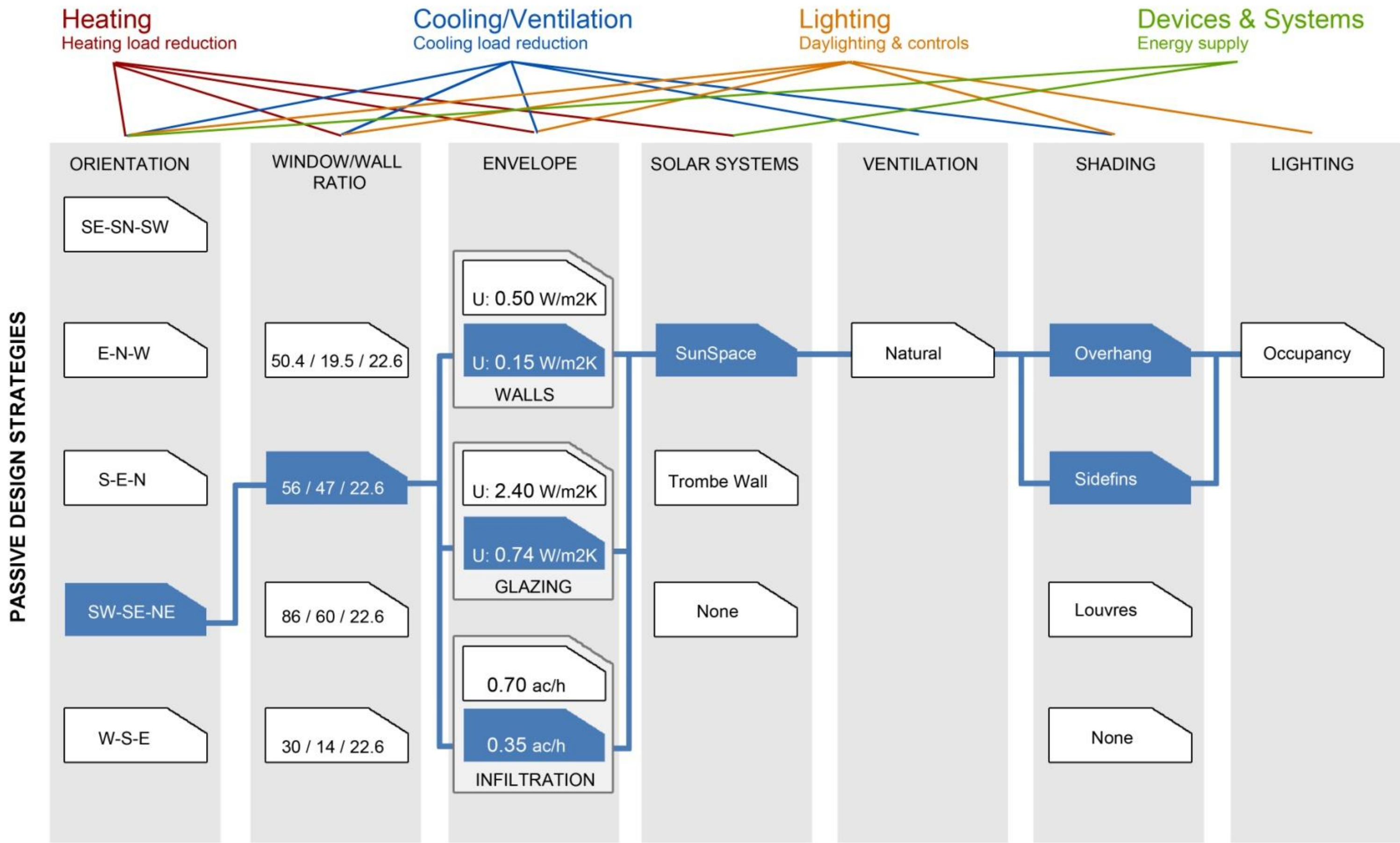

Figure 5.1: Selection of tested passive strategies for residential module that studied.

