EVALUATION INDICATORS FOR SELECTION OF SUSTAINABLE BUILDING MATERIALS

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ABSTRACT

EVALUATION INDICATORS FOR SELECTION OF
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Environmental issues have gained importance due to global environmental threat, such as depletion of energy resources and the impacts of climate change. The building sector is responsible for almost half of the impacts on the environment. Hence, this study focuses on the importance of environmental impacts of building materials.

In this regard, firstly, sustainability indicators for building materials were determined and the environmental impacts of selected building materials were studied. Then, the evaluation system BREEAM and the evaluation software BEES were selected and used to evaluate one block of bachelor flats and one of housing units in ODTUKENT, which is located in the Middle East Technical University campus in Ankara, Turkey.

Building materials used for the construction of walls, floors and roofs were evaluated according to the indicators accepted by BREEAM and BEES. The results for both units were compared and it was seen that the block of bachelor flats takes lower ratings than the triplex unit for BREEAM and also lower values for BEES. Therefore, the block of bachelor flats has less environmental impact than the triplex unit.

While evaluating the materials an exact match for all the materials used in the case buildings could not be found in these tools. Hence, it was not possible to exact results for these materials. In this regard, countries should determine their own evaluation indicators and develop their evaluation systems.

Keywords: Sustainable Architecture, Sustainability Indicators, Environmental Evaluation Tools, BREEAM, BEES.

ÖZ

SÜRDÜRÜLEBİLİR YAPI MALZEMELERİ SEÇİMİNDE DEĞERLENDİRME GÖSTERGELERİ

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İklim değişikliğinin etkileri, enerji kaynaklarının tükenmeye başlaması gibi çevresel tehlikelerin ortaya çıkması nedeniyle çevreyle ilgili konular önem kazanmaya başlamıştır. Çevreye verilen zararın yaklaşık yarısı yapı sektörünün etkisiyle ortaya çıkmaktadır. Bu nedenden, bu çalışma, yapı malzemelerinin çevresel etkilerinin önemi üzerinde durmaktadır.

Buna göre, öncelikle yapı malzemelerinin sürdürülebilirlik göstergeleri belirlendi ve seçilen yapılarda kullanılan yapı malzemelerinin çevreye verdikleri zararlar araştırıldı. Bunun için BREEAM değerlendirme sistemi ve BEES bilgisayar programı seçildi. Ankara'da Orta Doğu Teknik Üniversitesi kampüsü içinde bulunan ODTÜKENT lojmanlarında yer alan iki yapı belirlenerek, bu yapılarda kullanılan yapı malzemeleri, BREEAM ve BEES'e göre değerlendirildi. Bu yapılar, 3 katlı bir konut bloğu ve evli olmayan öğretim elemanlarına ait olan yapının bir bloğu olarak seçilmiştir.

Çalışma kapsamında seçilen binaların duvar, yer ve çatılarında kullanılan yapı malzemeleri, BREEAM ve BEES'in kabul ettiği göstergelere göre değerlendirildi. Iki yapıya ait olan sonuçlar karşılaştırıldığında, evli olmayan öğretim elemanlarına ait olan yapı bloğunun 3 katlı konut bloğundan daha düşük çevresel etkilere sahip olduğu görüldü. Bundan dolayı, evli olmayan öğretim elemanlarına ait olan yapı bloğunun konut bloğuna oranla çevreye etkisi daha az olduğu sonucuna ulaşıldı.

Seçilen yapılarda kullanılan yapı malzemeleri değerlendirilirken, uygulanan sistemlerde (BREEAM ve BEES) bu yapı malzemesinin tam karşılıklarının olmadığı görüldü. Bu yüzden her malzeme için kesin değerlendirme sonuçlarına ulaşılamadı. Değerlendirmede karşılaşılan bu kısıtlamadan hareketle, her ülke kendi değerlendirme göstergelerinin belirleyerek kendine ait değerlendirme sistemini oluşturması gerekliliği ortaya çıkmıştır.

Anahtar Kelimeler: Sürdürülebilir Mimarlık, Sürdürülebilirlik Göstergeleri, Çevresel Etkileri Değerlendirme Sistemleri, BREEAM, BEES.

To my beloved family
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ABBREVATIONS

ACEEE	American Council for an Energy-Efficient Economy
BEES	Building for Environmental and Economic Sustainability
BREEAM	British Research Establishment Environmental Assessment
CIB	Conseil International du Batiment
CSTB	Centre Scientifique et Technique du Bâtiment
DCTW	Directorate of Construction and Technical Works
ISF	Institute for Sustainable Futures
METU	Middle East Technical University
SBIC	Sustainable Buildings Industry Council
TUIK	Turkish Statistical Institute
USGBC	United States Green Building Council
WGBC	World Green Building Council

CHAPTER 1

INTRODUCTION

In this chapter is presented the argument for the study. It also includes a statement of its objectives and its procedure. Concluding is an overview of its disposition.

1.1. Argument

The population of the world is rapidly increasing; therefore, natural resources are being used up. Since resources are such limited, the world is faced with global environmental threats. Increased use of fossil fuels and nuclear energy cause air pollution. In addition, toxic wastes which are causing global warming are a huge threat for the future of this planet. Therefore, environmental problem is one of the most important problems for human health. There is a need to pay more attention to this issue.

After the oil crisis of the 1970s, people become aware that nature and natural resources can be finite. In 1990s, the issue of global warming and its environmental effects gain importance. Consequently, researches about environmental problems and reducing their impacts become increasing.

As looking after the environment is everyone’s responsibility, designers, architects and builders have to share this responsibility. They need to beware not only of the cost of building but also human health and the environment.

While designing a building, which is sustainable, its cost and materials should be also considered in terms of energy efficiency. Sustainable design is necessary for future generation to live in a better environment.

Architects have to take action to combat the environmental problems not only in theory, but also in practice. Firstly, the sustainability guidelines should be known by designers, and applied by the builders. In this regard, the selection of building materials plays an important role in protecting the environment through design decisions.

1.2. Objective

The main objective of this research was to evaluate the building materials used in two of ODTUKENT housing units in terms of sustainability indicators. The other objectives were;

- to study sustainability in architecture,
- to determine the sustainability indicators of building materials,
- to research the literature to determine the evaluation tools using in building sector for materials,
- to determine the environmental impacts of buildings in terms of building materials.

1.3. Procedure

In the first stage of this study, literature survey was conducted based on theses, publications in libraries, articles and web sources. It was used as background information to determine the sustainability indicators and evaluation tools for building materials of these tools. BREEAM and BEES were selected and applied to evaluate building materials used in the case study buildings.

BREEAM was selected because it has a wide usage area around the world; and BEES was selected because of its availability.

The building materials used in two of the selected buildings in ODTUKENT in Ankara were evaluated through the evaluation tools (BREEAM and BEES). The houses were selected according to their construction types. Architectural drawings and information on the building materials of these units were obtained from the METU Office of Construction and Technical Works; photographs were taken by author.

1.4. Disposition

This study is composed of five chapters. In this first chapter, the argument, objectives and methodology of the study are introduced. It includes also disposition of the chapters and their contents.

In the second chapter, the literature survey is presented regarding sustainability, sustainable architecture and sustainability indicators. Thereafter information on sustainability indicators, evaluation tools and software programs used for evaluating building materials are presented. Finally, building materials are classified and their selection criteria are stated.

In the third chapter, the case study is defined in the survey material section. Furthermore, the survey methodology is described.

In the fourth chapter, evaluation systems are applied to the case buildings. Then the results of this survey are shown and discussed.

In the fifth chapter, the findings and their interpretations are summarized.

CHAPTER 2

LITERATURE SURVEY

This chapter is comprised of information related to sustainability, especially building materials. It also includes the indicators of sustainability and the evaluation tools accepted as a guide in the world. This literature survey is based on thirty-five published sources and sixteen websites.

2.1. Definition of Sustainability

The first sustainability definition is described in 1981 by Brown (Kibert, 2005), as “one that is able to satisfy its needs without diminishing the chances of future generations”.

According to the Unesco web site, in 1987, United Nations prepared and published the Brundtland Report due to the increase in concern about the effects of economic development on health, natural resources and the environment. In this report, sustainable development was defined by the World Commission on Environment and Development (WCED) as "development which meets the needs of the present without compromising the ability of future generations to meet their own needs".

Helmore and Singh (2001) define sustainability as the management and use of natural resources to make sure that these resources will stay intact for future generations. One other web source (www.sustainablemeasures.com) defines sustainability as “related to the quality of life in a community, whether the economic, social and environmental systems that make up the community are providing a healthy, productive, meaningful life for all community residents, present and future”.

According to Pijawka (1995), sustainability aims to decrease energy consumption, operation and maintenance costs in addition to that it targets to reduce waste and pollution. As Pearce (1998) notes, sustainability has a new approach to problem solving, in this new approach considering the finite resources of earth within the context of the estimated future, and it also tries to maintain the importance of meeting human needs and aspirations both now and in future generations. He explains that the natural environment is the first source for all physical resources to protect environmental quality, and it is also a crucial factor of sustainability. While trying to achieve sustainability for the human species, he emphasizes three primary objectives of sustainability which are reducing consumption of matter and energy, avoiding negative effects on environmental life support systems, satisfying human needs and aspirations.

Researchers of the National Park Service in America (www.nps.gov) have emphasized that sustainable design can balance human needs rather than human wants, and it also reduces environmental impacts, importation of goods and energy as well as the generation of waste, in long-term, it will help to minimize resource degradation and consumption on a global scale. According to the same web source (www.nps.gov), “sustainable building design must aspire to:

- use the building as an educational tool to show the importance of the environment in sustaining human life,
- reconnect human beings with their environment for the spiritual, emotional, and therapeutic benefits that nature provides,

- create new human values and lifestyles to have a more harmonious relationship with local, regional, and global resources and environments,
- increase public awareness about appropriate technologies and the cradle-to-grave energy, damaging effects of various building and consumer materials,
- encourage living cultures to continue indigenous responsiveness to, and be harmonious with local environmental factors,
- pass on cultural and historical understandings of the site with local, regional, and global relationships."

2.2. Sustainable Architecture

Kremers (1995) argues that the term sustainable architecture, used to explain the movement related with environmentally conscious architectural design, has created hesitation and confusion. He also describes sustainable architecture as an approach to extend the availability of natural resources to architectural design that minimizes sustenance or resource consumption. The author also says that although the term sustainable architecture corresponds to slightly different meanings to various audiences, however, the focus is on the built environment and its long term viability.

Sustainable architecture is described by Hawken (1993) as the reimagining of the relationship between human beings and living systems. Sev and Özgen (2003) describe sustainable architecture as the best way of using energy adequately and materials without destroying our natural environment.

According to Kohler and Chini (2005), the principal objectives of sustainability are to increase equity and quality of life over the long-term. They also state the main objectives of sustainable architecture as;

- using a minimum of materials,
- ensuring a long-term use,
- choosing materials that do not cause huge environmental problems
- designing buildings to make sure that they can be easily maintained, refurbished and deconstructed.

According to Willis (2000), sustainability seems to present a much bigger task for building designers than it does for most other professions. She explains that it is because building designers work in and on the environment in very directs ways.

2.3. Sustainability Indicators for Building Materials

As Farrell and Hart (1998) note, a number of different indicators have been developed to measure sustainability and that these indicators vary considerably, depending on the underlying view of the sustainability they represent, the organizing framework they utilize, and the interests and goals of creators of the indicators. Additionally, they note that such indicators help not only to establish numerical goals and analyze trends but also to explore the full implications of the sustainability concept. The authors also explain what information is needed and how it will be used in practice to determine the selection of a particular indicator.

Ranganathan (1998) defines sustainability indicators as information used to measure and motivates progress toward sustainability goals. According to Gallopin (1997), indicators are variables, and results are the actual measurements or observations. He also suggests that at the more concrete level, indicators are thought as variables and each variable may take different values depending on specific measurements or observations.

According to Veleva (2001), the importance of developing sustainability indicators has increased worldwide. She also added that although the number of sustainability indicators is growing. But, there is little or no guidance in simple lists of indicators as to how to select or apply them over time in order to become more sustainable. The author argues that giving an exact definition of indicators is not something easy to do; moreover, the literature is relatively confusing on this subject. According to the author, indicators need to be:

- in manageable number,
- appropriate to the task of evaluating sustainable production practices,
- based on available and accurate data,
- confirmable,
- simple and yet meaningful,
- developed through a transparent process,
- allowing for comparisons, among others.

According to Harris (1999), an environmental assessment method must take into account a number of factors, such as those listed in Table 2.1. There is no general agreement as yet on an appropriate range of indicators, nor are there any specific benchmarks or agreed standards.

Table 2. 1: Indicators and their environmental impact of building materials
(Source: Harris, 1998)

Indicator	Form of environmental impact
1. Embodied energy	CO_2 emission, other gaseous pollutants, NO_x, SO_x. Quantifiable
2. Raw materials consumption (Resource conservation)	Quarrying local nuisance, noise, dust. Partially Quantifiable
3. Scarcity factor	Raw material consumption. Are there better alternative uses for the material? Partially Quantifiable
4. Recycling potential	Difficult to quantify. Affects indicators 1–3 above
5. Effects on occupants of building or handlers (Toxic hazard)	Asthma, etc. Difficult to quantify (reactions vary between individuals)
6. Potential for using recycled materials	Difficult to quantify
7. Influence on energy consumption	CO_2 emission, other gaseous pollutants, NO_x, SO_x. Possible to quantify, but depends on location (i.e. climate)

Canarslan and Ozkan (2007) also point out that no single comprehensive standard exists for evaluating the characteristics of all building materials from the point of view of sustainability; therefore, there is a need to establish universal indicators of sustainability in order to evaluate and choose material for sustainable buildings.

Reilly (1997), for instance rated building materials according to five categories, namely, energy efficiency, resource responsibility, social/public health responsibility, economic/functional, quality of manufacturer. These indicators can be used to evaluate building materials, as presented in Table 2.2. The environmental impacts are rated from 1 to 5, where 1 indicates the least negative impact.

Table 2.2 : Evaluation criteria of building materials (Source: Reilly, 1997)

BUILDING EXTERIOR CATEGORIES	COMPARATIVE ENVIRONMENTAL PARAMETRES																			TOTALS
	Energy Efficiency (1)			Resource Responsibility (2)						Social/Public Health Responsibility (3)				Economic/ Functional (4)			Quality of Manufacturer (5)			
	Energy -Efficient Use	Use of Renewable Source of Energy	Transportation	Min.Need for Other Materials	Maintenance Requirements	Durability (life expectancy)	Efficient Use of Resource Material	Recycled Contend	Recyclable	Harmful Chemicals in Production	Reduction of Off Gassing	Worker/Installer Health	Building Occupant Health	Cost Effectiveness	Availability	Acceptability	Local Resource	Local Manufacture	In House Environmental Programs	
																				0
Synder-crete	2	3	1	2	3	3	2	1	4	3	3	4	3	2	3	2	4	4	2	153
Arch. Precast	3	3	4	4	3	3	4	5	4	3	3	4	3	2	3	2	4	4	4	183
American Cellular	3	3	3	3	3	3	3	1	4	3	3	4	3	2	3	2	4	4	3	165
																				0
																				0
																				0
																				0

Note: 1=excellent 2= good 3= fair 4=poor 5= very poor

In another system developed by Pearce (1998), performance requirements for sustainable building materials are classified under four main groups; namely, environmental, technological, resource use and socio-economic performances (Table 2.3).

Table 2. 3: Sample Information Requirements for Sustainable Building Materials (Source: Pearce, 1998)

Environmental Performance	Technological Performance	Resource Use Performance	Socio-Economic Performance
Impacts on Air Quality • Carbon Dioxide • Hydrocarbons Impacts on Water Quality Impacts on Soil Quality Ozone Depletion Potential Site Disturbance Assimilability Scarceness Impacts during Harvest Processing Impacts	Durability Service Life Maintainability Serviceability Code Compliance R-value Strength Constructability	Energy • Embodied • Operational • Efficiency • Distributional Degree of Processing Source Reduction Materials • Renewable • Recycled/ Recyclability • Reused/ Reusability • Renewability • Local/Transport Distance • Packaging Requirements	Occupant Health/ Indoor Env'l Quality • VOC Outgassing • Toxicity • Susceptibility to biocontamination Appropriateness for: • Scale • Climate • Culture • Site Economics: • Contribution to Economic Development. • Cost • Labor Skill Requirements • Labor Amount Requirements

In the 1990s, the development of a number of methods for evaluating the greenness of buildings, both for new designs and existing buildings was seen by the construction and property sector (Crawley and Aho, 1999). Many countries are more sensitive about environmental issues; hence they have developed their own evaluation criteria. Some of them have been sponsored by government and some have been developed by research organizations. Some of organizations related to sustainable or green architecture and environmental issues are listed below:

- American Council for an Energy-Efficient Economy (ACEEE)
- Centre Scientifique et Technique du Bâtiment (CSTB)
- Conseil International du Batiment (CIB)
- Institute for Sustainable Futures (ISF)
- Sustainable Buildings Industry Council (SBIC)
- United States Green Building Council (USGBC)
- World Green Building Council (WGBC)

Following sections give an overview of evaluation tools and software that can be used by architects to design sustainable buildings and to select sustainable building materials.

2.3.1. Evaluation Tools

The most well known and advanced evaluation systems in use today are the following:

- BREEAM (British Research Establishment Environmental Assessment): BREEAM developed in UK sets the standard for best practice in sustainable development and demonstrates a level of achievement.
- LEED (The Green Building Council's Leadership in Energy and Environmental Design): LEED enhanced in USA is the benchmark for the design, construction and operation of high performance green buildings (www.usgbc.org).

- BEPAC (British Columbia’s Building Environmental Performance Assessment Criteria): It is Canada's first evaluation system for measuring the environmental performance of existing and new commercial buildings (www.sustainableiowa.org).
- ECP (The Environmental Choice Programme): It was developed by the Government of Canada. It is one of many ecolabelling programs around the world rewarding products and services for their environmental leadership (www.terrachoice.com).
- SCS (The Scientific Certification System): It was developed in USA.
- PormisE (VTT Technical Research Centre of Finland): It is an environmental assessment and classification system for residential, office and retail buildings in Finland.
- ESCALE: It was developed in France.
- EcoEffect: It is a system to measure and estimate the environmental impact of a building during a life cycle. It was developed in Sweden.
- Casbee (Comprehensive Assessment System for Building Environmental Efficiency): It was developed in Japan.

In addition to this list, Howard (2005) prepared a chart to present the scope of environmental assessment methods (Table 2.4). Such tools are limited in scope for performance assessment, but provide the framework for preparing the documentation needed for certification. According to the author, green building rating systems in general focus on the following six categories of building design and life cycle performance:

1. Site,
2. Transport,
3. Water,
4. Energy,
5. Materials,

6. Indoor Environment.

Table 2. 4: Environmental Assessment Methods and Scope (Source: Howard, 2005)

Rating System		Site	Transport	Water	Energy&Atmosphere	Materials&Resources	Indoor Environment
Green Globes	Ca	X		X	X	X	X
NAHB Green Guidelines	US	X	X	X	X	X	X
HK BEAM	HK	X	X	X	X	X	X
SPEAR	Int	X	X	X	X	X	X
BREEAM	UK	X	X	X	X	X	X
LEED	US	X	X	X	X	X	X
Green Stars	Au	X	X	X	X	X	X
Green Building Label	Ta	X	X	X	X	X	X
Korea Green Building Label	Ko	X		X	X	X	X
CASBEE	Ja	X	X	X	X	X	X
GOBAS	Ch	X	X	X	X	X	X
GBTool	Int	X		X	X	X	X
Escale	Fr			X	X	X	X
ENVEST	UK			X	X	X	
LEGEP	Ge						
PromisE	Fi	X	X	X	X	X	X
Equer	Fr	X	X	X	X	X	
ATHENA	Ca/US					X	
Ecoquantum	NI					X	

Seo (2002) notes that in the past several years, interests and researches in the development of building and environmental assessment methods have increased significantly. Howard (2005) points out that if a tool or method is too simple and prescriptive then it will not be considered credible; on the other hand, if a tool or method is too complex, then it will appeal to only a small segment of the market willing to invest the time and expense of the sophisticated approach. According to the author, the future development of existing sustainability assessment methods for buildings is likely to include:

1. Continuing modification of the metrics and methods of assessment of the sustainability of buildings which is likely to include:
    - Improved methodology to provide a level playing field and publicly available data for the use of LCA in buildings
    - Improved tools to make the complexity of LCA accessible and practical for designers, operators and owners of buildings.
    - Improved performance based metrics, underpinned by better research for a broader range of sustainability measures in existing assessment and certification systems.
2. Steady progress in the market uptake of these methods and transformation of the building and real estate industries.

The most popular evaluation systems in the world are considered to be BREEAM and LEED which are explained in detail in the following sections.

(i) BREEAM

The first simplified environmental assessment and certification system developed internationally was the BREEAM rating system developed in the UK in 1990 (Howard, 2005). According to Skopek (1999), BREEAM is the most widely used international environmental assessment methodology; it has been applied to over a thousand buildings in Europe, Asia, and America. The author points out that its success depends on a benchmarking approach;

comprehensive coverage of issues related to energy, environmental impact, and health and productivity; and the identification of realistic opportunities for improvement as well as potential additional financial rewards.

In 1996 the Canadian Standards Association (CSA) adapted BREEAM for use in Canada. In 2001, the Canada Mortgage and Housing Corporation (CMHC) conducted *BREEAM/Green Leaf* pilot assessments of several typical multi-residential buildings (CMHC, 2001). Gowri (2004) also gives examples as BEPAC (Building Environmental Performance Assessment Criteria), BREEAM Canada and BREEAM GreenLeaf. The author notes that BREEAM is recognized by the U.K. building industry as the reference for assessing environmental performance, and that Canada, Australia and several European countries have developed variations of BREEAM incorporating local environmental requirements in their rating scheme.

There are currently four versions of BREEAM for different building types, such as; offices, residences, industrial units and supermarkets/superstores. Assessments are carried out by licensed assessors, who are trained by BRE. The website of BREEAM explains the rating process as the assessor reviews the building against a broad range of environmental issues to give an overall score, which is then translated into a BREEAM rating of ‘pass’, ‘good’, ‘very good’ or ‘excellent’.

Huovila, Rao, Sunikka, Curwell (2001) note that BREEAM can be used in a number of different ways by customers, design teams and building managers: Clients can use BREEAM to specify the environmental sustainability of their buildings in a way that is quick, comprehensive and visible in the market place. On the other hand, letting agents can use BREEAM to promote the environmental certificate and benefits of a building to potential clients. Additionally, building managers can benchmark their performance against others, both generally and within their own company; design teams can use BREEAM as a tool to improve the performance of their buildings and their own experience and knowledge of environmental aspects of sustainability.

Seo (2002) explains that the data required to evaluate through BREEAM is in two forms; quantitative and qualitative as follows:

- Quantitative: energy and water consumption, materials data, environmental profiling system based on LCA data which is used to determine the credits attributed for the materials.
- Qualitative: the use of high frequency weights in fluorescent lighting, (a health and comfort factor) or whether efforts have been made to plant new trees (a site ecology factor).

The objectives of the Building Research Establishment's Environmental Assessment Method (BREEAM) are to;

- build to the appropriate quality and to last. Longevity depends much on form, finishes and the method of assembly employed as on the material used.
- wherever feasible, use the construction techniques which are native to the area, learning from local traditions in materials and design;
- avoid using materials from non renewable sources or which cannot be reused or recycled, especially in structures which have a short life.

BREEAM includes eight categories, which are energy, transport, pollution, materials, land use, ecology, water consumption, health and well-being and management. There are further divided into subcategories which are assigned a maximum credit. These evaluation categories, their subcategories and the maximum obtainable credits are presented in Table 2.5.

Table 2. 5: Evaluation categories of BREEAM (Source: Adapted from website of BREEAM, accessed August 2007)

	Code	Evaluation Categories	Credits
Energy	Ene1	Dwelling Emission Rate	15
	Ene2	Building Fabric	2
	Ene3	Drying Space	1
	Ene4	EcoLabelled Goods	2
	Ene5	Internal Lighting	2
	Ene6	External Lighting	2
Transport	Tra1	Public Transport	2
	Tra2	Cycle Storage	2
	Tra3	Local Amenities	3
	Tra4	Home Office	1
Pollution	Pol1	Insulant GWP(Global Warming Potential)	1
	Pol2	NOx Emissions	3
	Pol3	Reduction of Surface Runoff	2
	Pol4	Renewable and Low Emission Energy Source	3
	Pol5	Flood Risk	2
Materials	Mat1	Environmental Impact of Materials	16
	Mat2	Responsible sourcing of Materials:Basic Building Elements	6
	Mat3	Responsible sourcing of Materials:Finishing Elements	3
	Mat4	Recycling Facilities	6
Water	Wat1	Internal Potable Water Use	5
	Wat2	External Potable Water Use	1
Land use and Ecology	Eco1	Ecological Value of Site	1
	Eco2	Ecological Enhancement	1
	Eco3	Protection of Ecological Features	1
	Eco4	Change of Ecological Value of Site	4
	Eco5	Building Footprint	2
Health and Wellbeing	Hea1	Daylighting	3
	Hea2	Sound Insulation	4
	Hea3	Private Space	1
Management	Man1	Home User Guide	3
	Man2	Considerate Constructors	2
	Man3	Construction Site Impacts	3
	Man4	Security	2

According to Seo (2002) the percentage of credits achieved under each category is then calculated and environmental weightings are applied to produce an overall score for the building. Then, the overall score is translated into a BREEAM rating. This weighting system is predetermined through the national review process therefore the users cannot apply their own individual weighting priorities.

BREEAM is applied to non-residential buildings and the Ecohomes, a version of BREEAM for homes, is used for residential developments of new private or social residential property including conversions (www.chelmsford.gov.uk). Ecohomes assessments can be carried out at both the design stage or post construction for new buildings and major refurbishment projects.

Ecohomes determines the credits by using The Green Guide which was developed by incorporation with the BRE method of Environmental Profiles of UK construction materials. The Green Guide used for residential building is called The Green Guide to Housing Specification. This guide assesses used specification for walls, roof, and floor and window construction, together with sections on landscaping, kitchen fittings and refurbishment. As shown in Table 2.6. building materials and components are evaluated according to a range of environmental issues, including climate change, fossil fuel depletion, ozone depletion, freight transport, human toxicity, waste disposal, water extraction, acid deposition, ecotoxicity, eutrophication, summer smog and minerals extraction. The table also gives the weighting factors of these issues which were determined through the consensus of local and central governments, materials producers, construction professionals, environmental activists, academic and environmental researchers.

Table 2. 6: Environmental issues covered in The Green Guide and weighting of environmental issues (Source: The Green Guide to Housing Specification, 2007)

Environmental issues and production of building materials concerns		% Weights
Climate change	Global warming or greenhouse gases	36,0
Fossil fuel depletion	Coal, oil and gas consumption	11,4
Ozone depletion	Gases which destroy the ozone layer	7,7
Freight transport	Distance and mass of freight moved	7,4
Human toxicity	Pollutants which are toxic to humans	6,7
Waste disposal	Material sent to landfill or incineration	5,8
Water extraction	Mains, surface and ground water consumption	5,1
Acid deposition	Gases which cause acid rain, etc.	4,8
Ecotoxicity	Pollutants which are toxic to the ecosystem	4,1
Eutrophication	Water pollutants which promote algal blooms, etc.	4,1
Summer smog	Air pollutants which cause respiratory problems	3,6
Minerals extraction	Metal ores, minerals and aggregates	3,3

In the Green Guide, environmental issues are explained in detailed as given below:

> "Climate change: 'Global Warming' is associated with problems of increased desertification, rising sea levels, climatic disturbance and spread in disease. It has been the subject of major international activity, and methods for measuring it have been presented by the Intergovernmental Panel on Climate Change (IPCC).
>
> Fossil fuel depletion: This issue reflects the depletion of the limited resource that fossil fuels represent. It is measured in terms of the primary fossil fuel energy needed for each fuel.
>
> Ozone depletion: Ozone depleting gases cause damage to atmospheric ozone or the 'ozone layer'. Damage to the ozone layer reduces its ability to prevent ultraviolet (UV) light entering the earth's atmosphere, increasing the amount of harmful UVB light hitting the earth's surface.
>
> Freight transport: The movement of freight causes congestion, noise, and discomfort to those local to transport routes such as

roads, ports or flight paths. All transport modes are included with the same weighting, and the issue takes account of both the distance traveled and the mass carried. This issue does not reflect the impacts of energy use or emissions from each type of transport, which is accurately accounted for within other relevant categories, e.g. fossil fuel depletion.

Human toxicity: the emission of some substances such as heavy metals can have impacts on human health. Assessment of toxicity has been based on tolerable concentrations in air, air quality guidelines, tolerable daily intake and acceptable daily intake for human toxicity.

Waste disposal: This issue reflects the depletion of landfill capacity, the noise, dust and odour from landfill (and other disposal) sites, the gaseous emissions and leachate pollution from incineration and landfill, the loss of resources from economic use and risk of underground fires, etc.

Water extraction: This issue reflects the depletion, disruption or pollution of aquifers or disruption or pollution of rivers and their ecosystems due to over abstraction.

Acid deposition: Acidic gases such as sulphur dioxide (SO_2) react with water in the atmosphere to form ‘acid rain’, a process known as acid deposition. When this rain falls, often a considerable distance from the original source of the gas, it causes ecosystem impairment of varying degree, depending upon the nature of the landscape ecosystems.

Eutrophication: Nitrates and phosphates are essential for life, but in increased concentrations of in water, they over-encourage the growth of algae, reducing the oxygen within the water leading to increasing mortality of aquatic fauna and flora and to loss of species dependent on low-nutrient environments. Emissions of ammonia, nitrates, nitrous oxides and phosphorus to air or water all have an impact on eutrophication.

Ecotoxicity: The emission of some substances such as heavy metals can have impacts on the ecosystem. Assessment of toxicity has been based on maximum tolerable concentrations in water for ecotoxicity.

Summer smog: Because the reactions depend on sunlight and are common in polluted atmospheres, this issue has known as 'summer smog'. Although ozone in the upper part of the atmosphere is essential to prevent ultraviolet light entering the atmosphere, increased ozone in the lower part of the atmosphere is implicated in impacts as diverse as crop damage and increased incidence of asthma and other respiratory complains.

Minerals extraction: This issue reflects the total quantity of mineral resource extracted. This issue is a proxy for levels of local environmental impact from mineral extraction such as dust and noise. It assumes that all mineral extractions are equally disruptive of the local environment."

The Green Guide uses 'A, B, C' rating system to evaluate building materials and components. The lowest environmental impact is given an 'A' rating, while the highest environmental impact is given a 'C' rating. This rating system is used to evaluate the major building elements. When A-rated specifications have been chosen for major elements, the impacts of the minor elements become more significant in the overall impacts of the housing unit.

(ii) LEED

LEED was launched in 1998 by U.S. Green Building Council. It aims to improve the quality of the buildings and their impact on the environment. It is used by builders, designers and occupants to measure the impacts of their building's performance (see Appendix A). LEED evaluates five areas of human and environmental health, which are;

- Sustainable site development,
- Water savings,
- Energy efficiency,
- Materials selection,
- Indoor environmental quality
- Bonus credits for Process and Design Innovation.

To obtain a rating, a building must fulfill seven prerequisites and then obtain points for credits related to the four criteria, namely, sustainable sites, water efficiency, energy and atmosphere, materials and resources, and indoor environmental quality (Seo, 2002). These prerequisites are listed in Table 2.7 along with their objectives.

According to Gowri (2004), the prerequisites are critical because they do not provide any credit points towards the overall score, but must be met irrespective of meeting other credit requirements. The author expresses the success of LEED in that it has created demands for adapting the rating system for existing buildings, commercial interiors and residential buildings.

Table 2. 7: Seven prerequisites to obtain a rating in LEED green building rating system (Source: Seo, 2002)

Criteria	Prerequisite	Objective
Sustainable Sites	Erosion and Sedimentation Control	to control erosion to reduce negative impacts on water and air quality
Energy and Atmosphere	Fundamental Building Systems Commissioning	to verify and ensure that fundamental building elements and systems are designed, installed and calibrated to operate as intended
	Minimum Energy Performance	to establish the minimum level of energy efficiency for the base building and systems
	CFC Reduction in HVAC&R Equipment	to reduce ozone depletion
Materials and Resources	Storage and Collection of Recyclables	to facilitate the reduction of waste generated by building occupants that is hauled to and disposed of in landfills
Indoor Environmental Quality	Minimum IAQ Performance	to establish minimum indoor air quality (IAQ) performance to prevent the development of indoor air quality problems in buildings, maintaining the health and well being of the occupants
	Environmental Tobacco Smoke (ETS) Control	to prevent exposure of building occupants and systems to environmental tobacco smoke

The LEED project checklist is applied to calculate the number of credits (see Appendix A). According to version 1.11 updated in January 2007, the checklist has a maximum of obtainable credits as 130 (Table 2.8).

Table 2. 8: LEED Project Checklist (Source: Adapted from LEED for Homes Program Pilot Rating System; 2007)

	Max. Points Available
Innovation and Design Process	9
Location and Linkages	10
Sustainable Sites	21
Water Efficiency	15
Energy and Atmosphere	38
Materials and Resources	14
Indoor Environmental Quality	20
Awareness and Education	3
Project Totals	**130**

To earn a LEED certificate, firstly, a project has to be registered. The project must comply with all prerequisites and performance credits within each category. Different levels of green building certification are awarded based on the total credits earned. According to the number of credits obtained a project can earn a Certified status, a Silver, a Gold, or a Platinum certification in the following manner:

- When projects achieve 40% or more of the Core Credits, they can became a LEED Certified project,
- When projects achieve 50% or more of the Core Credits, they are awarded the LEED Silver certification,
- When projects achieve 60% or more of the Core Credits, they are awarded the LEED Gold certification,
- When projects achieve 80% or more of the Core Credits, they are awarded the LEED Platinum certification.

2.3.2. Environmental Evaluation Software

There are a number of computer programmes available for evaluating a product. This variety makes it difficult to select an appropriate programme. According to Seo (2002), the building evaluation software generally assess buildings at the whole building level, based on some form of Life Cycle Assessment (LCA)[1] database but some of them i.e. BEES and Eco-quantum are focused on building products.

Existing software can measure environmental impacts of materials, assess passive solar heating, natural lighting and ventilation, calculate life-cycle cost

[1] LCA is a method for determining the environmental and resource impacts of a material, product, or even a whole building over its entire life.

and select appropriate building product in terms of environmental issues. The most commonly used software for environmental evaluation are the following;

- ATHENA EcoCalculator
- BEAT (Building Environment Assessment Tool)
- BEES (Building for Environmental and Economic Sustainability)
- EcoProfile
- Eco-Quantum
- ECOTECT
- ENERGY-10
- ENVest (Environmental Impact Estimating Software)
- GBA (Green Building Advisor)

(i) Eco-Quantum

The Interfaculty Environmental Science Department (IVAM) of the University of Amsterdam, which is a research and consultancy agency in the field of sustainability, developed Eco-Quantum in 1999 to calculate a building's environmental impact. The aim was to assess the environmental performance of the building during its design phase so that steps may be taken to improve it before the construction phase.

Kortman, Ewjik, Mak, Anink, and Knapen (1998) explain the objectives of Eco-Quantum as it enables a designer to quickly identify environmental consequences of material choices and water and energy consumption of their designs. Eco-Quantum is used in design and end-of-life stages for building design and building materials (Seo, Tucker, Ambrose, Mitchell and Wang, 2005). Eco-Quantum permits large, diverse quantities of information on the environmental performance of a building to be converted for the use of all parties in the construction process (Larsson, 2003).

According to Seo (2002), Eco-Quantum calculates the environmental effects during the entire life cycle of the building from production to use to demolition. The Eco-Quantum has four assessment criteria, namely natural resources, environmental loading, land use and biodiversity (Table 2.10).

According to information on the Eco-Quantum website the required input consist of the quantities, specifications and details on material of the building components. The results are submitted into the form, as well as its energy consumption for interior heating, cooling, hot water *etc.*, which is taken from the energy-performance calculation.

According to Soebarto and Williamson (2005), this program assesses the environmental performance of the building on the basis of a life-cycle assessment (LCA) technique where specified environmental effect scores are converted into four environmental indicators which represent the environmental consequences of design decisions. These indicators are raw material depletion, emissions, energy consumption and waste.

(ii) Green Building Advisor (GBA)

The official website of Green Building Advisor (GBA) states the aim of the software as helping users to identify actions to reduce the environmental impacts of a building project, while ensuring healthy and productive indoor spaces. It identifies the specific design strategies, which are grouped into environmental topics (energy, water, or indoor environment) and subtopics.

Users determine which areas or systems they want to focus on improving the building environmentally and the basic building description. GBA gives a report including lists of relevant green building strategies, the advice of experts and precedent building cases.

(iii) ENVest- Environmental Impact Estimating Software

ENVEST, the Environmental Impact Estimation Software, is a tool based on life cycle assessment methodology developed by BRE with the support of the Department of Employment, Training and Rehabilitation (DETR) in USA. This software is designed for offices and commercial buildings and enables architects and designers to evaluate the environmental impacts of different design option for a chosen building. It deals with the environmental impacts of materials used during construction and maintenance, as well as the energy and resources consumed during the buildings lifetime (Huovila, Rao, Sunikka, Curwell, 2001).

ENVest is a tool that helps designers to consider the life cycle environmental impact of buildings at the building inception stage. It provides a holistic approach to the design by:

- helping to optimise the form of the building, for the least environmental impact over the building life cycle.
- informing choice about the environmental impacts of the main elements of the building structure.
- providing and maintaining reference data acquired from material manufacturers.
- aiding designers to balance the environmental impact of the energy and water consumed during the operational life of the building, with the choice of building materials.
- performing comparisons of various building schemes.

Envest uses Ecopoints to calculate the environmental impacts of the design. Almost all data entry is from menu choices, thereafter the assessment continues. This process is explained on one of the web sources (www.environmental-expert.com) in the following sequence:

Step 1: Select a building shape from a choice of eight generic shapes.

Step 2: Input basic building dimensions and details - height, storeys, window area etc.

Step 3: Enter details of main building elements [all presented as menu choices]. Refine the design by experimenting with different specifications to see how this affects the Ecopoint score.

Step 4: Enter details for the building services e.g. heating, lighting, air conditioning etc. so Envest can estimate operational impacts.

Step 5: Examine the final 'Ecopoints' score. This can be compared with benchmarks for other buildings, either those designed by other architects, or against other buildings designed by the same team. This enables the progress of the design to be monitored and the final design to be assessed.

(iv) BEES - Building for Environmental and Economic Sustainability

The BEES (Building for Environmental and Economic Sustainability) is designed for decision support in material choice stages (Borg, 2001). This software allows a technique for selecting cost-effective, environmentally-preferable building products (www.bfrl.nist.gov/info/software.html). It helps users to balance the environmental and economic performance of building products. Inventory flow items have to be indicated as inputs. It presents charts and graphs of production processes, energy requirements and environmental performance.

The BEES programme (NIST, 1998; Lippiatt, 1998) developed by the US National Institute of Standards and Technology aims to help designers to select building products that strike a balance between environmental and economic performance. This can be achieved by placing the economic and the overall environmental performance on the same hierarchical level in the decision-making or assessment matrix. BEES allows decision-makers to assign different weights to environmental and economic performance aspects and thus arrive at a single performance score for decision making. There are approximately 230 products in BEES 4.0. Major product groupings and their subgroups are listed in Table 2.9.

Table 2. 9: Major product groupings and their subgroups

Building maintenance	cleaning products	bath and tile cleaners
		carpet cleaners
		floor strippers
Building repair and remodeling	remodeling products	adhesive and mastic removers
Building sitework	site electrical utilities	transformer oil
	site improvements	fertilizer
		parking lot paving
		roadway dust control
Equipment and furnishings	furnishings	chairs
		fixed casework
		table tops, counter tops, shelving
Interiors	fittings	fabricated toilet partitions
	interior construction	lockers
		partitions
	interior finishes	ceiling finishes
		floor coverings
		wall finishes to interior walls
Shell	exterior enclosure	exterior sealers or coatings
		exterior wall finishes
		exterior wall systems
	roofing	ceiling insulation
		roof coatings
		roof coverings
	superstructure	beams
		columns
		roof sheathing
Substructure	basement construction	basement walls
	foundations	slabe on grade

2.4. Sustainable Building Materials

According to Kohler and Chini (2005), one of the central objectives of sustainable building is the optimal use of resources in a long-term perspective. These resources are mainly materials, energy, water, and land. Buildings and their planned co-location crucially affect the majority of our consumption of resources, air, water and land pollution (Howard, 2005). In the U.S., buildings use one third of the total energy, two-thirds of the electricity, one-eighth of the water, and transform land that provides valuable ecological services. The natural resources used in construction are building materials, energy and water.

According to Pearce (1998), the act of construction results in the consumption of large quantities of energy and materials over a relatively short period of time, and can cause significant quantities of waste which must be recovered or disposed. Additionally, the transportation required to move materials and equipment to and from the site also consumes energy and results in environmental impacts due to emissions and other conflicts with natural ecosystems. The author notes that a building consumes not only energy for heating, cooling, lighting, and other purposes, but matter for both operation of the physical structure and for the processes undertaken by users such as manufacturing, residential applications (e.g., cooking, dining, and bathing), or retailing. Lacasse (1999) notes that the construction industry needs to take steps in the direction of achieving sustainable buildings; since it consumes natural and physical resources, it has a significant impact on the environment.

Building materials have to be investigated at the design stage to make the building sustainable. Sustainable design deals with harmony with environment. It provides human needs rather than human wants with the carrying capacity of the natural and cultural environments, so sustainable building has to be constructed from natural sustainable materials collected onsite, generate its own energy from renewable sources such as solar or wind, and manage its own waste (www.nps.gov). Godfaurd, Derek and Jeroimidis (2004) note that building materials must serve their planned function for a reasonable length of time after installation. The authors also point out that the rational use of natural resources and appropriate management of the building stock will contribute to saving scarce resources, reducing energy consumption, and improving environmental quality.

Zachariah (2003) refers to Wilson's (2005) words where the author emphasizes that, "in the greenest of projects it is likely that many products will be used that are not themselves green, but are used in a manner that helps to reduce the overall environmental impacts of the building".

Decisions based on impacts should be carefully considered in decisions making stage during design (Pearce, 1998). It is thought that environmentally friendly building materials may cost more because of expenditure on research and development, limited production quantities and specialized distribution arrangements that cannot take advantage of the economy of scale of conventional products. However, this is not always the case. Greener materials may cost less than conventional materials if waste resources are used in their production, or there are lower costs associated with reduced embodied energy, smaller transportation costs in the case of local production and direct distribution from the manufacturer over a multi-step supply chain (Malin, 2005, Wilson, 1999).

2.4.1. Classification of Sustainable Building Materials

According to Pearce (1999), in recent years the construction materials technology has changed and there is an increased emphasis on reuse and recycling of construction and demolition waste materials like timber, steel and concrete; improving traditional products such as concrete into fiber or plastic-reinforced concrete; and development of completely new technology such as geotextiles.

Building materials can be classified in different ways, i.e. way of using, physical, chemical properties. According to Reilly (1997), building materials can be divided into two categories, those which serve as part of an exterior construction system; such as walls or roofing systems and those which serve as part of an interior construction system; such as floors, partitions or ceiling components. Mazzoleni (1998) investigated building materials in four categories given below:

- Structural materials
- Partitions
- Floor/roof
- Window/door

On the other hand, Saraylı (1978) organizes building materials in three groups in terms of their intended use as follows:

- structural materials
- finishing materials
- protecting materials

According to data by Turkish Statistical Institute (TUIK), reinforced concrete, timber, brick, stone, sun-dried brick and aerated concrete are commonly used in buildings as structural materials in Turkey.

2.4.2. Selection of Building Materials

Spiegel and Meadow (1999) point out that the planet earth is affected directly or indirectly by the selection of products used in buildings. The authors express concern that the type and quantity of raw materials used in building industry are extracted and processed impacts the earth directly. They argue there is a close link between the materials selected and how the building occupants use the building.

According to Pearce (1998), specification of particular materials creates a market demand for those materials during construction, stimulating the harvesting of raw materials to be manufactured into the specified components, which in turn must be transported to the site and assembled into the facility system. The author also points out that

> "even when ecologically sound alternatives to traditional building materials can be found, their use often presents conflicts with other parameters for materials selection, especially economic considerations".

Careful selection of environmentally sustainable building materials is the easiest way for architects to begin incorporating sustainable design principles in buildings (Godfaurd *et al*, 2004). The author points out that natural materials are generally lower in embodied energy and toxicity than man-made materials, they require less processing and are less damaging to the environment. When low-embodied-energy natural materials are incorporated into building products, the products become sustainable.

US National Park Service (NPS) indicates that in selecting building materials, it is helpful to prioritize them by origin, avoiding materials from nonrenewable sources. When their source is sustainable:

- Natural materials are less energy-intensive and polluting to produce, and contribute less to indoor air pollution.
- Local materials have a reduced level of energy cost and air pollution associated with their transportation, and can help sustain the local economy.
- Durable materials can save on energy costs for maintenance as well as for the production and installation of replacement products.

Geiser and Harriman believe that measurement is the key to managing and improving performance. To respond to need for standardized measures, several organizations, such as The Global Reporting Initiative (GRI), the World Business Council for Sustainable Development (WBCSD), the World Resource Institute (WRI), the Centre for Waste Reduction Technologies (CWRT) and the International Organization for Standardization (ISO) have begun to develop standardized sets of indicators.

The huge number of potential materials available to designers and contractors makes optimization of material choices a nearly impossible task (Pearce, 1998). It has been seen that there is some weakness in the published indicators. According to Veleva (2001), these weaknesses are the lack of a sustainability definition, too large a number of indicators, a lack of detailed guidance on how to use the indicators in practice, and a complicated reporting framework suitable for large corporations but not for small and medium-sized companies.

CHAPTER 3

MATERIAL AND METHODOLOGY

In this chapter is explained the material and research method used in the study. The survey materials include the case study unit of ODTUKENT housing. The methodology part presents the evaluation processes of materials.

3.1. Material

This study was implemented to evaluate building materials in terms of their sustainability. A case study was carried out on two units of ODTÜKENT housing on METU Campus in Ankara. Photographs and production drawings of the selected units are presented in more detail in this chapter. ODTÜKENT housing units are occupied by the academic and administrative staff of METU. They are located on the west of METU campus (Figure 3.1). There are a total of 213 units ranging from triplex villas to apartments.

The first stage of ODTUKENT housing project consisted of six different types of plans. They were designed by the Architectural Firm Atabaş and constructed by METU Directorate of Construction and Technical Works (DCTW).

Figure 3. 1: Map of existing METU Campus. (Source: Website of Middle East Technical University, accessed September 2007)

The second stage consisting of four types of plans were constructed between 1996 and 1998 by EBİ (Electronic – Computer and Construction) Corporation. On the west of the ODTUKENT housing area, Konukevi blocks were constructed between 2003 and 2005 by EBI Corporation. Konukevi 1 has 3 blocks consisting of bachelor flats. Konukevi 2 has 36 units and Konukevi 3 and 4 consist of 16 flats each. Site plan of ODTÜKENT and Konukevi and location of units are shown in Figure 3.2.