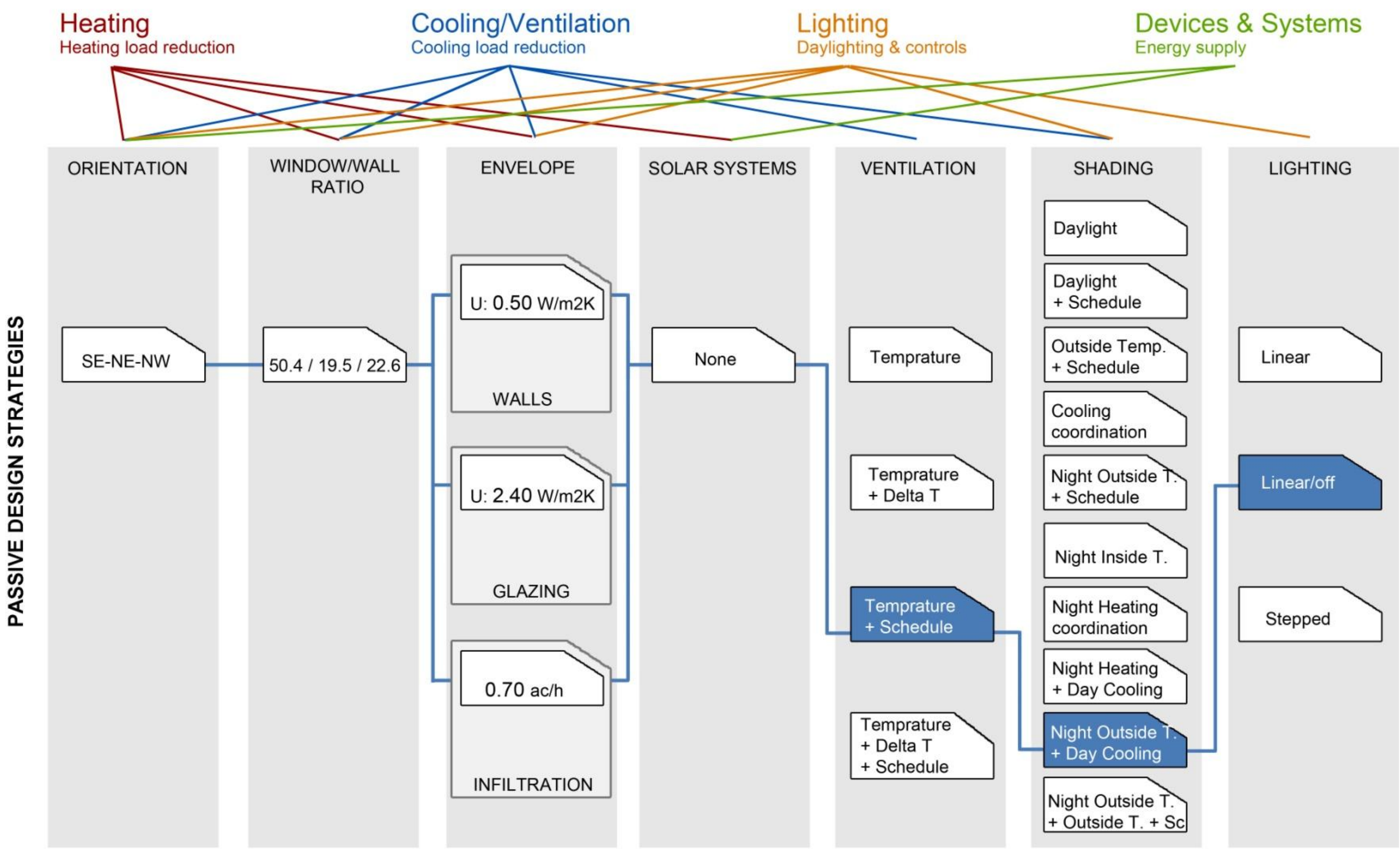

Figure 5.2: Selection of tested active systems for residential module that studied.