Figure 3. 2: Satellite image of ODTUKENT Housing area (Source: Google Earth, 2007)

Triplex Unit (Code 11):

Selected unit (Code 11) is an example of a row house in ODTÜKENT. It is a 3-storey building, composed of basement floor, ground floor and first floor. It covers approximately 140 m². The basement floor consists of two store rooms and a boiler room. In the ground floor, a dining room connects with the kitchen and there is a living room. Also there is a WC, an entrance hall and a terrace. In the first floor, there are two rooms, a hall and a bathroom. Construction materials used in this building are given in Table 3.1. The floor plans are shown in Figure 3.3-3.5 and a picture of the unit is presented in Figure 3.6.

Table 3. 1: Construction materials of the triplex unit

Subcategory for Environmental Impact of Materials	**Construction materials used in the triplex unit**
Roof	Timber roof structure with insulation covered with clay tiles
External walls	Brickwork outer leaf, insulation, brickwork inner leaf covered with plaster
Internal walls	Brick covered with plaster
Floors	In-situ concrete slab covered with plaster
Windows	PVC frame, double glazed
External surfacing	There is no surfacing
Boundary protection	There is no boundary wall

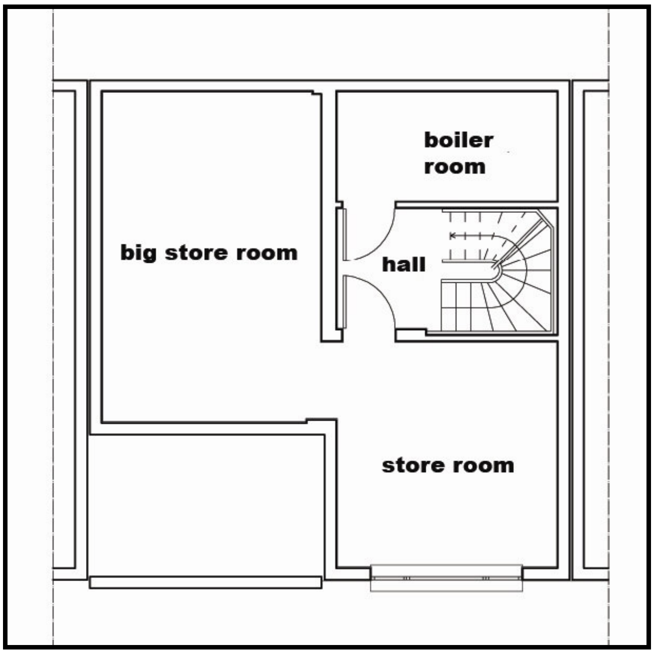

Figure 3. 3: Basement floor plan of case study building. (Source: Çeliknalça, 2006)

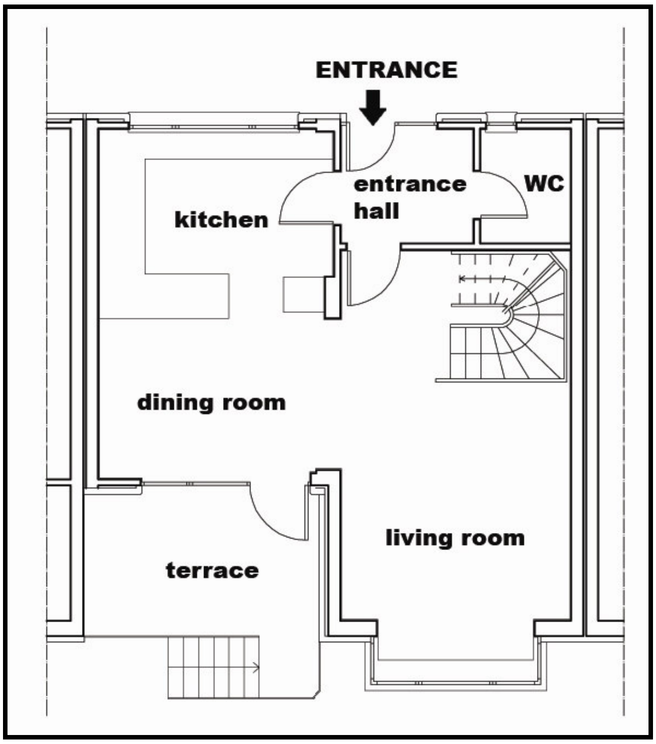

Figure 3. 4: Ground floor plan of case study building. (Source: Çeliknalça, 2006)

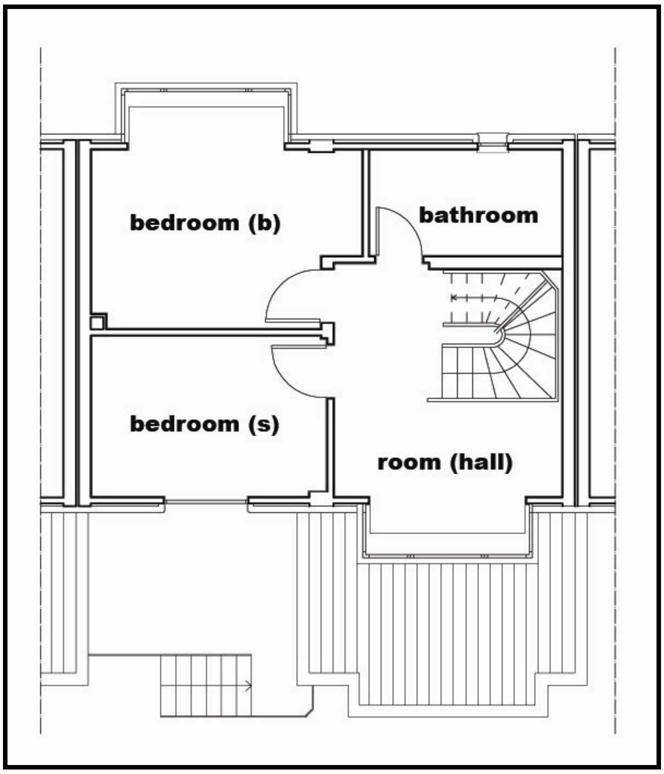

Figure 3. 5: First floor plan of case study building. (Source: Çeliknalça, 2006)

Figure 3. 6: Side view of row houses in ODTUKENT

Konukevi 1 – Bachelor Flats:

Konukevi 1 was designed in 2000 by Gönül Evyapan and the Architectural Firm Sanal. This building is composed of 3 blocks, connected to each other. They are used as bachelor flats. In this study, material used for Block A was investigated. It is a 4-storey-building. There are a boiler room and storages in the basement floor. The ground floor consists of a reception area and has 6 units. The first floor has 6 duplex units. Each unit has a common living area and a kitchen. These units also have their own bathrooms. Construction materials used in this building are given in Table 3.2. The floor plans are shown in Figure 3.7 - 3.10 and a picture of the block is presented in Figure 3.11.

Table 3. 2: Construction materials of Block A of bachelor flats

Subcategory for Environmental Impact of Materials	Construction materials used in Block A of bachelor flats
Roof	Timber roof structure with insulation covered with metal sheet
External walls	Aerated concrete blocks covered with plaster
Internal walls	Brick and plasterboard covered with plaster
Floors	Block flooring covered with plaster
Windows	PVC frame, double glazed
External surfacing	Face brick
Boundary protection	There is no boundary wall

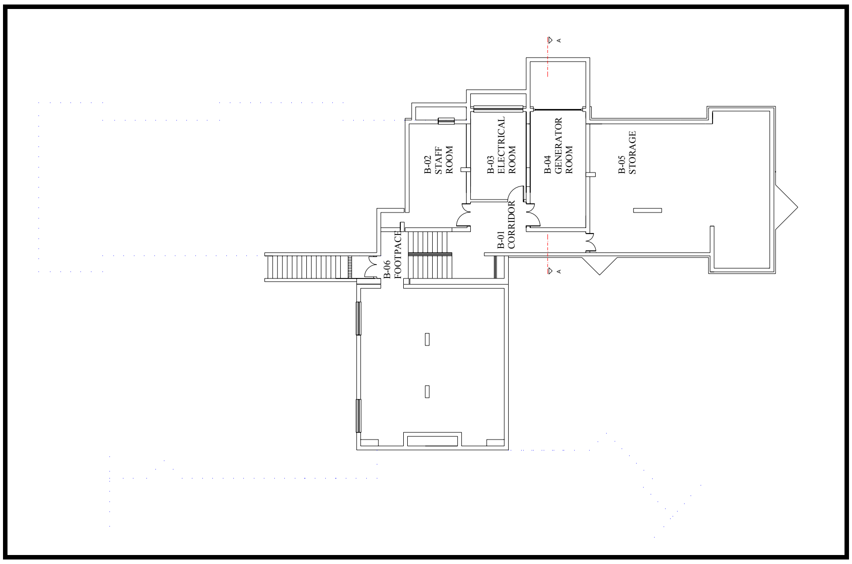

Figure 3. 7: Basement plan of the block of bachelor flats

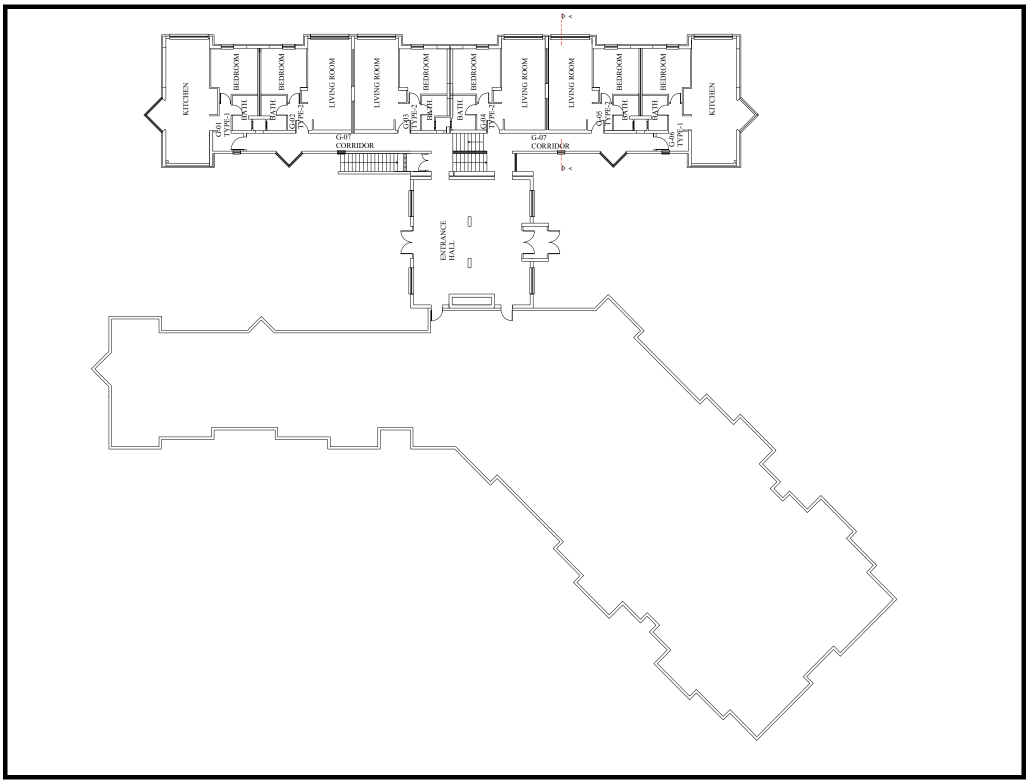

Figure 3. 8: Ground floor plan of the block of bachelor flats

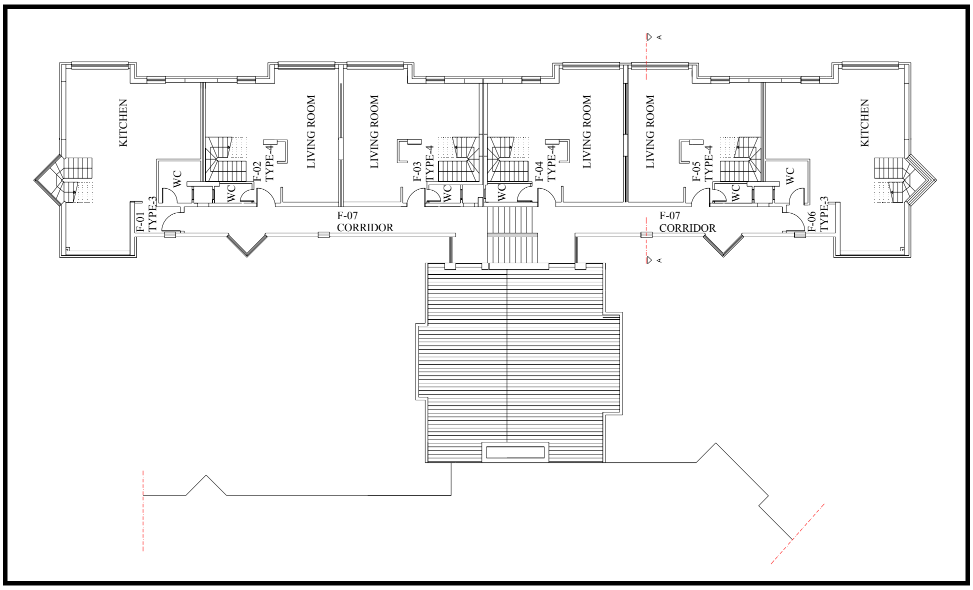

Figure 3. 9: First floor plan of the block of bachelor flats

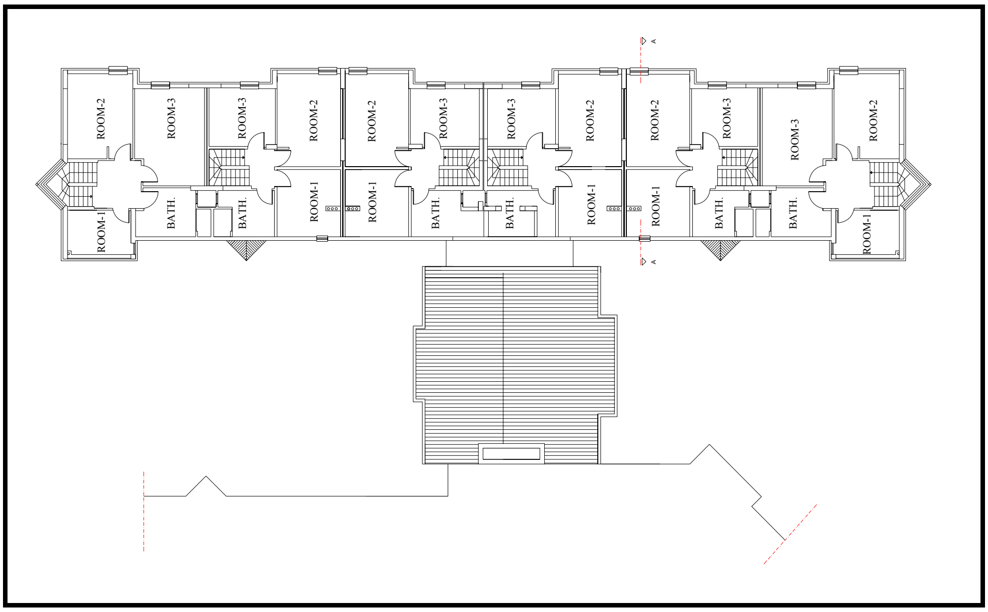

Figure 3. 10: Second floor plan of the block of bachelor flats

Figure 3. 11: East side view of bachelor flats

3.2. Methodology

The case study buildings, the triplex unit and one block of bachelor flats (Konukevi 1), were chosen in ODTUKENT housing area for the survey. They were selected to evaluate the materials in terms of the sustainability indicator through the evaluation system 'BREEAM Ecohomes' and the evaluation software 'BEES 4.0'.

The plans and detailed information was obtained from the METU Directorate and Construction Department. Photographs of the buildings were taken by the author. Drawings of the plans and section were reproduced through AutoCad 2006.

(i) Evaluation through BREEAM

According to the BREEAM evaluation system, materials are evaluated in terms of environmental impact, responsible sourcing of materials in basic building elements and finishing elements and recycling facilities. Table 3.3 gives the weight of evaluation categories.

Table 3. 3: Evaluation categories of BREEAM EcoHomes in Material section

Evaluation Categories	Max. Credits
Environmental Impact of Materials	16
Responsible sourcing of Materials: Basic Building Elements	6
Responsible sourcing of Materials: Finishing Elements	3
Recycling Facilities	6

In this study, only the 'environmental impact of materials' section is used to evaluate ODTUKENT housing. The environmental impacts of materials used in the construction of the following categories; roof, external walls, internal walls, floors, windows, external surfacing and boundary protection which are calculated to determine the environmental impact credits of the building (Table 3.4).

Table 3. 4: Subcategory for environmental impact of materials

Credits	Subcategory for Environmental Impact of Materials
3	Roof
3	External walls
3	Internal walls
3	Floors
2	Windows
1	External surfacing
1	Boundary protection

Credits are scored for each component for each subcategory. Earned scores are calculated according to environmental weightings as listed in Table 2.6, added to get a single score. After calculating the credits as a single score, it is converted into Ecohomes rating. As mentioned earlier, Ecohomes utilises an ‘A, B, C’ rating system. If a material gains at least 80% of the credits for each of the subcategories, it obtains an ‘A’ rating. An ‘A’ rating means the least environmental impact and hence the best rating.

(ii) Evaluation through BEES

Additionally, the evaluation software BEES 4.0 was applied to case study buildings. It was chosen because of its availability, it can be downloaded via internet.

Firstly, a material is selected from the 3 hierarchical groups, i.e. major group element, group element and individual element (Figure 3.12). For instance, to get the values of floor coverings, ‘interiors’ is selected from the menu of ‘major group element’, then ‘interior finishes’ is chosen from ‘group element’ and ‘floor coverings’ is selected from the ‘individual element’ list and ‘View product list’ button is used for getting more information about materials included in this list.

After finishing the first step, a product alternatives screen appears (Figure 3.13), which is used to select one material or more than one material to compare their results. For instance, it is possible to calculate the environmental impacts values of ceramic tile and marble tile together, as illustrated in Figure 3.13.

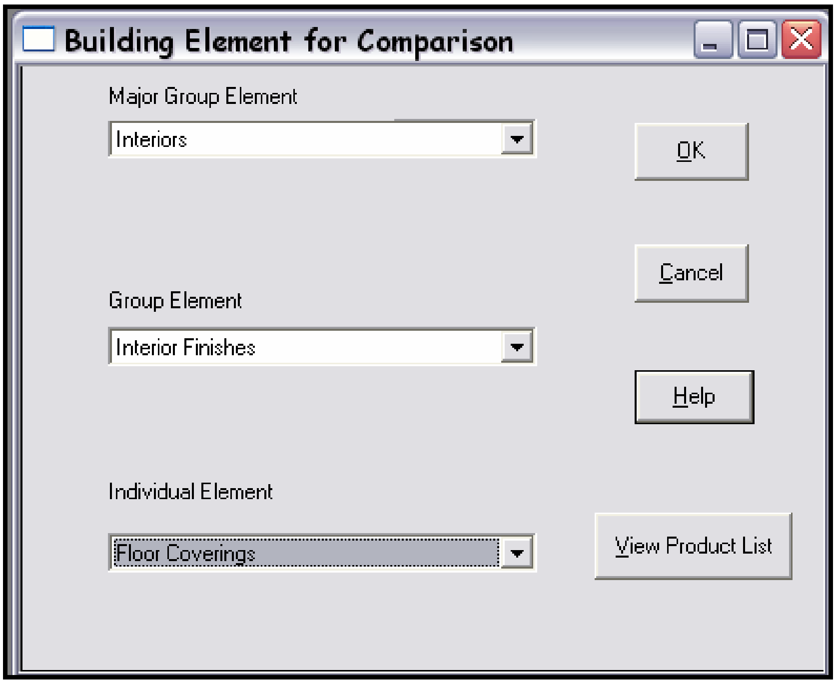

Figure 3. 12: Screen shot of building elements

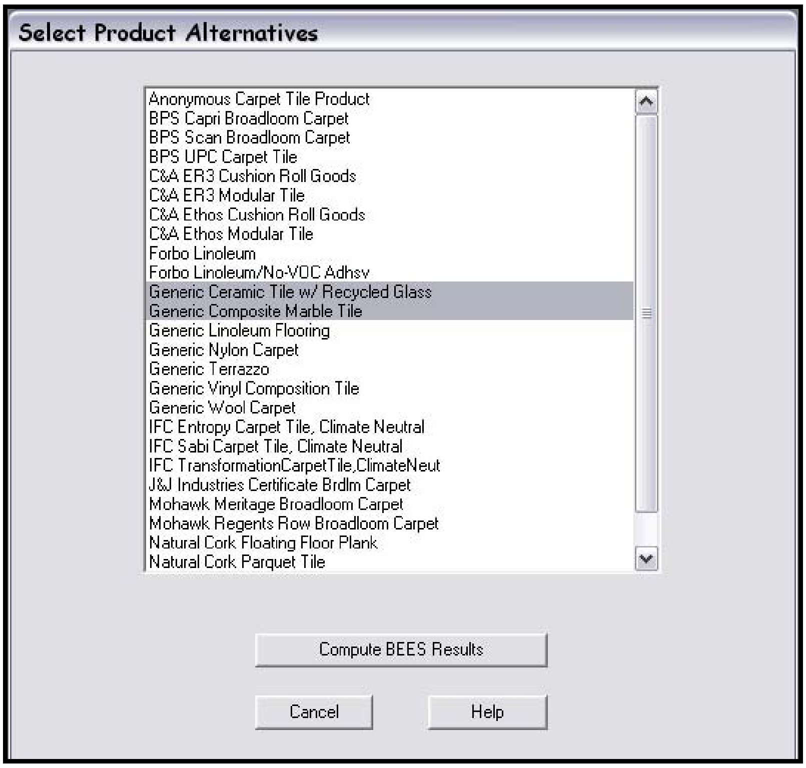

Figure 3. 13: Screen shot of product alternatives

After selecting the products BEES can compute the environmental impacts and present them (Figure 3.14). The results are produced individually or together as graphs. For instance, both environmental and economic performances can be evaluated, if it is needed. Additionally, graphs are detailed in terms of life cycle stage and environmental flow. Environmental flow has thirteen indicators, namely, global warming, acidification, eutrophication, fossil fuel depletion, indoor air quality, habitat alteration, water intake, air pollutants, ecological toxicity, human health in terms of cancerogenous, ozone depletion and smog. BEES gives reports to summarize the results or all tables in one, as optional.

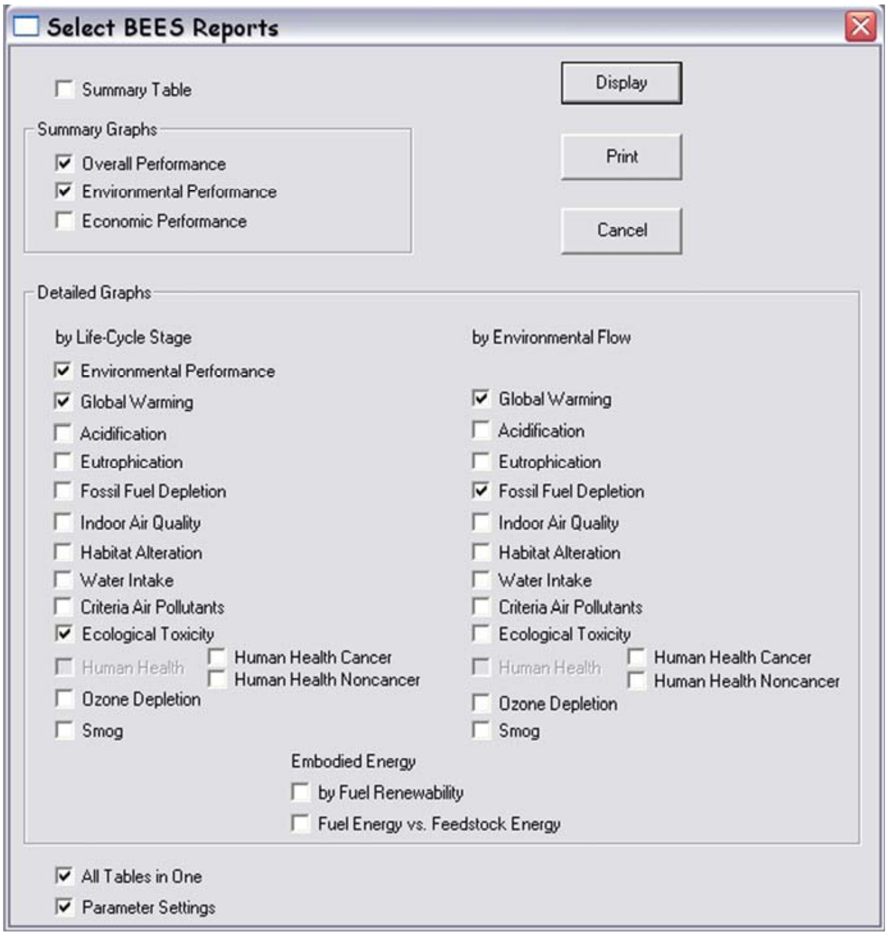

Figure 3. 14: Screen shot of parameters of reports

In this study, the plans were obtained and the materials were defined. They were calculated through BEES. BEES gave the environmental impacts values of these materials. Thereafter, the amounts of materials used in the block of bachelor flats and the triplex unit of ODTUKENT housing were calculated. The total amounts of environmental impacts were calculated.

CHAPTER 4

RESULTS AND DISCUSSION

In this chapter, evaluation of sustainability of building materials used in case buildings is presented. Then, the results are given. Building materials of case study buildings are evaluated in terms of their environmental impacts. In the last part, results are discussed.

4.1. Evaluation through BREEAM

Materials used for the triplex unit of ODTUKENT housing are presented in Table 3.1 in the previous chapter. To evaluate the materials used in case buildings, the evaluation charts of Green Guide to Housing Specification were applied. These charts have sustainability indicators accepted by BREEAM, construction materials and summary ratings. As determined in previous chapter, ‘A, B, C’ rating system is carried out in BREEAM EcoHomes. Indicators used for Green Guide to Housing Specification are also explained in Chapter 2. The assessors of Green Guide give a rating for each sustainability indicators. Building materials used in roof, external walls, internal walls, floor and windows of case study building are determined through the Green Guide and ratings are shown in Table 4.1. The specifications of the Green Guide to Housing Specification used for these buildings are shown in Appendix B.

Table 4. 1: Ratings of construction materials of the triplex unit

	ROOF	EXTERNAL WALLS	INTERNAL WALLS	FLOOR	WINDOW
	Timber roof structure with insulation covered with clay tiles	Brickwork outer leaf, insulation, brickwork inner leaf covered with plaster	Brick blocks covered with plaster	In-situ concrete slab covered with plaster	PVC frame, double glazed
Indicators					
Climate change	A	A	B	B	B
Fossil fuel depletion	A	A	B	A	C
Ozone depletion	C	A	A	A	C
Freight transport	B	A	B	C	A
Human toxicity	A	A	A	C	B
Waste disposal	A	C	C	C	A
Water extraction	A	B	B	C	A
Acid deposition	A	A	B	B	B
Ecotoxicity	A	A	A	A	C
Eutrophication	A	A	A	C	A
Summer smog	A	A	C	A	A
Minerals extraction	A	A	B	C	B
Recycled input	C	C	C	C	C
Recyclability	A	A	A	A	C
Currently recycled	C	A	A	A	C
Energy saved by recycling	A	A	A	B	C
Average rating	**A**	**B**	**B**	**C**	**C**

Materials used for Block A of bachelor flats are presented in Table 3.2 in the previous chapter. These materials were evaluated according to the Green Guide to Housing Specifications as used in the triplex unit of ODTUKENT housing. While evaluating the roofing materials an exact match could not be found in the specifications of the Green Guide. Roofing components could therefore not be rated. The average ratings are presented in Table 4.2.

Table 4. 2: Ratings of construction materials of Block A of bachelor flats

	EXTERNAL WALLS	INTERNAL WALLS	FLOOR	WINDOW
	Aerated concrete blocks covered with plaster	Brick blocks and plasterboard covered with plaster	Block flooring covered with plaster	PVC frame, double glazed
Indicators				
Climate change	A	B	A	B
Fossil fuel depletion	A	B	A	C
Ozone depletion	A	A	A	C
Freight transport	A	B	C	A
Human toxicity	B	A	B	B
Waste disposal	B	C	B	A
Water extraction	B	B	B	A
Acid deposition	A	B	A	B
Ecotoxicity	A	A	A	C
Eutrophication	A	A	B	A
Summer smog	A	C	A	A
Minerals extraction	B	B	B	B
Recycled input	A	C	B	C
Recyclability	A	A	A	C
Currently recycled	A	A	A	C
Energy saved by recycling	A	A	B	C
Average rating	**A**	**B**	**B**	**C**

4.2. Evaluation through BEES

Triplex Unit:

Building materials of triplex unit were evaluated in terms of indicators used in BEES. The values of roofing, external walls, internal walls, floor, ceiling and floor covering materials are given below.

a) Roofing:

The construction material of roof is timber and it is covered with clay tiles. BEES can calculate only the values of clay tile because of limitations. It has no environmental impacts in terms of indoor air quality, habitat alteration and ozone depletion. The various impacts and their amounts are given in Table 4.3 below.

Table 4. 3: Values of materials used for roofing according to BEES indicators

		ROOF
	units	clay tile
global warming	g CO2 / unit	171817,6
acidification	mg H / unit	66495,64
eutrophication	g N / unit	40,94
fossil fuel depletion	MJ / unit	438,82
indoor air quality	g TVOCs / unit	0
habitat alteration	T&E species / unit	0
water intake	liters / unit	34,5
criteria air pollutants	microDALYs / unit	16,99
ecological toxicity	g 2,4D / unit	451,61
human health	g C6H6 / unit	5113663,3
ozone depletion	g CFC-11 / unit	0
smog	g Nox / unit	680,78
Average		5353640,2

b) External walls:

In the triplex unit, external walls are made up of brick. Brick is used outer and inner leaves and insulation is applied between two brickworks. Reinforced concrete is used in basement walls. Walls are plastered and painted inside. Values of BEES indicators by plaster and paint are given below as figure. Figures of habitat alteration and ozone depletion by plaster and paint and indoor air quality by plaster are not presented, because they have no impacts. The figures of materials used in these two buildings are given in Appendix C. The various impacts and their amounts are given in Table 4.4 below.

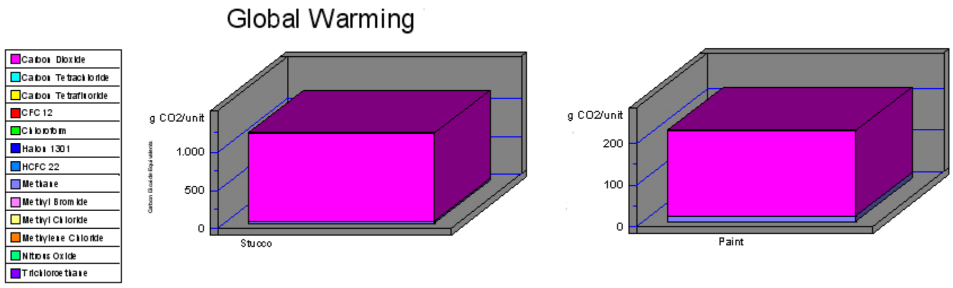

Figure 4. 1: Impact of global warming by plaster and paint

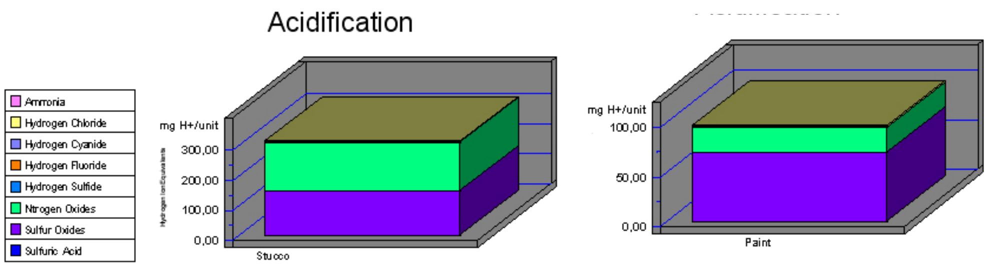

Figure 4. 2: Impact of acidification by plaster and paint

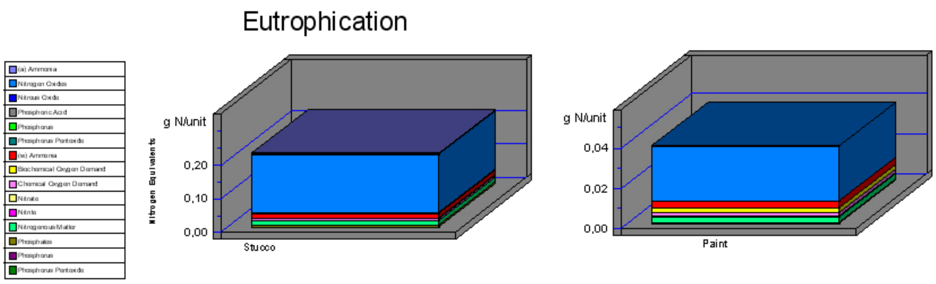

Figure 4. 3: Impact of eutrophication by plaster and paint

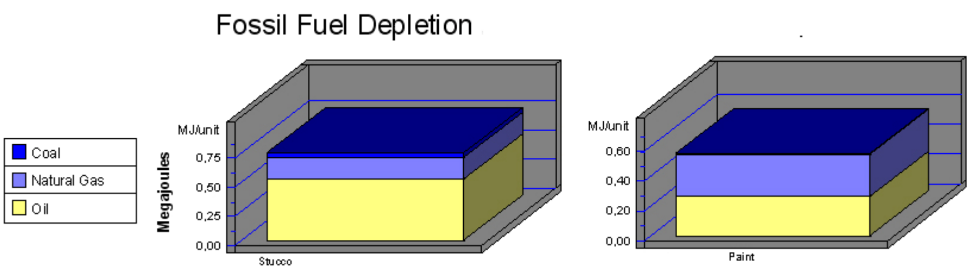

Figure 4. 4: Impact of fossil fuel depletion by plaster and paint

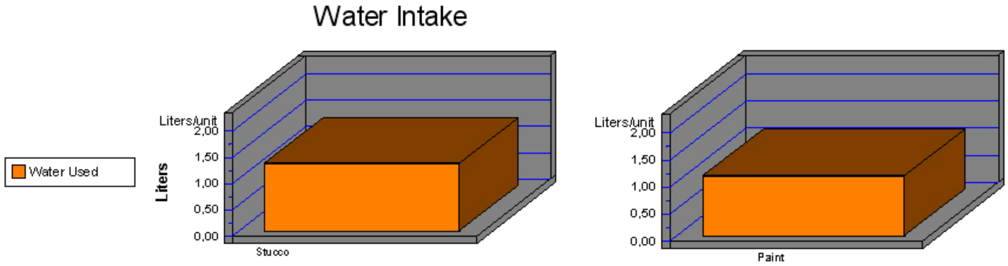

Figure 4. 5: Impact of water intake by plaster and paint

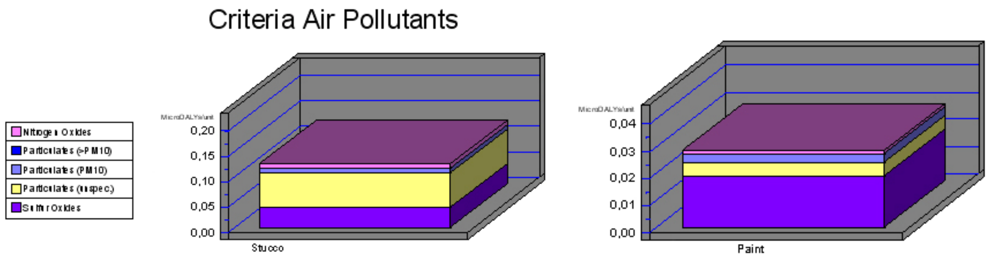

Figure 4. 6: Impact of criteria air pollutants by plaster and paint

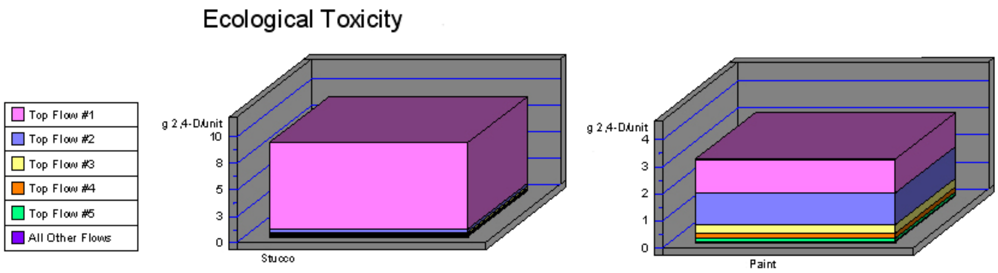

Figure 4. 7: Impact of ecological toxicity by plaster and paint

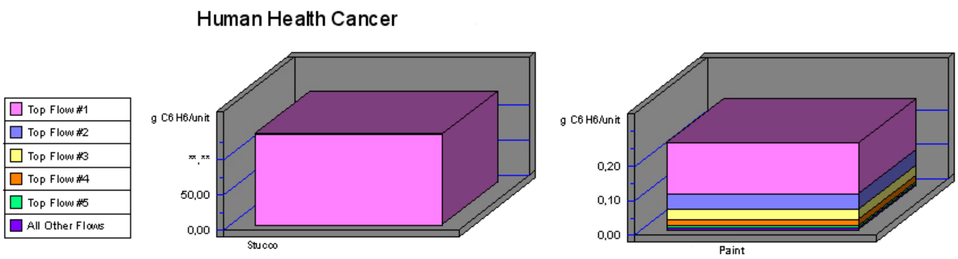

Figure 4. 8: Impact of human health by plaster and paint

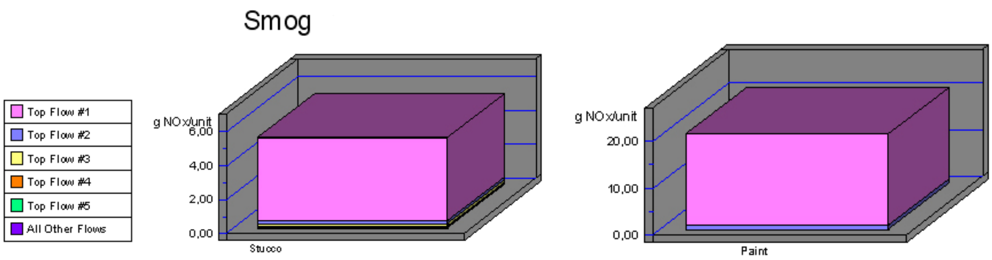

Figure 4. 9: Impact of smog by plaster and paint

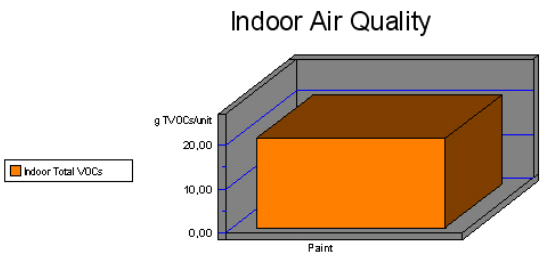

Figure 4. 10: Impact of smog by paint

Table 4. 4: Values of materials used for external walls according to BEES indicators

		EXTERNAL WALLS			
	units	**concrete (basement wall)**	**brick**	**paint**	**plaster**
global warming	g CO2 / unit	6874,69	5272	218,92	1188,64
acidification	mg H / unit	2028,72	1825,33	95,61	313,18
eutrophication	g N / unit	1,53	0,76	0,04	0,22
fossil fuel depletion	MJ / unit	4,58	9,23	0,56	0,75
indoor air quality	g TVOCs / unit	0	0	20,5	0
habitat alteration	T&E species / unit	0	0	0	0
water intake	liters / unit	8,71	4	1,11	1,3
criteria air pollutants	microDALYs / unit	2,24	0,51	0,03	0,13
ecological toxicity	g 2,4D / unit	46,5	12,92	3,08	8,91
human health	g C6H6 / unit	25748884	157,5	0,25	129,13
ozone depletion	g CFC-11 / unit	0	0	0	0
smog	g Nox / unit	40,32	18,08	20,42	5,39
Average		25757891	7300,33	360,52	1647,65

c) Internal walls:

Internal walls are composed of brick. Walls are covered with plaster and paint. Brick, paint and plaster have no environmental impacts in terms of habitat alteration and ozone depletion. Additionally, brick and plaster have no environmental impacts about indoor air quality. The various impacts and their amounts are given in Table 4.5 below.

Table 4. 5: Values of materials used for internal walls according to BEES indicators

		INTERNAL WALLS		
	units	**brick**	**paint**	**plaster**
global warming	g CO2 / unit	5272	218,92	1188,64
acidification	mg H / unit	1825,33	95,61	313,18
eutrophication	g N / unit	0,76	0,04	0,22
fossil fuel depletion	MJ / unit	9,23	0,56	0,75
indoor air quality	g TVOCs / unit	0	20,5	0
habitat alteration	T&E species / unit	0	0	0
water intake	liters / unit	4	1,11	1,3
criteria air pollutants	microDALYs / unit	0,51	0,03	0,13
ecological toxicity	g 2,4D / unit	12,92	3,08	8,91
human health	g C6H6 / unit	157,5	0,25	129,13
ozone depletion	g CFC-11 / unit	0	0	0
smog	g Nox / unit	18,08	20,42	5,39
Average		7300,33	360,52	1647,65

d) Floor and Ceiling:

Floors are made in-situ concrete and covered with plaster and paint. Paint, plaster and concrete have no environmental impacts in terms of habitat alteration and ozone depletion. Additionally, concrete and plaster have no environmental impacts about indoor air quality. The various impacts and their amounts are given in Table 4.6 below.

Table 4. 6: Values of materials used for ceiling and floor according to BEES indicators

		CEILING		FLOOR
	units	**paint**	**plaster**	**concrete**
global warming	g CO2 / unit	218,92	1188,64	4458,51
acidification	mg H / unit	95,61	313,18	1238,96
eutrophication	g N / unit	0,04	0,22	1,3
fossil fuel depletion	MJ / unit	0,56	0,75	3,13
indoor air quality	g TVOCs / unit	20,5	0	0
habitat alteration	T&E species / unit	0	0	0
water intake	liters / unit	1,11	1,3	5,85
criteria air pollutants	microDALYs / unit	0,03	0,13	1,24
ecological toxicity	g 2,4D / unit	3,08	8,91	28,94
human health	g C6H6 / unit	0,25	129,13	12993105
ozone depletion	g CFC-11 / unit	0	0	0
smog	g Nox / unit	20,42	5,39	23,04
Average		360,52	1647,65	12998866

e) Floor coverings:

Ceramic tiles are used in entrance hall, kitchen, bathroom and wc. Bedrooms are covered with carpet tiles. In the basement floor, mosaic tiles are used. Although wooden parquet is used in living room and dining room, this material can not be calculated through BEES. BEES has no values about wooden parquet. Values of environmental impacts according to BEES indicators of floor covering materials are shown in Table 4.7.

Table 4. 7: Values of materials used for floor coverings according to BEES indicators

	FLOOR COVERINGS		
	carpet	**ceramic tile**	**mosaic**
global warming	5902,05	2421,03	2531,61
acidification	1206,02	908,72	2157,32
eutrophication	6,52	0,39	1,42
fossil fuel depletion	16,74	3,91	6,3
indoor air quality	54,76	0,04	0
habitat alteration	0	0	0
water intake	421,49	15,1	95,2
criteria air pollutants	0,67	0,28	0,41
ecological toxicity	8,56	8,27	7,01
human health	3,91	20,48	1,75
ozone depletion	0	0	0
smog	29,32	11,62	19,06
Average	7650,04	3389,84	4820,08

Konukevi 1 – Bachelor Flats:

Building materials of Konukevi 1 – Bachelor Flat is evaluated in terms of indicators applied in BEES. These materials are given in Table 4.8. Indicators of BEES were given in detail in the previous chapter. The section drawing in Figure 4.11 gives more detail information about where the materials are used.