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APPENDIX A

TURKISH REGULATIONS FOR THERMAL INSULATION

Table A.1: Maximum U-values by regions.

Bölgelere göre en fazla değer olarak kabul edilmesi tavsiye edilen U değerleri

	U_D (W/m²K)	U_T (W/m²K)	U_t (W/m²K)	U_P* (W/m²K)
1. Bölge	0,70	0,45	0,70	2,4
2. Bölge	0,60	0,40	0,60	2,4
3. Bölge	0,50	0,30	0,45	2,4
4. Bölge	0,40	0,25	0,40	2,4

* : Pencerelerin ısıl geçirgenlik katsayıları(U_p), TS 825 Ek A.3'te ve Ek A.4'te verilmiş olup pencerelerden olan ısı kayıplarının en aza indirilmesi açısından U_p değerinin kaplamalı camlar kullanılarak 1,8 W/m2K'e kadar düşürülecek şekilde tasarımlanması tavsiye edilir. Diğer kapı ve pencere türleri için TS 2164'te verilen 11.05.2000 revizyon tarihli Çizelge 6a ve Çizelge 6b kullanılarak ısıl geçirgenlik katsayıları bulunur ve hesaba katılır. Bazı pencere tipleri için TS 2164'ten faydalanılarak bulunan Up değerleri, TS 825 Ek A.4'te verilmiştir.

Table A.2: Regions

İllere göre derece gün bölgeleri

1. BÖLGE DERECE GÜN İLLERİ

ADANA	AYDIN	MERSİN	OSMANİYE
ANTALYA	HATAY	İZMİR	

İli 2. Bölgede olupda kendisi 1.Bölgede olan belediyeler

AYVALIK (Balıkesir)	DALAMAN (Muğla)	FETHİYE (Muğla)	MARMARİS(Muğla)
BODRUM (Muğla)	DATÇA (Muğla)	KÖYCEĞİZ (Muğla)	MİLAS (Muğla)
GÖKOVA (Muğla)			

2. BÖLGE DERECE GÜN İLLERİ

SAKARYA	ÇANAKKALE	KAHRAMAN MARAŞ	RİZE	TRABZON
ADIYAMAN	DENİZLİ	KİLİS	SAMSUN	YALOVA
AMASYA	DİYARBAKIR	KOCAELİ	SİİRT	ZONGULDAK
BALIKESİR	EDİRNE	MANİSA	SİNOP	DÜZCE
BARTIN	GAZİ ANTEP	MARDİN	ŞANLI URFA	
BATMAN	GİRESUN	MUĞLA	ŞIRNAK	
BURSA	İSTANBUL	ORDU	TEKİRDAĞ	

İli 3. Bölgede olupda kendisi 2.Bölgede olan belediyeler

HOPA (Artvin) ARHAVİ (Artvin)

İli 4. Bölgede olupda kendisi 2.Bölgede olan belediyeler

ABANA(Kastamonu)	BOZKURT (Kastamonu)	ÇATALZEYTİN (Kastamonu)
İNEBOLU (Kastamonu)	CİDE (Kastamonu)	DOĞANYURT (Kastamonu)

3. BÖLGE DERECE GÜN İLLERİ

AFYON	BURDUR	KARABÜK	MALATYA
AKSARAY	ÇANKIRI	KARAMAN	NEVŞEHİR
ANKARA	ÇORUM	KIRIKKALE	NİĞDE
ARTVİN	ELAZIĞ	KIRKLARELİ	TOKAT
BİLECİK	ESKİŞEHİR	KIRŞEHİR	TUNCELİ
BİNGÖL	IĞDIR	KONYA	UŞAK
BOLU	ISPARTA	KÜTAHYA	

İli 1. Bölgede olupda kendisi 3.Bölgede olan belediyeler

POZANTI (Adana) KORKUTELİ (Antalya)

İli 2. Bölgede olupda kendisi 3.Bölgede olan belediyeler

MERZİFON (Amasya) DURSUNBEY (Balıkesir) ULUS (Bartın)