Table 4.8 : Materials of Block A of bachelor flats

space				INTERIOR WALLS					EXTERIOR WALLS			GROUND				CEILING	
code	type	name	material	brick	plasterboard	plaster	ceramic tile	paint	aerated concrete	plaster	paint	marble tile	carpet	ceramic tile	mosaic tile	plaster	paint
G - 01	type 1	entrance		X		X		X	X	X	X	X				X	X
G - 06		kitchen				X		X	X	X	X			X		X	X
G - 02	type 2	bathroom			X		X							X		X	X
G - 03 G - 04		living room		X		X		X	X	X	X		X			X	X
G - 05		bedroom		X		X		X	X	X	X		X			X	X
G - 07		corridor				X		X	X	X	X	X				X	X
G - 08		corridor				X		X	X	X	X	X				X	X
F - 01	type 3	entrance				X		X	X	X	X	X				X	X
		kitchen				X		X	X	X	X			X		X	X
F - 06		WC			X		X							X		X	X
F - 02	type 4	living room		X		X		X	X	X	X		X			X	X
F - 03		hall		X		X		X	X	X	X		X			X	X
		bathroom			X		X		X	X	X			X		X	X
F - 04		bedroom -1		X		X		X					X			X	X
		bedroom -2		X		X		X	X	X	X		X			X	X
F - 05		bedroom -3		X		X		X	X	X	X		X			X	X
F - 07		corridor		X		X		X	X	X	X	X				X	X
F - 08		corridor		X		X		X	X	X	X	X				X	X
B - 01		corridor		X		X		X				X				X	X
B - 02		staff room		X		X		X							X	X	X
B - 03		elect. room		X		X		X							X	X	X
B - 04		generator room		X		X		X							X	X	X
B - 05		storage		X		X		X							X	X	X
B - 06		footpace		X		X		X							X	X	X

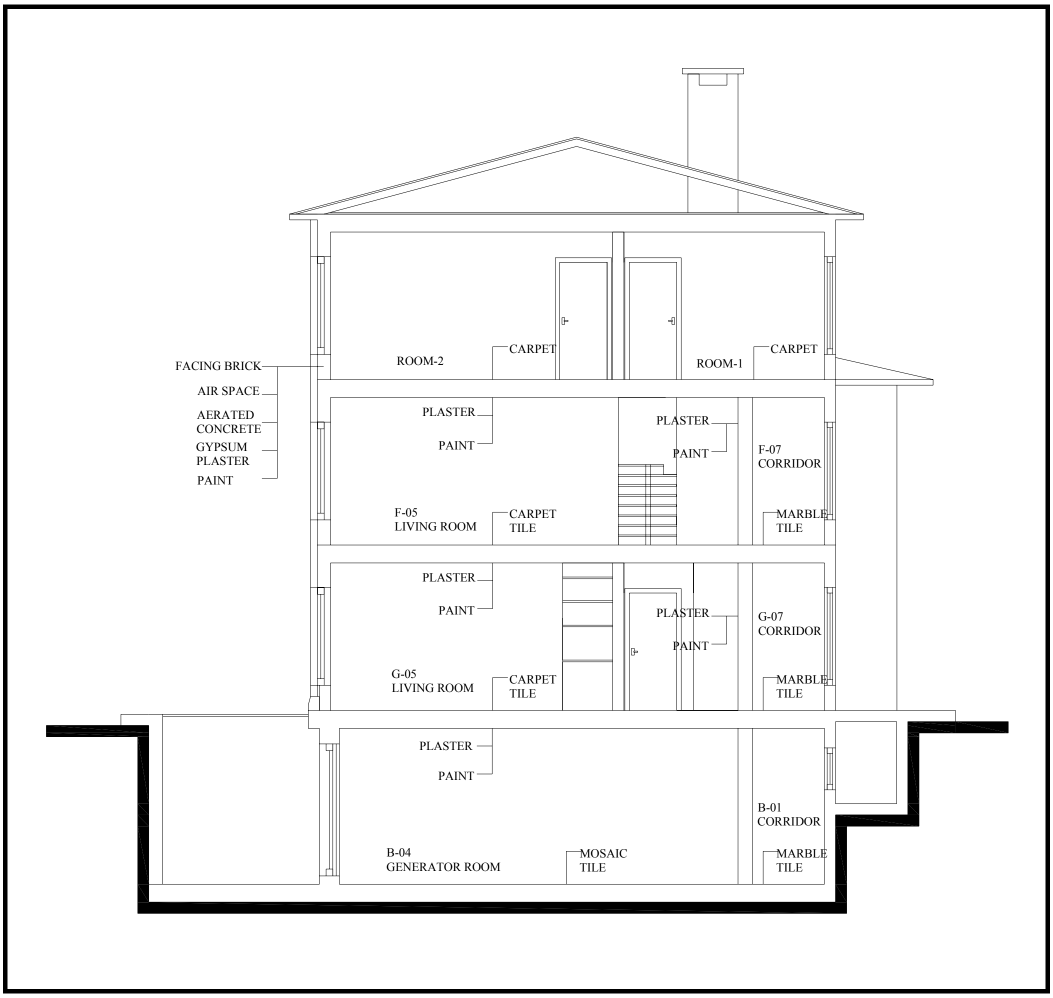

Figure 4. 11: Section of Block A of bachelor flats

a) External walls

Aerated concrete blocks were used for external walls in the block of flats. This material includes portland cement, limestone, gypsum and aluminium. While evaluating the materials an exact match could not be found in the product list of BEES. Therefore ‘Lafarge Block Set’ was used for evaluation since it has nearly the same contents as aerated concrete. As mentioned before, BEES calculate the values of indicators according to materials’ own criteria. Environmental impacts of global warming, for instance, are evaluated in terms of carbon dioxide, carbon tetrachloride, *etc.* Values belonging these criteria are given in Appendix D.

External walls of the block of bachelor flats are covered with plaster and painted. Values of indicators about exterior walls are presented in Table 4.9.

Table 4. 9: Values of materials used for exterior walls according to BEES indicators

	EXTERIOR WALL		
	aerated concrete block	**plaster**	**paint**
global warming	6621,73	1188,64	218,92
acidification	2148,02	313,18	95,61
eutrophication	1,35	0,22	0,04
fossil fuel depletion	3,89	0,75	0,56
indoor air quality	0	0	20,5
habitat alteration	0	0	0
water intake	5,82	1,3	1,11
criteria air pollutants	2,12	0,13	0,03
ecological toxicity	25,29	8,91	3,08
human health	691	129,13	0,25
ozone depletion	0	0	0
smog	38,64	5,39	20,42
Average	9537,86	1647,65	360,52

b) Internal walls

Internal walls of the block of bachelor flats are built with brick and plasterboard partitions. They are plastered and then painted or covered with ceramic tiles. Habitat alteration and ozone depletion by whole materials of interior walls and indoor air quality by brick and plasterboard have no impacts.

In addition, paint and plaster have same features as used for exterior walls. In Table 4.10, values of BEES results of these materials are shown.

Table 4. 10: Values of materials used for interior walls according to BEES indicators

	INTERIOR WALL				
	brick	gypsum board	paint	ceramic tile	plaster
global warming	5272	1933,52	218,92	2421,03	1188,64
acidification	1825,33	815,23	95,61	908,72	313,18
eutrophication	0,76	0,65	0,04	0,39	0,22
fossil fuel depletion	9,23	3,86	0,56	3,91	0,75
indoor air quality	0	0	20,5	0,04	0
habitat alteration	0	0	0	0	0
water intake	4	1,02	1,11	15,1	1,3
criteria air pollutants	0,51	0,29	0,03	0,28	0,13
ecological toxicity	12,92	6,36	3,08	8,27	8,91
human health	157,5	1,74	0,25	20,48	129,13
ozone depletion	0	0	0	0	0
smog	18,08	5,41	20,42	11,62	5,39
Average	7300,33	2768,08	360,52	3389,84	1647,65

c) Floor coverings

In the block of flats, carpet tiles are used as floor coverings in rooms. Bathrooms and wc are covered ceramic tiles. Marble tiles are applied in corridors and stairs. Mosaic tiles are used in basement floor. As mentioned before, all materials have not exact match in the product list of BEES. Therefore, terrazzo was used for evaluation since it has nearly the same contents as mosaic tile. Values of environmental impacts according to BEES indicators of these materials are shown in Table 4.11.

Table 4. 11: Values of environmental impacts according to BEES indicators

	FLOOR			
	marble tile	**carpet**	**ceramic tile**	**mosaic**
global warming	2548,39	5902,05	**2421,03**	2531,61
acidification	**759,07**	1206,02	908,72	2157,32
eutrophication	0,44	6,52	**0,39**	1,42
fossil fuel depletion	8,65	16,74	**3,91**	6,3
indoor air quality	**0,04**	54,76	**0,04**	0
habitat alteration	0	0	0	0
water intake	76,2	421,49	**15,1**	95,2
criteria air pollutants	**0,25**	0,67	0,28	0,41
ecological toxicity	15,83	8,56	8,27	**7,01**
human health	176,53	**3,91**	20,48	1,75
ozone depletion	0	0	0	0
smog	20,9	29,32	**11,62**	19,06
Average	3606,3	7650,04	**3389,84**	4820,08

d) Ceiling

Ceilings are covered with plaster and painted in the block of bachelor flats. These materials are same with the ones used for exterior walls. Hence, the impacts of indicators belonging to plaster and paint are not presented as figures in this section. Merely, values are shown in Table 4.12.

Table 4. 12: Values of environmental impacts for ceiling according to BEES indicators

	CEILING	
	Plaster	Paint
global warming	1188,64	218,92
acidification	313,18	95,61
eutrophication	0,22	0,04
fossil fuel depletion	0,75	0,56
indoor air quality	0	20,5
habitat alteration	0	0
water intake	1,3	1,11
criteria air pollutants	0,13	0,03
ecological toxicity	8,91	3,08
human health	129,13	0,25
ozone depletion	0	0
smog	5,39	20,42
Average	1647,65	360,52

4.3. Data Evaluation

According to the evaluation of the triplex unit and the block of bachelor flats through BREEAM Ecohomes, on the whole, the block of bachelor flat has less environmental impact than the triplex unit, as seen in Table 4.13. It is seen that the materials used for the external walls in bachelor flats (aerated concrete and plaster) have less environmental impact than the materials of external walls in the triplex unit (brick and plaster). Aerated concrete blocks have less environmental impact than the insulated brick wall in terms of the values for waste disposal and recycled input. They have same impacts in terms of the values for climate change, fossil fuel depletion, ozone depletion, freight transport, acid deposition, ecotoxicity, eutrophication, summer smog and recyclability. Insulated brick work has less environmental impacts in terms of the values for human toxicity and minerals extraction.

Table 4. 13: Comparison of the ratings of case buildings according to BREEAM

	The triplex unit	The block of bachelor flat
Roof	A	not available
External Walls	B	A
Internal Walls	B	B
Floors	C	B
Windows	C	C

Again, according to the BREEAM evaluation, materials used for the internal walls in both buildings have same ratings. As seen in Table 4.13, when comparing the floors, the material used for floors in the block of bachelor flats (in-situ concrete) has less environmental impact than the materials of floors in the triplex unit (fired clay block and concrete flooring). As concrete slabs can consume more cement, which is high in embodied energy and harmful emissions, it results in higher impacts. Block flooring has less environmental impacts in terms of the values of climate change, human toxicity, waste disposal, water extraction, acid deposition, eutrophication, minerals extraction and recycled input. The two types of floors have same impacts according to the values for fossil fuel depletion, ozone depletion, freight transport, ecotoxicity, summer smog and recyclability.

Windows, made of PVC, used in both buildings get a ‘C’ rating according to BREEAM; whish is the least desirable rating. PVC frames have higher environmental impacts than timber frame because of the high emission levels during their production and their shorter lifespan.

Gaining best rating for building elements can be achieved by changing the combinations of the materials. For instance, using insulation can raise the rating from ‘C’ to ‘B’. On the other hand, adding another material, depending on its properties, can change the rating from better to worse.

The amount of materials used in the triplex unit and the block of bachelor flats to calculate the whole impact of the building according to the BEES software are shown in Table 4.14 and 4.15.

In this study, it was not possible to compare all materials within their own categories in with BEES, except the materials of floor coverings. According to the results, ceramic tiles have a better average of environmental values than marble, carpet and mosaic tiles. Ceramic tiles have the best value in terms of global warming; the value for ceramic tiles is very close to the value for marble tiles and mosaic tiles, but carpet tiles have the highest value. It is seen that, carpet tiles have nearly twice the value compared to ceramic and marble tiles. Ceramic tiles also have the best value in terms of eutrophication, fossil fuel depletion, water intake and smog. Ceramic tile and marble tile have the same value in terms of indicators of indoor air quality. Marble tile has the best values in acidification and criteria air pollutants. Mosaic tile is the best only in ecological toxicity.

Environmental impacts are calculated by using the data obtained from the BEES evaluation. Amounts of materials used in the building are multiplied by the environmental impact values of these materials for each unit. It is seen from the results that the value for human health has the highest environmental impact in the triplex unit. On the other hand, the value for global warming has the highest environmental impact in the block of bachelor flats.

Although the indicators cannot be added as they have different units, they are totalled to give an average point. The triplex unit has 8,306,009,055 overall points and the block of bachelor flat has only 339,631,992.7 overall points. Yet, on the whole the block of bachelor flats has less environmental impact than the triplex unit.

Table 4.14 : The amount of materials in the triplex unit

		ROOF	EXTERNAL WALLS				INTERNAL WALLS			FLOOR	CEILING		FLOOR COVERINGS			
	materials	**clay tile**	**concrete (basement wall)**	**brick**	**paint**	**plaster**	**brick**	**paint**	**plaster**	**concrete**	**paint**	**plaster**	**carpet**	**ceramic tile**	**mosaic**	
	amount of materials	885	82	8850	250	250	2500	200	200	105,5	105,5	105,5	21,5	23,5	60,5	
		unit	m^2	block	m^2	m^2	block	m^2	m^2	m^2	m^2	m^2	m^2	m^2	m^2	
indicators	**units**															
global warming	g CO2 / unit	152058576	563724,58	46657200	54730	297160	13180000	43784	237728	470372,805	23096,06	125401,52	126894,075	56894,205	153162,405	214048723,7
acidification	mg H / unit	58848641,4	166355,04	16154170,5	23902,5	78295	4563325	19122	62636	130710,28	10086,855	33040,49	25929,43	21354,92	130517,86	80268087,28
eutrophication	g N / unit	36231,9	125,46	6726	10	55	1900	8	44	137,15	4,22	23,21	140,18	9,165	85,91	45500,195
fossil fuel depletion	MJ / unit	388355,7	375,56	81685,5	140	187,5	23075	112	150	330,215	59,08	79,125	359,91	91,885	381,15	495382,625
indoor air quality	g TVOCs / unit	0	0	0	5125	0	0	4100	0	0	2162,75	0	1177,34	0,94	0	12566,03
habitat alteration	T&E species / unit	0	0	0	0	0	0	0	0		0	0	0	0	0	0
water intake	liters / unit	30532,5	714,22	35400	277,5	325	10000	222	260	617,175	117,105	137,15	9062,035	354,85	5759,6	93779,135
criteria air pollutant	microDALYs / unit	15036,15	183,68	4513,5	7,5	32,5	1275	6	26	130,82	3,165	13,715	14,405	6,58	24,805	21273,82
ecological toxicity	g 2,4D / unit	399674,85	3813	114342	770	2227,5	32300	616	1782	3053,17	324,94	940,005	184,04	194,345	424,105	560645,955
human health	g C6H6 / unit	4525592029	2111408452	1393875	62,5	32282,5	393750	50	25826	1370772619	26,375	13623,215	84,065	481,28	105,875	8009633267
ozone depletion	g CFC-11 / unit	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
smog	g Nox / unit	602490,3	3306,24	160008	5105	1347,5	45200	4084	1078	2430,72	2154,31	568,645	630,38	273,07	1153,13	829829,295
										overall impact						8306009055

Table 4.15 : The amount of materials in Block A of bachelor flats

	materials	EXTERNAL WALLS				INTERNAL WALLS				FLOOR	CEILING		FLOOR COVERINGS				
		concrete (basement wall)	aerated concrete block	paint	plaster	brick	gypsum board	paint	plaster	brick block	paint	plaster	marble tile	carpet	ceramic tile	mosaic	
	amount of materials	165	6630	900	900	30145	512	1600	1600	14000	1400	1400	170	600	720	164	
		m^2	block	m^2	m^2	block	m^2	m^2	m^2	block	m^2	m^2	m^2	m^2	m^2	m^2	
indicators	**units**																
global warming	g CO2 / unit	1134323,85	43902069,9	197028	1069776	158924440	989962,24	350272	1901824	73808000	306488	1664096	433226,3	3541230	1743141,6	415184,04	245147640,2
acidification	mg H / unit	334738,8	14241372,6	86049	281862	55024572,9	417397,76	152976	501088	25554620	133854	438452	129041,9	723612	654278,4	353800,48	84365555,39
eutrophication	g N / unit	252,45	8950,5	36	198	22910,2	332,8	64	352	10640	56	308	74,8	3912	280,8	232,88	39361,48
fossil fuel depletion	MJ / unit	755,7	25790,7	504	675	278238,35	1976,32	896	1200	129220	784	1050	1470,5	10044	2815,2	1033,2	429402,57
indoor air quality	g TVOCs / unit	0	0	18450	0	0	0	32800	0	0	28700	0	6,8	32856	28,8	0	94391,6
habitat alteration	T&E species / unit	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
water intake	liters / unit	1437,15	38586,6	999	1170	120580	522,24	1776	2080	56000	1554	1820	12954	252894	10872	15612,8	477835,04
criteria air pollutant	microDALYs / unit	369,6	14055,6	27	117	15373,95	148,48	48	208	7140	42	182	42,5	402	201,6	67,24	23972,77
ecological toxicity	g 2,4D / unit	7672,5	167672,7	2772	8019	389473,4	3256,32	4928	14256	180880	4312	12474	2691,1	5136	5954,4	1149,64	632529,86
human health	g C6H6 / unit	4248565787	4581330	225	116217	4747837,5	890,88	400	206608	2205000	350	180782	30010,1	2346	14745,6	287	7505474,08
ozone depletion	g CFC-11 / unit	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
smog	g Nox / unit	6652,8	256183,2	18378	4851	545021,6	2769,92	32672	8624	253120	28588	7546	3553	17592	8366,4	3125,84	915829,76
																	339631992,7

The BREEAM as well as the BEES evaluation results show that the triplex unit has more environmental impact than the block of bachelor flats according to the materials of external walls and floors. However, they have same impacts in terms of the materials of internal walls and windows. Although the BEES results related to the amounts of materials used in the buildings, the BREEAM evaluates the impacts per unit material. Therefore, these results show that the materials used in the block of bachelor flats are better than those used in the triplex unit. However, we can not claim that the materials used in the bachelor flats are the best in terms of all the sustainability indicators determined during this study.

CHAPTER 5

CONCLUSION

The construction industry consumes most of the resources in nature and since these resources are limited, selection of building materials gains importance. Not only do the designers have the responsibility for selection of building materials, but also producers and policy makers have a share in this responsibility. From the literature survey it was determined that:

- If the value of global warming increases, it causes more climate changes.
- The more acidification, the more acid rains.
- Increasing the value of eutrophication means the decline of quality of sea-life.
- If the fossil fuel depletion increases, it causes higher air pollution and climate changes.
- Indoor air quality affects human life in terms of health condition.
- The more value of habitat alteration causes decrease or extinction of species.
- The higher value of water intake causes the reducing of water resources.
- If the value of air pollutant is higher, it affects human life in terms of health condition and causes climate change.
- Ecological toxicity causes the changes in ecosystem.

- The higher value of indicator of human health causes the huge health problems, especially, cancer.
- If the value of ozone depletion rises, more ultraviolet light by sun passes through the atmosphere and affects human health.
- Smog increases the sensitivity to illness and affects human life in terms of health condition

In this study, indicators of environmental impact were determined and evaluation systems for these impacts were investigated. It was seen that there is no standardization for evaluating sustainability in the world, and each country has determined its own evaluation systems based on its own set of indicators.

In this study, two methods, from UK (BREEAM) and the USA (BEES), were applied. So far such systems are being applied in developing countries only. BREEAM is not used to evaluate the total impact of a building but the impacts of each component individually. These impacts are independent of each other and cannot be averaged. On the other hand, the whole impact of building can be calculated through BEES in relation with the collected data about environmental impacts of materials. BEES gives outputs as numerical values according to the emission of gases during production stage, therefore it seems more complex than BREEAM. On the other hand, BREEAM is more understandable by users because of its easy (A, B, C) rating system; it is more user-friendly.

However, since the databases of the BREEAM and BEES did not have an exact match for all the materials used in the case buildings, it was not possible to get an exact result for the whole building. Therefore, evaluation systems should be developed for each country based on the properties of their own materials; and designers should be encouraged to use these evaluation systems.

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APPENDICES

APPENDIX A

Table A.1: Project Checklist LEED for Homes

Project Checklist

LEED for Homes

Builder Name:	
Home Address (Street/City/State):	

Input Values: No of Bedrooms: 4 Floor Area (SF): 2400

Minimum No. of Points Required: Certified: 45 Silver: 60 Gold: 75 Platinum: 90

Detailed information on the measures below are provided in the companion document "LEED for Homes Rating System"

Y/Pts	No	N/A	No.	Credit		Measure	OR	*Max Points Available*
				Innovation and Design Process (ID)		(Minimum of 0 ID Points Required)		8
			1.1	**Integrated Project Planning**		Preliminary Rating		Prerequisite
			1.2			Integrated Project Team		1
			1.3			Design Charrette		1
			2.1	**Quality Management for Durability**		Durability Planning; (Pre-Construction)		Prerequisite
			2.2			Wet Room Measures		Prerequisite
			2.3			Quality Management		Prerequisite
			2.4			Third-Party Durability Inspection		3
			3.1	**Innovative / Regional Design**		Provide Description and Justification for Specific Measure		1
			3.2			Provide Description and Justification for Specific Measure		1
			3.3			Provide Description and Justification for Specific Measure		1
			3.4			Provide Description and Justification for Specific Measure		1
0				Sub-Total				
				Location and Linkages (LL)		(Minimum of 0 LL Points Required)	OR	10
HOLD			1	**LEED-ND Neighborhood**			LL2-6	10
			2	**Site Selection**		Avoid Environmentally Sensitive Sites and Farmland	LL1	2
			3.1	*Preferred Locations*		Select an Edge Development Site	LL1	1
			3.2		*OR*	Select an Infill Site	LL1	2
			3.3			Select a Previously Developed Site	LL1	1
			4	**Infrastructure**		Site within 1/2 Mile of Existing Water and Sewer	LL1	1
			5.1	**Community Resources & Public Transit**		Basic Community Resources / Public Transportation	LL1	1
			5.2		*OR*	Extensive Community Resources / Public Transportation	LL1	2
			5.3		*OR*	Outstanding Community Resources / Public Transportation	LL1	3
			6	*Access to Open Space*		Publicly Accessible Green Spaces	LL1	1
0				Sub-Total				
				Sustainable Sites (SS)		(Minimum of 5 SS Points Required)	OR	21
			1.1	**Site Stewardship**		Erosion Controls (During Construction)		Prerequisite
			1.2			Minimize Disturbed Area of Site		1
			2.1	**Landscaping**		No Invasive Plants		Prerequisite
			2.2			Basic Landscaping Design		2
			2.3			Limit Turf		3
			2.4			Drought Tolerant Plants		2
			3	**Shading of Hardscapes**		Locate and Plant Trees to Shade Hardscapes		1
			4.1	**Surface Water Management**		Design Permeable Site		4
			4.2			Design and Install Permanent Erosion Controls		2
			5	**Non-Toxic Pest Control**		Select Insect and Pest Control Alternatives from List		2
			6.1	**Compact Development**		Average Housing Density ≥ Units / Acre	LL1	2
			6.1		*OR*	Average Housing Density ≥ 10 Units / Acre	LL1	3
			6.3		*OR*	Average Housing Density ≥ 20 Units / Acre	LL1	4
0				Sub-Total				
				Water Efficiency (WE)		(Minimum of 3 WE Points Required)	OR	16
			1.1	**Water Reuse**		Rainwater Harvesting System		4
			1.2			Grey Water Re-Use System		1
			2.1	**Irrigation System**		Select High Efficiency Measures from List		3
			2.2			Third Party Verification		1
			2.3		*OR*	Install Landscape Designed by Licensed or Certified Professional	WE 2.2	4
			3.1	**Indoor Water Use**		High Efficiency Fixtures (Toilets, Showers, and Faucets)		3
			3.2		OR	Very High Efficiency Fixtures (Toilets, Showers, and Faucets)	WE 3.1	6
0				Sub-Total				

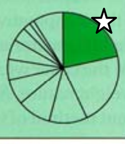
Project Checklist (cont'd)

HERS Index Value Achieved: 80
IECC Climate Zone: 6
EA 1.2 Pts Achieved: 0.0

Y/Pts	No	Maybe		Credit		Requirement	OR	Points
				Energy and Atmosphere (EA)		(Minimum of 0 EA Points Required)	OR	38
			1.1	**ENERGY STAR Home**		Meets ENERGY STAR for Homes with Third-Party Testing		Prerequisite
			1.2			Exceeds ENERGY STAR for Homes	EA 2-10	34
			7.1	**Water Heating**		Improved Hot Water Distribution System		2
			7.2			Pipe Insulation		1
			11	**Refrigerant Management**		Minimize Ozone Depletion and Global Warming Contributions		1
0				Sub-Total (or Sub-Total from Adendum A - Prescriptive EA Credits)				
				Materials and Resources (MR)		(Minimum of 2 MR Points Required)		14
			1.1	**Material Efficient Framing**		Overall Waste Factor for Framing Order Shall be No More than 10%.		Prerequisite
			1.2			Advanced Framing Techniques		3
			1.3		*OR*	Structurally Insulated Panels	MR 1.2	2
			2.1	**Environmentally Preferable**		Tropical Woods, If Used, Must be FSC		Prerequisite
			2.2	**Products**		Select Environmentally Preferable Products from List		8
			3.1	**Waste Management**		Document Overall Rate of Diversion		Prerequisite
			3.2			Reduce Waste Sent to Landfill by 25% to 100%		3
0				Sub-Total				
				Indoor Environmental Quality (IEQ)		(Minimum of 6 IEQ Points Required)	OR	20
			1	**ENERGY STAR with IAP**		Meets ENERGY STAR w/ Indoor Air Package (IAP)	IEQ2-10	11
			2.1	**Combustion Venting**		Space Heating & DHW Equip w/ Closed/Power-Exhaust	IEQ 1	Prerequisite
			2.2			Install High Performance Fireplace	IEQ 1	2
			3	**Moisture Control**		Analyze Moisture Loads AND Install Central System (If Needed)	IEQ 1	1
			4.1	**Outdoor Air Ventilation**		Meets ASHRAE Std 62.2	IEQ 1	Prerequisite
			4.2			Dedicated Outdoor Air System (w/ Heat Recovery)	IEQ 1	2
			4.3			Third-Party Testing of Outdoor Air Flow Rate into Home		1
			5.1	**Local Exhaust**		Meets ASHRAE Std 62.2	IEQ 1	Prerequisite
			5.2			Timer / Automatic Controls for Bathroom Exhaust Fans	IEQ 1	1
			5.3			Third-Party Testing of Exhaust Air Flow Rate Out of Home		1
			6.1	**Supply Air Distribution**		Meets ACCA Manual D	IEQ 1	Prerequisite
			6.2			Third-Party Testing of Supply Air Flow Into Each Room in Home		2
			7.1	**Supply Air Filtering**		≥ 8 MERV Filters, w/ Adequate System Air Flow	IEQ 1	Prerequisite
			7.2		*OR*	≥ 10 MERV Filters, w/ Adequate System Air Flow		1
			7.3		*OR*	≥ 13 MERV Filters, w/ Adequate System Air Flow		2
			8.1	**Contaminant Control**		Seal-Off Ducts During Construction	IEQ 1	1
			8.2			Permanent Walk-Off Mats *OR* Shoe Storage *OR* Central Vacuum		2
			8.3			Flush Home Continuously for 1 Week with Windows Open		1
			9.1	**Radon Protection**		Install Radon Resistant Construction if Home is in EPA Zone 1	IEQ 1	Prerequisite
			9.2			Install Radon Resistant Construction if Home is not in EPA Zone 1	IEQ 1	1
			10.1	**Garage Pollutant Protection**		No Air Handling Equipment OR Return Ducts in Garage	IEQ 1	Prerequisite
			10.2			Tightly Seal Shared Surfaces between Garage and Home	IEQ 1	2
			10.3			Exhaust Fan in Garage		1
			10.4		*OR*	Detached Garage or No Garage	IEQ 1	3
0				Sub-Total				
				Awareness and Education (AE)		(Minimum of 0 AE Points Required)		3
			1.1	**Education for Homeowner**		Basic Occupant's Manual and Walkthrough of LEED Home		Prerequisite
			1.2	**and/or Tenants**		Comprehensive Occupant's Manual and Multiple Walkthroughs / Trainings		1
			1.3			Public Awareness of LEED Home		1
			2.1	**Education for Building Mgrs**		Basic Building Manager's Manual and Walkthrough of LEED Home		1
0				Sub-Total				
0				**Project Totals** (pre-certification estimates)				**130**

APPENDIX B

Table B.1: External Walls Specifications in the Green Guide to Housing Specification



External walls	Summary Rating	Climate change	Fossil fuel depletion	Ozone depletion	Freight transport	Human toxicity	Waste disposal	Water extraction	Acid deposition	Ecotoxicity	Eutrophication	Summer smog	Minerals extraction	Cost	Typical replacement interval	Recycled input	Recyclability	Currently recycled	Energy saved by recycling
Cavity and solid wall construction																			
Brickwork outer leaf, aerated blockwork inner leaf, plasterboard/plaster, paint	**B**	B	A	A	A	B	B	B	A	A	A	A	A	£49–£71	60	B	A	A	A
Brickwork outer leaf, insulation, aerated blockwork inner leaf, plasterboard/plaster, paint	**A**	A	A	A	A	A	B	B	A	A	A	A	A	£49–£71	60	C	A	A	A
Brickwork outer leaf, insulation, dense blockwork inner leaf, plasterboard/plaster, paint	**B**	A	A	A	A	A	C	B	A	A	A	A	A	£51–£67	60	C	A	A	A
PVC weatherboarding, insulation, aerated blockwork wall, plasterboard/plaster, paint	**C**	C	C	C	A	C	A	A	C	C	A	A	A	£55–£86	30	A	B	B	B
Rendered aerated blockwork cavity wall, plasterboard/plaster, paint	**A**	A	A	A	A	A	B	B	A	A	A	A	B	£44–£72	60	A	A	A	A
Rendered dense blockwork cavity wall, insulation, plasterboard/plaster, paint	**B**	A	A	A	A	A	C	C	A	A	A	A	B	£49–£65	60	C	A	A	A
Rendered dense blockwork outer leaf, insulation, aerated concrete blockwork inner leaf, plaster/plasterboard/plaster, paint	**A**	A	A	A	A	A	B	B	A	A	A	A	B	£28–£40	60	C	A	A	A
Rendered lightweight blockwork outer leaf, insulation, aerated blockwork inner leaf, plasterboard/plaster, paint	**B**	B	A	A	A	B	B	B	A	A	A	A	B	£45–£64	60	A	A	A	A
Rendered solid aerated blockwork, plasterboard/plaster, paint	**A**	A	A	A	A	B	B	B	A	A	A	A	B	£38–£55	60	A	A	A	A
Stone outer leaf, insulation, dense blockwork inner leaf, plasterboard/plaster, paint	**A**	A	A	A	A	A	C	C	A	A	A	A	C	£97–£109	60	C	A	A	A

To determine the specifications of triplex unit

To determine the specifications of bachelor flats

☆ Piechart shows the weighting of environmental issues.

Table B.2: Roofing Specifications in the Green Guide to Housing Specification

Roofing 	Summary Rating	Climate change	Fossil fuel depletion	Ozone depletion	Freight transport	Human toxicity	Waste disposal	Water extraction	Acid deposition	Ecotoxicity	Eutrophication	Summer smog	Minerals extraction	Cost	Typical replacement interval	Recycled input	Recyclability	Currently recycled	Energy saved by recycling
Pitched roof construction																			
Clay tiles, battens, sarking felt on timber roof structure with insulation between rafters	**A**	A	A	C	B	A	A	A	A	A	A	A	A	£32–£67	60	C	A	C	A
Concrete tiles, battens, sarking felt, battens on timber roof structure with insulation between rafters	**A**	A	A	A	B	A	A	B	A	A	A	A	A	£28–£54	60	C	A	C	A
Fibre cement slates, battens, sarking felt on timber roof structure with insulation between rafters	**B**	A	B	A	B	B	A	A	B	B	A	B	A	£50–£77	30	C	A	C	A
Polymer resin bonded slates, battens, sarking felt on timber roof structure with insulation between rafters	**C**	C	C	A	C	C	A	B	C	C	C	C	A	£36–£69	35	C	C	C	C
Slates, battens, sarking felt on timber roof structure with insulation within rafters	**A**	A	A	A	C	A	C	A	A	A	A	A	C	£51–£143	60	C	A	A	A

Table B.3: Internal Walls Specifications in the Green Guide to Housing Specification

Internal walls 	Summary Rating	Climate change	Fossil fuel depletion	Ozone depletion	Freight transport	Human toxicity	Waste disposal	Water extraction	Acid deposition	Ecotoxicity	Eutrophication	Summer smog	Minerals extraction	Cost	Typical replacement interval	Recycled input	Recyclability	Currently recycled	Energy saved by recycling
Internal partitions																			
Aerated blockwork partition, plasterboard/plaster, paint	**A**	A	A	A	A	A	A	B	A	A	A	C	A	£26–£41	60	A	B	B	B
Brickwork, plasterboard/plaster, paint	**B**	B	B	A	B	A	C	B	B	A	A	C	B	£35–£50	60	C	A	A	A
Dense blockwork, plasterboard/plaster, paint	**B**	A	A	A	B	A	C	C	A	A	A	C	A	£37–£50	60	C	A	A	A
Fairfaced brickwork	**B**	B	A	A	B	A	C	B	A	A	A	A	B	£22–£27	60	C	A	A	A
Glass block wall	**C**	C	C	C	A	C	B	A	C	C	C	A	C	£185–£420	40	C	A	C	A
Lightweight blockwork partition, plasterboard/plaster, paint	**C**	C	A	A	C	A	C	B	A	A	A	C	A	£33–£39	60	A	A	A	A
Softwood framed safety glass — single glazed	**A**	A	A	A	A	A	A	A	B	A	A	A	A	£150–200	60	C	A	C	C
Steel stud, plasterboard, paint	**A**	A	A	A	A	A	A	A	A	A	A	C	A	£36–£44	60	C	C	C	C
Timber studwork partition, plasterboard, paint	**A**	A	A	A	A	A	A	A	A	A	A	C	A	£27–£30	60	C	C	C	C
Timber studwork with tongue and groove boarding to one face, plasterboard to the other, paint to both sides	**A**	A	A	A	A	A	A	A	A	A	A	C	A	£32–£44	35	C	B	C	B

Table B.4: Floors Specifications in the Green Guide to Housing Specification

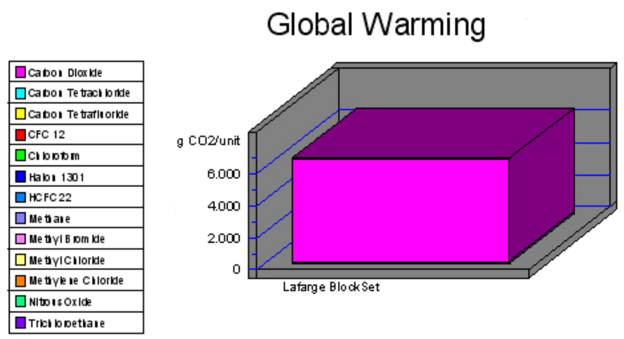
Upper floors	Summary Rating	Climate change	Fossil fuel depletion	Ozone depletion	Freight transport	Human toxicity	Waste disposal	Water extraction	Acid deposition	Ecotoxicity	Eutrophication	Summer smog	Minerals extraction	Cost	Typical replacement interval	Recycled input	Recyclability	Currently recycled	Energy saved by recycling
Upper floor construction																			
Beam and block flooring, chipboard or OSB decking on timber battens, plasterboard ceiling	**C**	C	C	B	C	B	A	A	C	B	C	C	A	£24–£28	20	A	B	B	B
Beam and block flooring, plywood decking on timber battens, plasterboard ceiling	**C**	B	B	B	C	B	A	A	B	B	C	B	A	£25–£40	25	B	B	A	B
Screeded beam and block flooring, plasterboard ceiling	**B**	A	A	A	C	B	B	B	A	A	B	A	B	£24–£33	60	B	A	A	B
Screeded in-situ concrete slab, plasterboard/plaster ceiling	**C**	B	A	A	C	C	C	C	B	A	C	A	C	£40–£80	60	C	A	A	B
Steel joists, chipboard or OSB decking, plasterboard ceiling	**C**	C	C	C	A	B	A	A	C	C	C	C	A	£21–£47	20	A	B	C	C
Steel joists, plywood decking, plasterboard ceiling	**B**	B	B	C	A	B	A	A	B	C	C	A	A	£22–£34	25	C	C	B	C
Timber joists, chipboard or OSB decking, plasterboard ceiling	**B**	C	C	B	B	A	A	A	C	B	C	C	A	£21–£47	20	A	B	C	B
Timber joists, plywood decking, plasterboard ceiling	**A**	B	A	B	B	A	A	A	A	B	B	B	A	£22–£34	25	C	C	C	C
Timber joists, tongue and groove floorboards, plasterboard ceiling	**A**	A	A	A	C	A	A	A	A	A	A	A	A	£29–£56	60	C	C	B	C

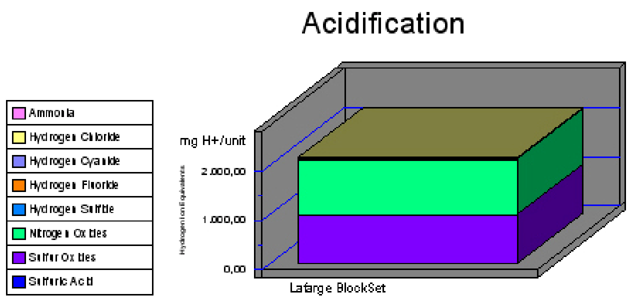
Table B.5: Window Specifications in the Green Guide to Housing Specification

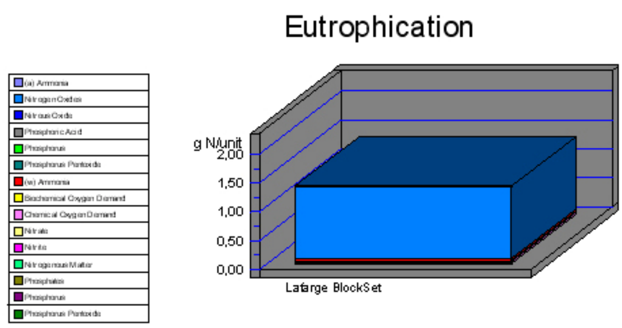
Windows	Summary Rating	Climate change	Fossil fuel depletion	Ozone depletion	Freight transport	Human toxicity	Waste disposal	Water extraction	Acid deposition	Ecotoxicity	Eutrophication	Summer smog	Minerals extraction	Cost	Typical replacement interval	Recycled input	Recyclability	Currently recycled	Energy saved by recycling
PVC-U frame, double glazed	**C**	B	C	C	A	B	A	A	B	C	A	A	B	£150–£530	25	C	C	C	C
Pre-treated softwood frame, double glazed, painted inside and out	**A**	A	A	A	A	A	A	A	A	A	A	C	A	£70–£320	25	C	A	B	A
Durable hardwood frame, double glazed, painted inside and out	**B**	A	A	A	C	A	A	A	A	B	B	A	A	£130–£355	35	C	A	A	A
Powder coated aluminium frame, double glazed	**C**	C	C	A	A	C	A	C	C	A	A	A	A	£270–£360	30	A	A	A	A
Aluminium faced timber composite frame, double glazed, painted inside	**C**	C	C	A	A	C	A	C	C	A	A	B	A	£275–£370	35	A	A	A	A
Glass block window	**C**	A	C	A	A	C	C	A	A	C	C	A	C	£185–£420	25	C	A	B	A

APPENDIX C

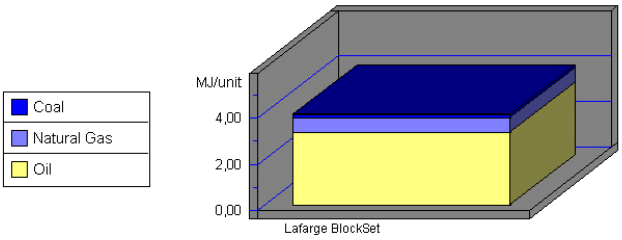
Figure C.1: Environmental impacts of aerated concrete block



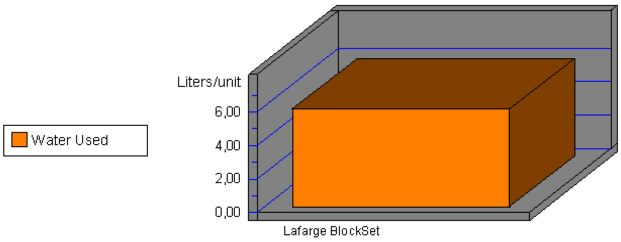




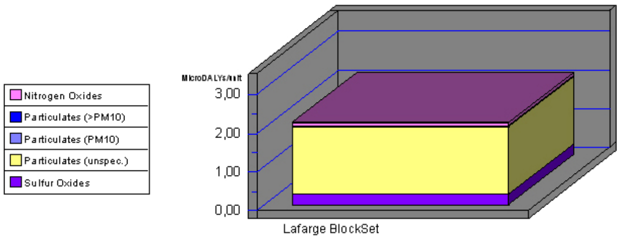
Fossil Fuel Depletion



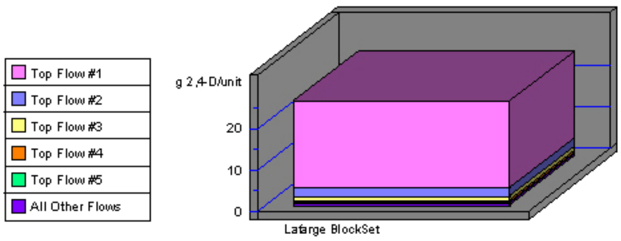
Water Intake

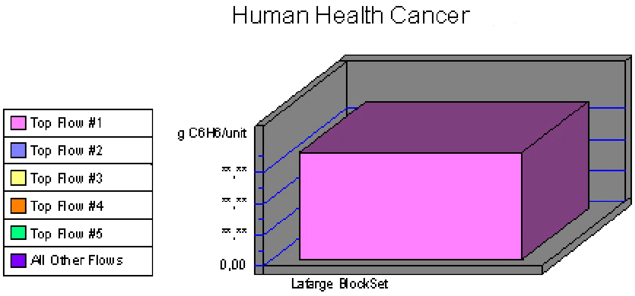


Criteria Air Pollutants



Ecological Toxicity




Human Health Cancer
Top Flow #1
Top Flow #2
Top Flow #3
Top Flow #4
Top Flow #5
All Other Flows
g C6H6/unit
0,00
Lafarge BlockSet

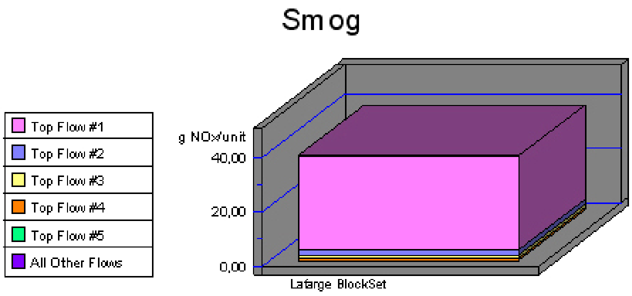
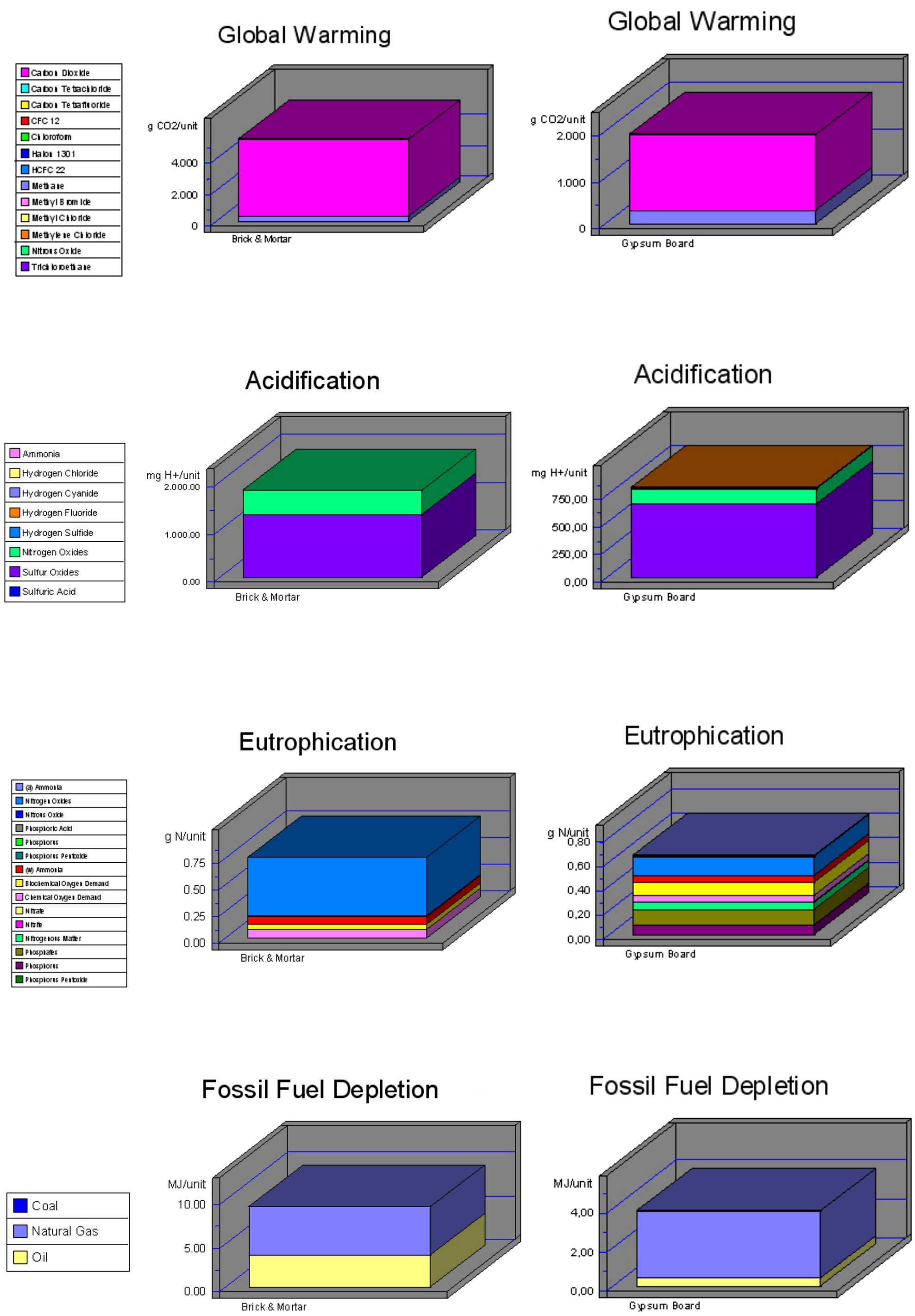
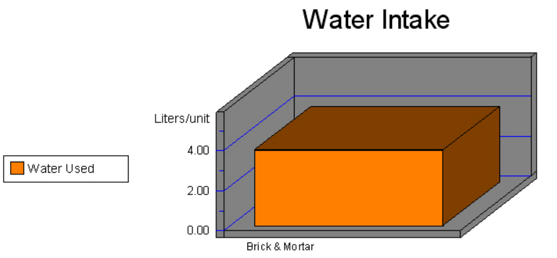
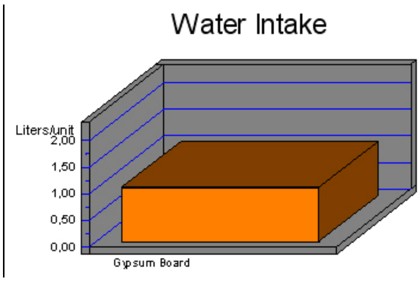
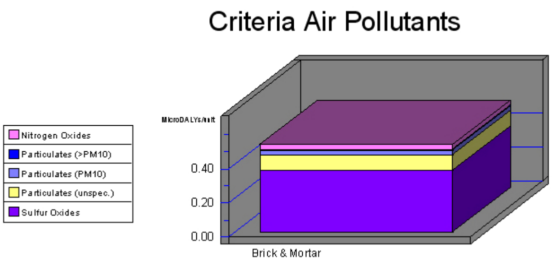

Smog
Top Flow #1
Top Flow #2
Top Flow #3
Top Flow #4
Top Flow #5
All Other Flows
g NOx/unit
40,00
20,00
0,00
Lafarge BlockSet

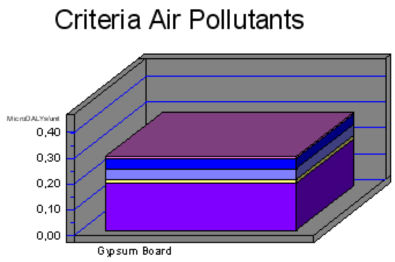
Figure C.2: Environmental impacts of brick and plasterboard