İli 4. Bölgede olupda kendisi 3.Bölgede olan belediyeler

TOSYA (Kastamonu)

4. BÖLGE DERECE GÜN İLLERİ

AĞRI	ERZURUM	KAYSERİ
ARDAHAN	GÜMÜŞHANE	MUŞ
BAYBURT	HAKKÂRİ	SİVAS
BİTLİS	KARS	VAN
ERZİNCAN	KASTAMONU	YOZGAT

İli 2. Bölgede olupda kendisi 4.Bölgede olan belediyeler

KELES (Bursa)	ŞEBİNKARAHİSAR (Giresun)	ELBİSTAN (K.Maraş)	MESUDİYE (Ordu)
ULUDAĞ (Bursa)	AFŞİN (K.Maraş)	GÖKSUN (K.Maraş)	

İli 3. Bölgede olupda kendisi 4.Bölgede olan belediyeler

KIĞI (Bingöl) PÜLÜMÜR (Tunceli) SOLHAN (Bingöl)

Not - Ek'te adı bulunmayan yerleşim birimleri, bağlı bulundukları belediyenin bölgesinde sayılır.

APPENDIX B

ILLUMINANCE LEVES

Table B.1: Illuminance levels

Aydınlık Düzeyleri / Illuminance Levels:

Ofisler / Offices	
Genel ofis alanları / General offices	500 Lux
Açık ofisler / Open-plan offices	750 Lux
Çizim yapılan ofisler / Drawing offices	1000 Lux
Bekleme salonları / Waiting rooms	200 Lux
Bilgi işlem merkezleri / Computer work stations	300 Lux
Alışveriş merkezleri / Shopping Centers	
Self servis mağazalar ve showroomlar / Self-service shops and showrooms	500 Lux
Mağazalar(Genel) / Shops (General)	300 Lux
Süpermarketler / Supermarkets	750 Lux
Konser salonları, sinemalar, tiyatrolar /Concert halls, cinemas and theatres	
Genel / General	100 Lux
Fuaye / Foyer	200 Lux
Müzeler ve sanat galerileri / Museums and art galleries	
Işığa duyarlı olmayan nesnelerin sergilenmesi / Exhibits insensitive to light	300 Lux
Işığa duyarlı nesnelerin teşhiri / Light-sensitive exhibits	150 Lux
Eğitim / Education	
Sınıflar / Classrooms	500 Lux
Konferans salonları / Lecture halls	300 Lux
Laboratuarlar / Laboratories	500 Lux
Kütüphaneler / Libraries	500 Lux
Konutlar, oteller, restoranlar / Residences, hotels, restaurants	
Yatak odaları (Genel) / Bedrooms (General)	50 Lux
Yatakbaşı / Bed-head	200 Lux
Banyolar (Genel) / Bathrooms (General)	100 Lux
Banyolar (Ayna önü) / Bathrooms (Shaving, make-up)	500 Lux
Oturma odaları (Genel) / Living rooms (General)	100 Lux
Oturma odaları (Okuma) / Living rooms (Reading)	500 Lux
Merdivenler / Stairs	100 Lux
Mutfaklar (Genel) / Kitchens (General)	300 Lux
Mutfaklar (Tezgah üstü) / Kitchens (Working areas)	500 Lux
Hastaneler / Hospitals	
Gece / Night	50 Lux
Gündüz / Daytime	200 Lux
Muayene odaları / Treatment rooms	500 Lux
Personel odaları / Staff rooms	100 Lux
Laboratuarlar / Laboratories	500 Lux
Endüstriyel alanlar / Industrial areas	
Tekstil atölyeleri / Textile workshops	750 Lux
Test ve kontrol noktaları / Testing and inspection positions	750 Lux
Dikiş atölyeleri / Sewing workshops	750 Lux
Deri atölyeleri / Leather workshops	500 Lux
Mobilya atölyeleri / Furniture workshops	300 Lux
Metal işleme atölyeleri / Processing of metal sheets	300 Lux