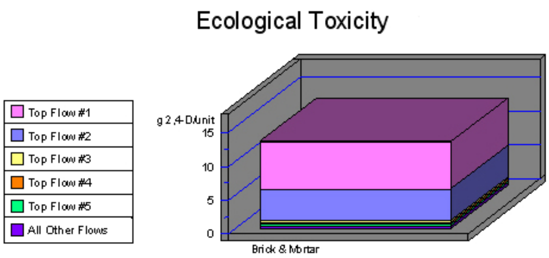


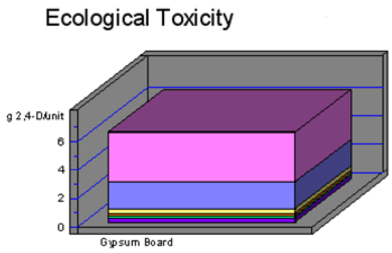

Water Intake
Water Used
Liters/unit
4.00
2.00
0.00
Brick & Mortar

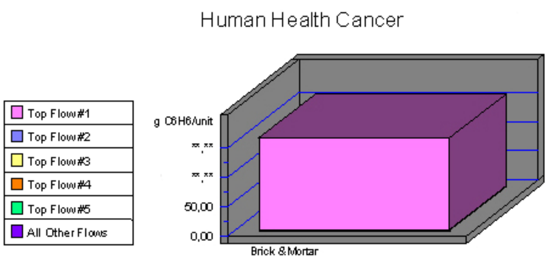

Water Intake
Liters/unit
2,00
1,50
1,00
0,50
0,00
Gypsum Board

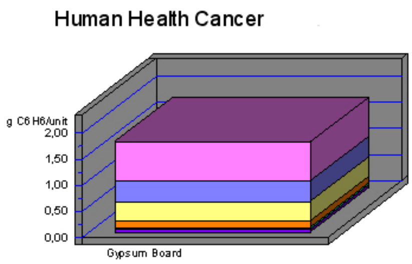

Criteria Air Pollutants
Nitrogen Oxides
Particulates (>PM10)
Particulates (PM10)
Particulates (unspec.)
Sulfur Oxides
0.40
0.20
0.00
Brick & Mortar

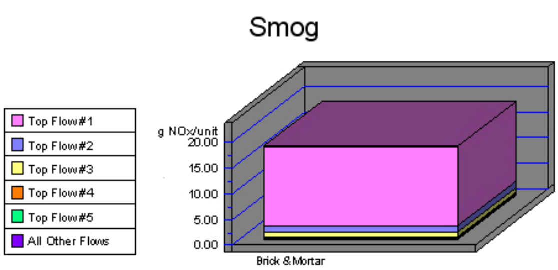

Criteria Air Pollutants
0,40
0,30
0,20
0,10
0,00
Gypsum Board


Ecological Toxicity
Top Flow #1
Top Flow #2
Top Flow #3
Top Flow #4
Top Flow #5
All Other Flows
g 2,4-D/unit
15
10
5
0
Brick & Mortar


Ecological Toxicity
g 2,4-D/unit
6
4
2
0
Gypsum Board


Human Health Cancer
Top Flow #1
Top Flow #2
Top Flow #3
Top Flow #4
Top Flow #5
All Other Flows
g C6H6/unit
50,00
0,00
Brick & Mortar


Human Health Cancer
g C6H6/unit
2,00
1,50
1,00
0,50
0,00
Gypsum Board


Smog
Top Flow #1
Top Flow #2
Top Flow #3
Top Flow #4
Top Flow #5
All Other Flows
g NOx/unit
20.00
15.00
10.00
5.00
0.00
Brick & Mortar

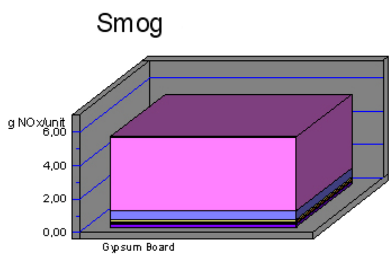
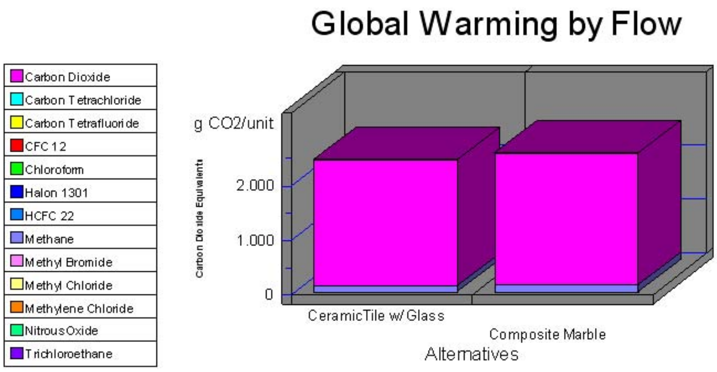
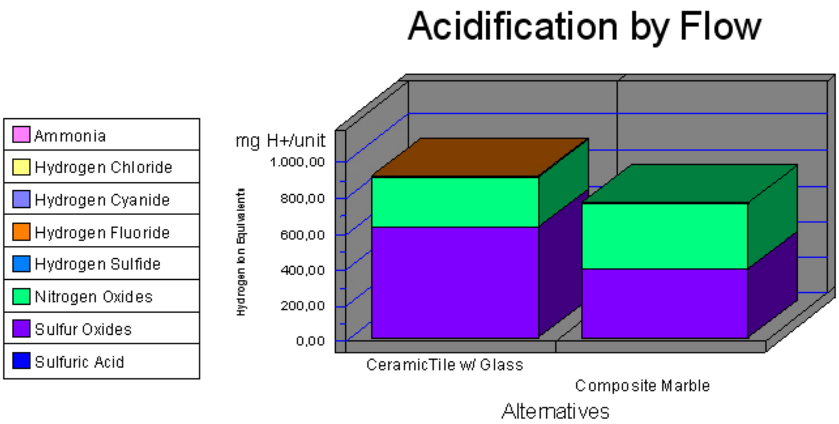
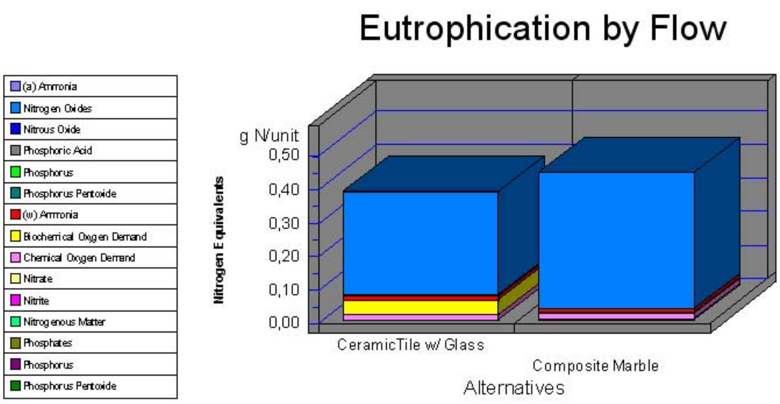
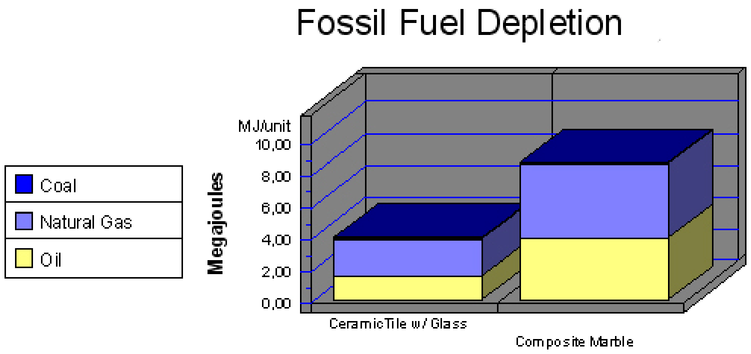

Smog
g NOx/unit
6,00
4,00
2,00
0,00
Gypsum Board

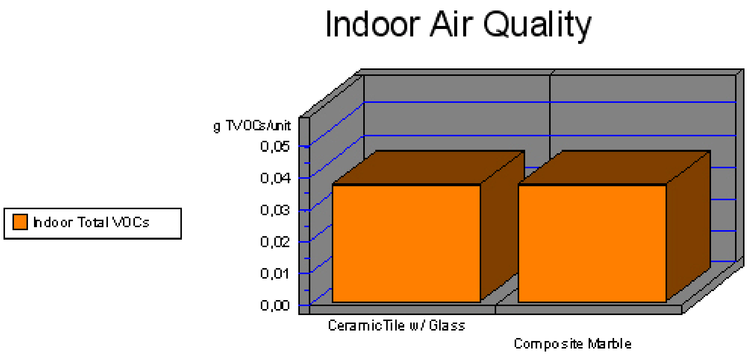
Figure C.3: Environmental impacts of ceramic and marble tiles

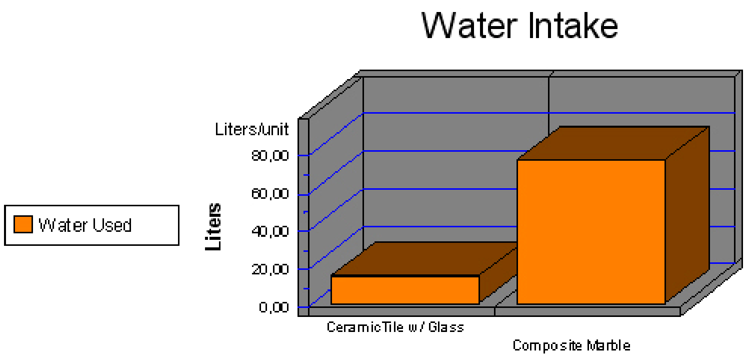


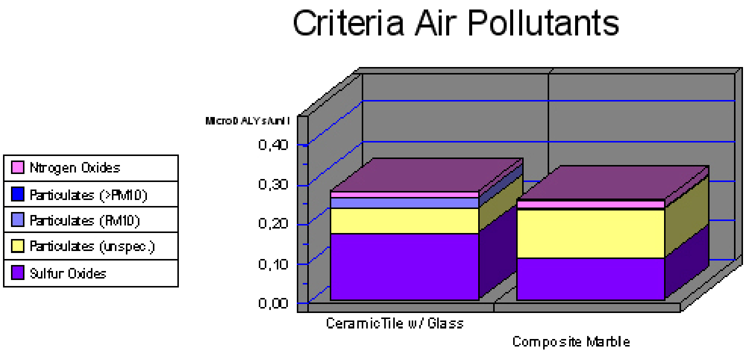


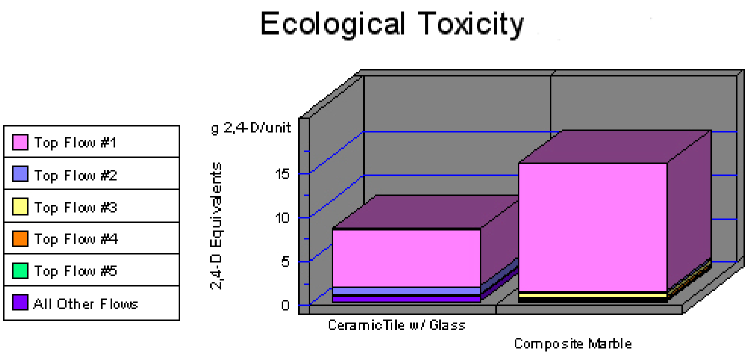


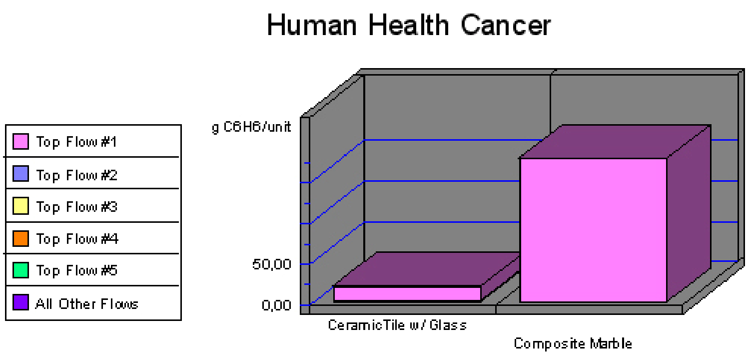

Fossil Fuel Depletion
Coal
Natural Gas
Oil
Megajoules
MJ/unit
10,00
8,00
6,00
4,00
2,00
0,00
CeramicTile w/ Glass
Composite Marble


Indoor Air Quality
Indoor Total VOCs
g TVOCs/unit
0,05
0,04
0,03
0,02
0,01
0,00
CeramicTile w/ Glass
Composite Marble


Water Intake
Water Used
Liters
Liters/unit
80,00
60,00
40,00
20,00
0,00
CeramicTile w/ Glass
Composite Marble


Criteria Air Pollutants
Nitrogen Oxides
Particulates (>PM10)
Particulates (PM10)
Particulates (unspec.)
Sulfur Oxides
0,40
0,30
0,20
0,10
0,00
CeramicTile w/ Glass
Composite Marble


Ecological Toxicity
Top Flow #1
Top Flow #2
Top Flow #3
Top Flow #4
Top Flow #5
All Other Flows
g 2,4-D/unit
2,4-D Equivalents
15
10
5
0
CeramicTile w/ Glass
Composite Marble


Human Health Cancer
Top Flow #1
Top Flow #2
Top Flow #3
Top Flow #4
Top Flow #5
All Other Flows
g C6H6/unit
50,00
0,00
CeramicTile w/ Glass
Composite Marble

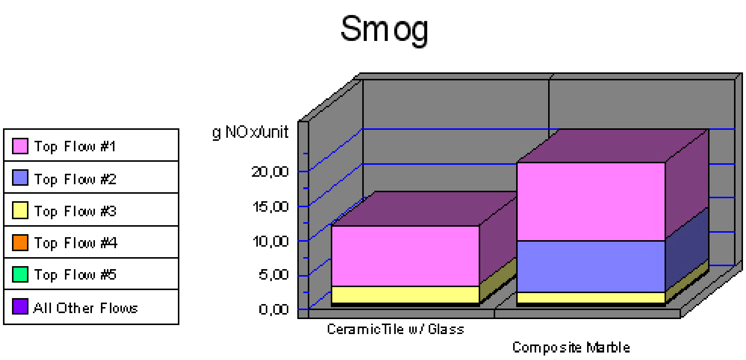
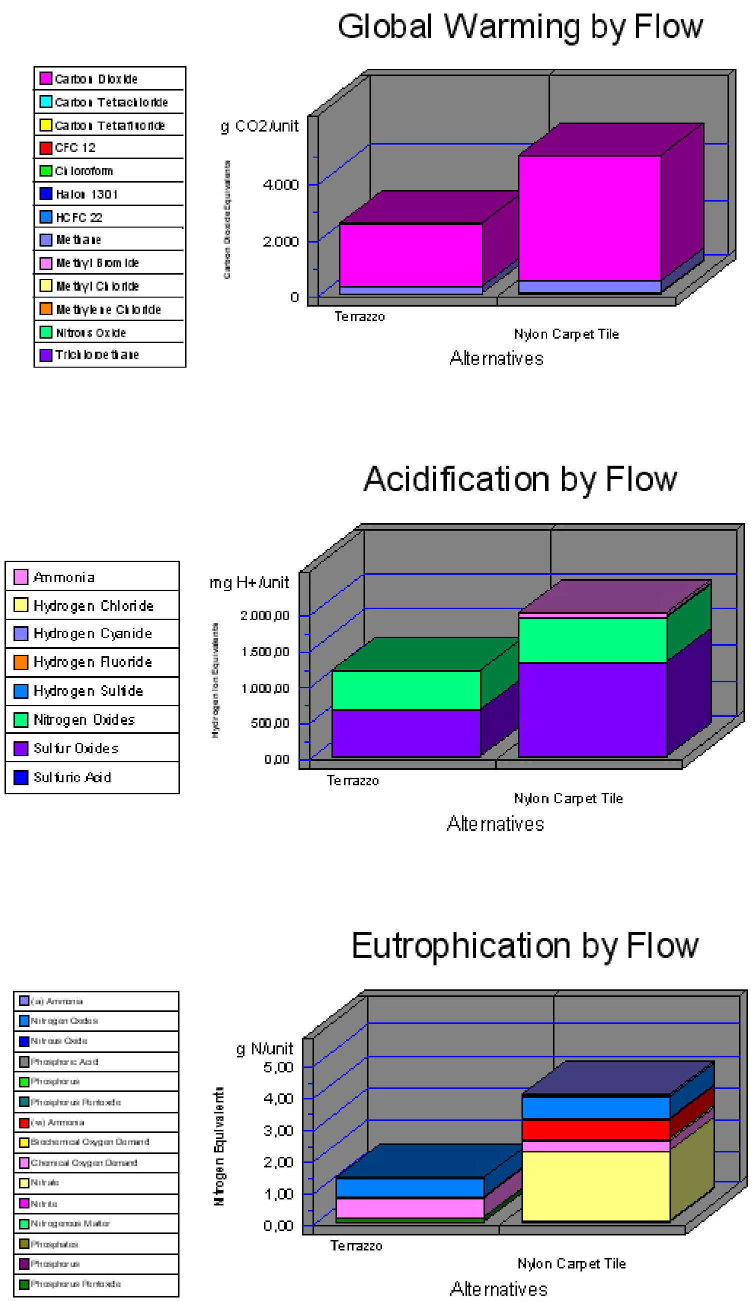
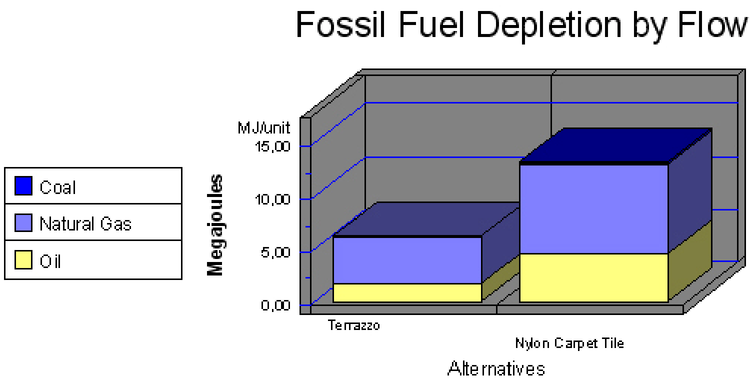
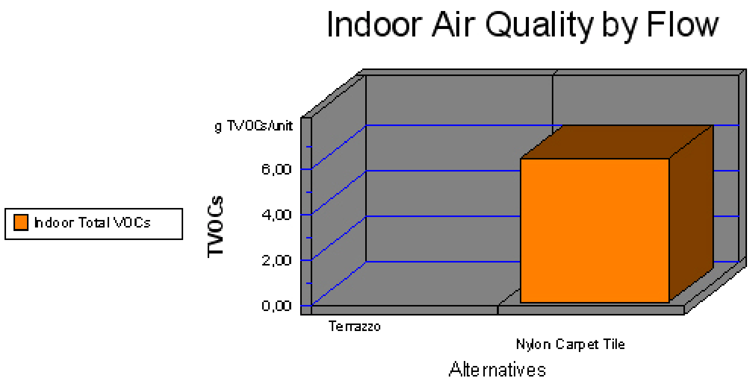
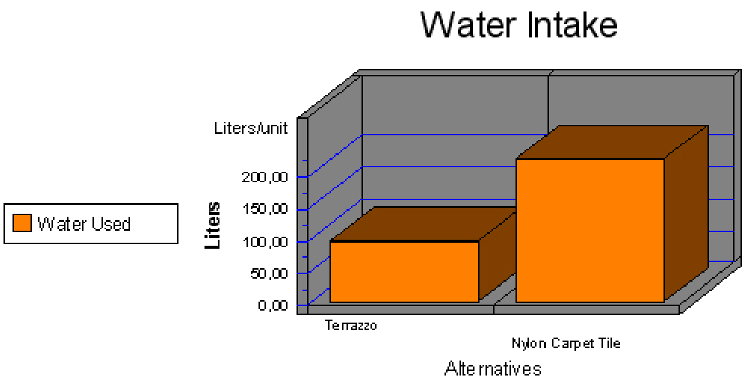

Smog
Top Flow #1
Top Flow #2
Top Flow #3
Top Flow #4
Top Flow #5
All Other Flows
g NOx/unit
20,00
15,00
10,00
5,00
0,00
CeramicTile w/ Glass
Composite Marble

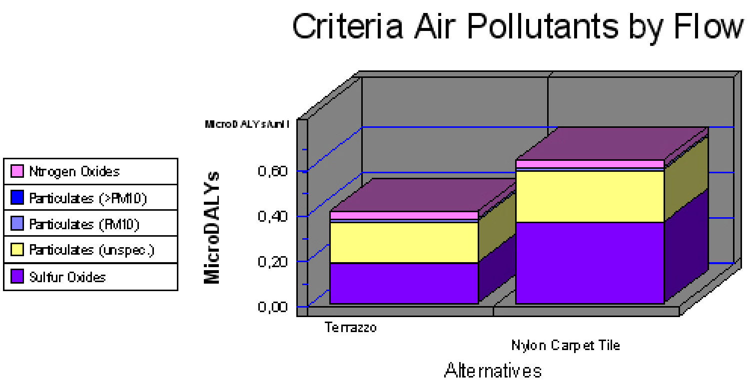
Figure C.4: Environmental impacts of mosaic tiles and nylon carpet

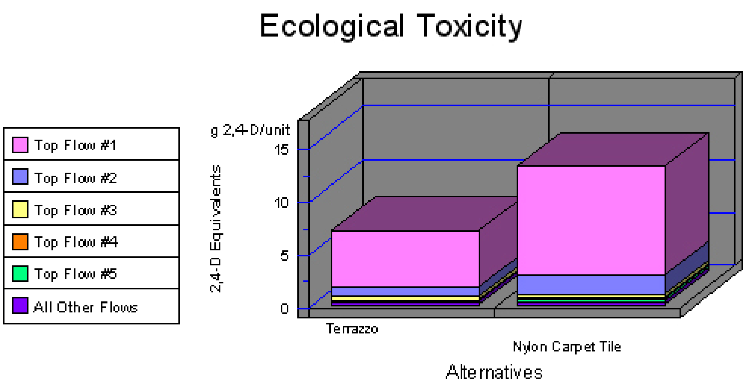



Fossil Fuel Depletion by Flow
Coal
Natural Gas
Oil
Megajoules
MJ/unit
15,00
10,00
5,00
0,00
Terrazzo
Nylon Carpet Tile
Alternatives

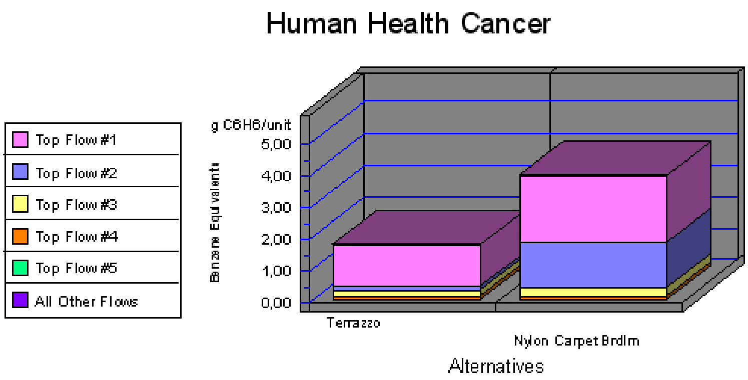

Indoor Air Quality by Flow
Indoor Total VOCs
TVOCs
g TVOCs/unit
6,00
4,00
2,00
0,00
Terrazzo
Nylon Carpet Tile
Alternatives


Water Intake
Water Used
Liters
Liters/unit
200,00
150,00
100,00
50,00
0,00
Terrazzo
Nylon Carpet Tile
Alternatives

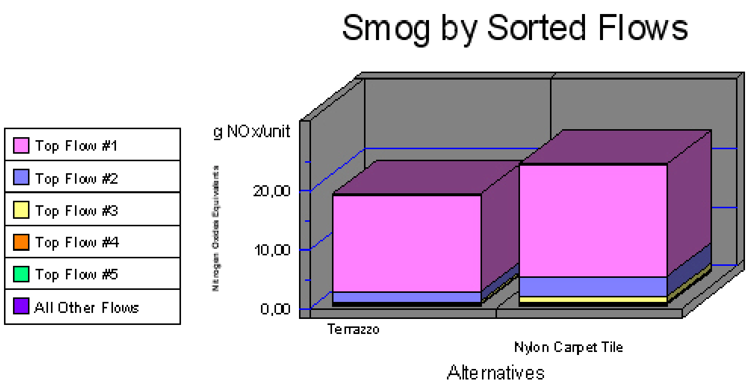

Criteria Air Pollutants by Flow
Nitrogen Oxides
Particulates (>PM10)
Particulates (PM10)
Particulates (unspec.)
Sulfur Oxides
MicroDALYs
MicroDALYs/unit
0,60
0,40
0,20
0,00
Terrazzo
Nylon Carpet Tile
Alternatives



Ecological Toxicity
Top Flow #1
Top Flow #2
Top Flow #3
Top Flow #4
Top Flow #5
All Other Flows
g 2,4-D/unit
2,4-D Equivalents
15
10
5
0
Terrazzo
Nylon Carpet Tile
Alternatives



Human Health Cancer
Top Flow #1
Top Flow #2
Top Flow #3
Top Flow #4
Top Flow #5
All Other Flows
g C6H6/unit
Benzene Equivalents
5,00
4,00
3,00
2,00
1,00
0,00
Terrazzo
Nylon Carpet Brdlm
Alternatives



Smog by Sorted Flows
Top Flow #1
Top Flow #2
Top Flow #3
Top Flow #4
Top Flow #5
All Other Flows
g NOx/unit
20,00
10,00
0,00
Terrazzo
Nylon Carpet Tile
Alternatives

APPENDIX D

Table D.1: Values of environmental impacts by aerated concrete block through BEES

Global Warming by Flow (grams CO2 equivalents/unit)

Category	BlockSet
(a) Carbon Dioxide (CO2, net)	6.480,00
(a) Carbon Tetrachloride (CCl4)	0,00
(a) Carbon Tetrafluoride (CF4)	0,00
(a) CFC 12 (CCl2F2)	0,00
(a) Chloroform (CHCl3, HC-20)	0,00
(a) Halon 1301 (CF3Br)	0,00
(a) HCFC 22 (CHF2Cl)	0,00
(a) Methane (CH4)	133,58
(a) Methyl Bromide (CH3Br)	0,00
(a) Methyl Chloride (CH3Cl)	0,00
(a) Methylene Chloride (CH2Cl2,	0,00
(a) Nitrous Oxide (N2O)	8,15
(a) Trichloroethane (1,1,1-CH3C	0,00
Sum	6.621,73

Acidification by Flow (milligrams H+ equivalents/unit)

Category	BlockSet
(a) Ammonia (NH3)	3,89
(a) Hydrogen Chloride (HCl)	20,89
(a) Hydrogen Cyanide (HCN)	0,00
(a) Hydrogen Fluoride (HF)	1,58
(a) Hydrogen Sulfide (H2S)	0,00
(a) Nitrogen Oxides (NOx as NO2	1.117,92
(a) Sulfur Oxides (SOx as SO2)	1.003,75
(a) Sulfuric Acid (H2SO4)	0,00
Sum	2.148,02

Eutrophication by Flow (grams nitrogen equivalents/unit)

Category	BlockSet
(a) Ammonia (NH3)	0,00
(a) Nitrogen Oxides (NOx as NO2	1,24
(a) Nitrous Oxide (N2O)	0,00
(a) Phosphoric Acid (H3PO4)	0,00
(a) Phosphorus (P)	0,00
(a) Phosphorus Pentoxide (P2O5)	0,00
(w) Ammonia (NH4+, NH3, as N)	0,04
(w) BOD5 (Biochemical Oxygen	0,02
(w) COD (Chemical Oxygen	0,04
(w) Nitrate (NO3-)	0,00
(w) Nitrite (NO2-)	0,00
(w) Nitrogenous Matter (unspeci	0,00
(w) Phosphates (PO4 3-, HPO4--,	0,00
(w) Phosphorus (P)	0,00
(w) Phosphorus Pentoxide (P2O5)	0,00
Sum	1,35

Fossil Fuel Depletion by Flow (MJ/unit)

Category	BlockSet
(r) Coal (in ground)	0,13
(r) Natural Gas (in ground)	0,60
(r) Oil (in ground)	3,16
Sum	3,89

Indoor Air Quality by Flow (grams Total VOCs/unit)

Category	BlockSet
(a) Indoor Total VOCs	0,00
Sum	0,00

Habitat Alteration by Flow (threatened & endangered species/unit)

Category	BlockSet
Land Use (End-of-Period Waste)	0,00
Land Use (Installation Waste)	0,00
Land Use (Replacement Waste)	0,00
Sum	0,00

Water Intake by Flow (liters/unit)

Category	BlockSet
Water Used (total)	5,82
Sum	5,82

Criteria Air Pollutants by Flow (micro disability-adjusted life years/unit)

Category	BlockSet
(a) Nitrogen Oxides (NOx as NO2	0,06
(a) Particulates (greater than	0,00
(a) Particulates (PM 10)	0,04
(a) Particulates (unspecified)	1,74
(a) Sulfur Oxides (SOx as SO2)	0,27
Sum	2,12

Ecological Toxicity by Flow (grams 2,4-dichlorophenoxy-acetic acid equivalents/unit)

Category	BlockSet
(a) Carbon Monoxide (CO)	0,27
(a) Dioxins (unspecified)	0,95
(a) Mercury (Hg)	21,04
(a) Nitrogen Oxides (NOx as NO2	0,57
(w) Silver (Ag+)	1,97
All Others	0,50
Sum	25,29

Human Health Cancer by Flow (grams benzene equivalents/unit)

Category	BlockSet
All Others	0,03
Cancer--(a) Arsenic (As)	0,39
Cancer--(a) Dioxins (unspecifie	689,65
Cancer--(a) Nickel (Ni)	0,01
Cancer--(w) Arsenic (As3+, As5+	0,48
Cancer--(w) Phenol (C6H5OH)	0,43
Sum	691,00

Ozone Depletion by Flow (grams CFC-11 equivalents/unit)

Category	BlockSet
(a) Carbon Tetrachloride (CCl4)	0,00
(a) CFC 12 (CCl2F2)	0,00
(a) Halon 1301 (CF3Br)	0,00
(a) HCFC 22 (CHF2Cl)	0,00
(a) Methyl Bromide (CH3Br)	0,00
(a) Trichloroethane (1,1,1-CH3C	0,00
Sum	0,00

Smog by Flow (grams NOx equivalents/unit)

Category	BlockSet
(a) Carbon Monoxide (CO)	0,21
(a) Hydrocarbons (except methan	1,16
(a) Hydrocarbons (unspecified)	0,81
(a) Nitrogen Oxides (NOx as NO2	34,62
(a) Particulates (unspecified)	1,74
All Others	0,10
Sum	38,64

Table D.2: Values of environmental impacts by plaster through BEES

Global Warming

Category	Stucco
(a) Carbon Dioxide (CO2, net)	1.158,00
(a) Carbon Tetrachloride (CCl4)	0,00
(a) Carbon Tetrafluoride (CF4)	0,00
(a) CFC 12 (CCl2F2)	0,00
(a) Chloroform (CHCl3, HC-20)	0,00
(a) Halon 1301 (CF3Br)	0,00
(a) HCFC 22 (CHF2Cl)	0,00
(a) Methane (CH4)	27,54
(a) Methyl Bromide (CH3Br)	0,00
(a) Methyl Chloride (CH3Cl)	0,00
(a) Methylene Chloride (CH2Cl2,	0,00
(a) Nitrous Oxide (N2O)	3,10
(a) Trichloroethane (1,1,1-CH3C	0,00
Sum	1.188,64

Acidification

Category	Stucco
(a) Ammonia (NH3)	0,37
(a) Hydrogen Chloride (HCl)	3,25
(a) Hydrogen Cyanide (HCN)	0,00
(a) Hydrogen Fluoride (HF)	0,37
(a) Hydrogen Sulfide (H2S)	0,25
(a) Nitrogen Oxides (NOx as NO2	159,52
(a) Sulfur Oxides (SOx as SO2)	149,42
(a) Sulfuric Acid (H2SO4)	0,00
Sum	313,18

Eutrophication

Category	Stucco
(a) Ammonia (NH3)	0,00
(a) Nitrogen Oxides (NOx as NO2	0,18
(a) Nitrous Oxide (N2O)	0,00
(a) Phosphoric Acid (H3PO4)	0,00
(a) Phosphorus (P)	0,00
(a) Phosphorus Pentoxide (P2O5)	0,00
(w) Ammonia (NH4+, NH3, as N)	0,01
(w) BOD5 (Biochemical Oxygen	0,00
(w) COD (Chemical Oxygen	0,01
(w) Nitrate (NO3-)	0,00
(w) Nitrite (NO2-)	0,00
(w) Nitrogenous Matter (unspeci	0,01
(w) Phosphates (PO4 3-, HPO4--,	0,01
(w) Phosphorus (P)	0,00
(w) Phosphorus Pentoxide (P2O5)	0,00
Sum	0,22

Fossil Fuel Depletion

Category	Stucco
(r) Coal (in ground)	0,04
(r) Natural Gas (in ground)	0,18
(r) Oil (in ground)	0,53
Sum	0,75

Indoor Air Quality

Category	Stucco
(a) Indoor Total VOCs	0,00
Sum	0,00

Habitat Alteration

Category	Stucco
Land Use (End-of-Period Waste)	0,00
Land Use (Installation Waste)	0,00
Land Use (Replacement Waste)	0,00
Sum	0,00

Water Intake

Category	Stucco
Water Used (total)	1,30
Sum	1,30

Criteria Air Pollutants

Category	Stucco
(a) Nitrogen Oxides (NOx as NO2	0,01
(a) Particulates (greater than	0,00
(a) Particulates (PM 10)	0,01
(a) Particulates (unspecified)	0,07
(a) Sulfur Oxides (SOx as SO2)	0,04
Sum	0,13

Ecological Toxicity

Category	Stucco
(a) Carbon Monoxide (CO)	0,07
(a) Dioxins (unspecified)	0,18
(a) Mercury (Hg)	8,16
(a) Nitrogen Oxides (NOx as NO2	0,08
(w) Silver (Ag+)	0,30
All Others	0,12
Sum	8,91

Human Health Cancer

Category	Stucco
All Others	0,03
Cancer--(a) Arsenic (As)	0,05
Cancer--(a) Chromium (Cr III, C	0,08
Cancer--(a) Dioxins (unspecifie	128,85
Cancer--(w) Arsenic (As3+, As5+	0,07
Cancer--(w) Phenol (C6H5OH)	0,07
Sum	129,13

Ozone Depletion

Category	Stucco
(a) Carbon Tetrachloride (CCl4)	0,00
(a) CFC 12 (CCl2F2)	0,00
(a) Halon 1301 (CF3Br)	0,00
(a) HCFC 22 (CHF2Cl)	0,00
(a) Methyl Bromide (CH3Br)	0,00
(a) Trichloroethane (1,1,1-CH3C	0,00
Sum	0,00

Smog

Category	Stucco
(a) Carbon Monoxide (CO)	0,06
(a) Hydrocarbons (except methan	0,17
(a) Hydrocarbons (unspecified)	0,13
(a) Nitrogen Oxides (NOx as NO2	4,94
(a) Particulates (unspecified)	0,07
All Others	0,02
Sum	5,39

Table D.3: Values of environmental impacts by ceramic and marble tiles through BEES

Global Warming by Flow (grams CO2 equivalents/unit)

Category	Tile/Glass	CompMarble
(a) Carbon Dioxide (CO2, net)	2.312,50	2.412,40
(a) Carbon Tetrachloride (CCl4)	0,03	0,00
(a) Carbon Tetrafluoride (CF4)	0,00	0,00
(a) CFC 12 (CCl2F2)	0,00	0,00
(a) Chloroform (CHCl3, HC-20)	0,00	0,00
(a) Halon 1301 (CF3Br)	0,00	0,00
(a) HCFC 22 (CHF2Cl)	0,00	0,00
(a) Methane (CH4)	97,42	134,45
(a) Methyl Bromide (CH3Br)	0,00	0,00
(a) Methyl Chloride (CH3Cl)	0,00	0,00
(a) Methylene Chloride (CH2Cl2,	0,00	0,00
(a) Nitrous Oxide (N2O)	11,08	1,54
(a) Trichloroethane (1,1,1-CH3C	0,00	0,00
Sum	2.421,03	2.548,39

Acidification by Flow (milligrams H+ equivalents/unit)

Category	Tile/Glass	CompMarble
(a) Ammonia (NH3)	0,56	0,48
(a) Hydrogen Chloride (HCl)	2,84	4,46
(a) Hydrogen Cyanide (HCN)	0,00	0,00
(a) Hydrogen Fluoride (HF)	4,29	0,41
(a) Hydrogen Sulfide (H2S)	0,00	0,03
(a) Nitrogen Oxides (NOx as NO2	277,16	366,93
(a) Sulfur Oxides (SOx as SO2)	623,86	386,76
(a) Sulfuric Acid (H2SO4)	0,00	0,00
Sum	908,72	759,07

Eutrophication by Flow (grams nitrogen equivalents/unit)

Category	Tile/Glass	CompMarble
(a) Ammonia (NH3)	0,00	0,00
(a) Nitrogen Oxides (NOx as NO2	0,31	0,41
(a) Nitrous Oxide (N2O)	0,00	0,00
(a) Phosphoric Acid (H3PO4)	0,00	0,00
(a) Phosphorus (P)	0,00	0,00
(a) Phosphorus Pentoxide (P2O5)	0,00	0,00
(w) Ammonia (NH4+, NH3, as N)	0,01	0,01
(w) BOD5 (Biochemical Oxygen	0,04	0,00
(w) COD (Chemical Oxygen	0,02	0,01
(w) Nitrate (NO3-)	0,00	0,00
(w) Nitrite (NO2-)	0,00	0,00
(w) Nitrogenous Matter (unspeci	0,00	0,00
(w) Phosphates (PO4 3-, HPO4--,	0,00	0,00
(w) Phosphorus (P)	0,00	0,00
(w) Phosphorus Pentoxide (P2O5)	0,00	0,00
Sum	0,39	0,44

Fossil Fuel Depletion by Flow (MJ/unit)

Category	Tile/Glass	CompMarble
(r) Coal (in ground)	0,02	0,04
(r) Natural Gas (in ground)	2,33	4,66
(r) Oil (in ground)	1,56	3,95
Sum	3,91	8,65

Indoor Air Quality by Flow (grams Total VOCs/unit)

Category	Tile/Glass	CompMarble
(a) Indoor Total VOCs	0,04	0,04
Sum	0,04	0,04

Habitat Alteration by Flow (threatened & endangered species/unit)

Category	Tile/Glass	CompMarble
Land Use (End-of-Period Waste)	0,00	0,00
Land Use (Installation Waste)	0,00	0,00
Land Use (Replacement Waste)	0,00	0,00
Sum	0,00	0,00

Water Intake by Flow (liters/unit)

Category	Tile/Glass	CompMarble
Water Used (total)	15,10	76,10
Sum	15,10	76,10

Criteria Air Pollutants by Flow (micro disability-adjusted life years/unit)

Category	Tile/Glass	CompMarble
(a) Nitrogen Oxides (NOx as NO2	0,02	0,02
(a) Particulates (greater than	0,00	0,00
(a) Particulates (PM 10)	0,03	0,00
(a) Particulates (unspecified)	0,06	0,12
(a) Sulfur Oxides (SOx as SO2)	0,17	0,11
Sum	0,28	0,25

Ecological Toxicity by Flow (grams 2,4-dichlorophenoxy-acetic acid equivalents/unit)

Category	Tile/Glass	CompMarble
(a) Dioxins (unspecified)	0,03	0,24
(a) Mercury (Hg)	6,51	14,48
(a) Nitrogen Oxides (NOx as NO2	0,14	0,19
(w) Silver (Ag+)	0,92	0,36
(w) Vanadium (V3+, V5+)	0,00	0,35
All Others	0,68	0,21
Sum	8,27	15,83

Human Health Cancer by Flow (grams benzene equivalents/unit)

Category	Tile/Glass	CompMarble
All Others	0,04	0,01
Cancer--(a) Arsenic (As)	0,09	0,04
Cancer--(a) Dioxins (unspecifie	18,69	175,67
Cancer--(a) Lead (Pb)	1,13	0,00
Cancer--(w) Arsenic (As3+, As5+	0,20	0,09
Cancer--(w) Phenol (C6H5OH)	0,33	0,72
Sum	20,48	176,53

Ozone Depletion by Flow (grams CFC-11 equivalents/unit)

Category	Tile/Glass	CompMarble
(a) Carbon Tetrachloride (CCl4)	0,00	0,00
(a) CFC 12 (CCl2F2)	0,00	0,00
(a) Halon 1301 (CF3Br)	0,00	0,00
(a) HCFC 22 (CHF2Cl)	0,00	0,00
(a) Methyl Bromide (CH3Br)	0,00	0,00
(a) Trichloroethane (1,1,1-CH3C	0,00	0,00
Sum	0,00	0,00

Smog by Flow (grams NOx equivalents/unit)

Category	Tile/Glass	CompMarble
(a) Hydrocarbons (except methan	0,16	0,19
(a) Hydrocarbons (unspecified)	2,66	1,40
(a) Nitrogen Oxides (NOx as NO2	8,58	11,36
(a) Particulates (unspecified)	0,06	0,12
(a) Styrene (C6H5CHCH2)	0,00	7,62
All Others	0,15	0,20
Sum	11,62	20,90

Table D.4: Values of environmental impacts by plasterboard through BEES

Global Warming by Flow (grams CO2 equivalents/unit)

Category	GypsmBoard
(a) Carbon Dioxide (CO2, net)	1.642,68
(a) Carbon Tetrachloride (CCl4)	0,06
(a) Carbon Tetrafluoride (CF4)	0,00
(a) CFC 12 (CCl2F2)	0,00
(a) Chloroform (CHCl3, HC-20)	0,00
(a) Halon 1301 (CF3Br)	0,00
(a) HCFC 22 (CHF2Cl)	0,00
(a) Methane (CH4)	276,65
(a) Methyl Bromide (CH3Br)	0,00
(a) Methyl Chloride (CH3Cl)	0,00
(a) Methylene Chloride (CH2Cl2,	0,00
(a) Nitrous Oxide (N2O)	14,13
(a) Trichloroethane (1,1,1-CH3C	0,00
Sum	1.933,52

Acidification by Flow (milligrams H+ equivalents/unit)

Category	GypsmBoard
(a) Ammonia (NH3)	3,46
(a) Hydrogen Chloride (HCl)	2,66
(a) Hydrogen Cyanide (HCN)	0,00
(a) Hydrogen Fluoride (HF)	0,45
(a) Hydrogen Sulfide (H2S)	0,01
(a) Nitrogen Oxides (NOx as NO2	142,29
(a) Sulfur Oxides (SOx as SO2)	666,36
(a) Sulfuric Acid (H2SO4)	0,00
Sum	815,23

Eutrophication by Flow (grams nitrogen equivalents/unit)

Category	GypsmBoard
(a) Ammonia (NH3)	0,00
(a) Nitrogen Oxides (NOx as NO2	0,16
(a) Nitrous Oxide (N2O)	0,00
(a) Phosphoric Acid (H3PO4)	0,00
(a) Phosphorus (P)	0,00
(a) Phosphorus Pentoxide (P2O5)	0,00
(w) Ammonia (NH4+, NH3, as N)	0,06
(w) BOD5 (Biochemical Oxygen	0,10
(w) COD (Chemical Oxygen	0,05
(w) Nitrate (NO3-)	0,00
(w) Nitrite (NO2-)	0,00
(w) Nitrogenous Matter (unspeci	0,06
(w) Phosphates (PO4 3-, HPO4--,	0,12
(w) Phosphorus (P)	0,08
(w) Phosphorus Pentoxide (P2O5)	0,00
Sum	0,65

Fossil Fuel Depletion by Flow (MJ/unit)

Category	GypsmBoard
(r) Coal (in ground)	0,02
(r) Natural Gas (in ground)	3,43
(r) Oil (in ground)	0,41
Sum	3,86

Indoor Air Quality by Flow (grams Total VOCs/unit)

Category	GypsmBoard
(a) Indoor Total VOCs	0,00
Sum	0,00

Habitat Alteration by Flow (threatened & endangered species/unit)

Category	GypsmBoard
Land Use (End-of Period Waste)	0,00
Land Use (Installation Waste)	0,00
Land Use (Replacement Waste)	0,00
Sum	0,00

Water Intake by Flow (liters/unit)

Category	GypsmBoard
Water Used (total)	1,02
Sum	1,02

Criteria Air Pollutants by Flow (micro disability-adjusted life years/unit)

Category	GypsmBoard
(a) Nitrogen Oxides (NOx as NO2	0,01
(a) Particulates (greater than	0,04
(a) Particulates (PM 10)	0,04
(a) Particulates (unspecified)	0,02
(a) Sulfur Oxides (SOx as SO2)	0,18
Sum	0,29

Ecological Toxicity by Flow (grams 2,4-dichlorophenoxy-acetic acid equivalents/unit)

Category	GypsmBoard
(a) Chlorpyrifos	0,12
(a) Mercury (Hg)	3,51
(a) Metolachlor (C15H22ClNO2)	0,30
(w) Cobalt (Co I, Co II, Co III	0,18
(w) Silver (Ag+)	1,90
All Others	0,36
Sum	6,36

Human Health Cancer by Flow (grams benzene equivalents/unit)

Category	GypsmBoard
All Others	0,06
Cancer--(a) Arsenic (As)	0,13
Cancer--(a) Benzene (C6H6)	0,04
Cancer--(a) Dioxins (unspecifie	0,75
Cancer--(w) Arsenic (As3+, As5+	0,39
Cancer--(w) Phenol (C6H5OH)	0,37
Sum	1,74

Ozone Depletion by Flow (grams CFC-11 equivalents/unit)

Category	GypsmBoard
(a) Carbon Tetrachloride (CCl4)	0,00
(a) CFC 12 (CCl2F2)	0,00
(a) Halon 1301 (CF3Br)	0,00
(a) HCFC 22 (CHF2Cl)	0,00
(a) Methyl Bromide (CH3Br)	0,00
(a) Trichloroethane (1,1,1-CH3C	0,00
Sum	0,00

Smog by Flow (grams NOx equivalents/unit)

Category	GypsmBoard
(a) Hydrocarbons (except methan	0,13
(a) Hydrocarbons (unspecified)	0,55
(a) Methane (CH4)	0,04
(a) Nitrogen Oxides (NOx as NO2	4,41
(a) Xylene (C6H4(CH3)2)	0,07
All Others	0,21
Sum	5,41