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August 2023

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ABSTRACT

INVESTIGATION OF MATERIAL PROPERTIES, ENERGY CONSUMPTION VALUES AND ENVIRONMENTAL EFFECTS OF HISTORICAL AND MODERN BUILDINGS CONSTRUCTED IN GAZİANTEP

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At present, nearly 35% of global energy demand and corresponding carbon dioxide outputs are created by the building sector. This study examines and matches the life cycle energy consumption (LCEC) and carbon dioxide emissions (LCCE) of a historic listed building (BT1) built in 1875, a novel building (BT2) constructed with the most recent building components with compatible plans of the historic listed building and the historic listed building thereafter the restoration and structural retrofit (BT3) via utilizing actual findings from the building site of an existing project in Gaziantep, Turkey. It is estimated that the use phase was dominant throughout the building's service life and BT1 has the highest use energy demand. LCEC and LCCE values of the BT1, BT2, and BT3 are calculated to be 102.63, 70.13, 78.07 GJ/m^2, and 14.18, 9.75, and 10.06 tons of CO_2 per m^2 (tCO_2/m^2), respectively. With the present practices and methodologies, the retrofit and restoration of the historic building raises the embodied energy (EE) value by 56.6%. Sustainable restoration and retrofit of historic buildings should be executed by employing proper techniques respecting the conservation principles of history, environment, and energy.

Key Words: Energy consumption, Embodied energy, Historic listed building, Carbon dioxide emissions, Life cycle assessment.

ÖZET

GAZİANTEP’TEKİ TARİHİ VE MODERN YAPILARIN MALZEME ÖZELLİKLERİ, ENERJİ TÜKETİM DEĞERLERİ VE ÇEVRESEL ETKİLERİNİN ARAŞTIRILMASI

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Günümüzde, küresel enerji talebinin ve buna karşılık gelen karbondioksit emisyonlarının yaklaşık %35'i inşaat sektörü tarafından oluşturulmaktadır. Bu çalışmada, 1875 yılında inşa edilmiş, tarihi bir yapının (BT1), tarihi yapı ile uyumlu yapı formuna sahip modern yapı malzemeleriyle inşaa edildiği varsayılan yeni yapının (BT2) ve tarihi yapının yakın geçmişte gerçekleştirilen restorasyon ve yapısal güçlendirme uygulamasının inşaat sahası verileri kullanılarak (BT3) yaşam döngüsü enerji tüketimi (LCEC) ve karbondioksit emisyonları (LCCE) incelenmiş ve elde edilen veriler karşılaştırılmıştır. Çalışma sonucunda bina hizmet ömrü boyunca kullanım aşamasının baskın olduğu ve BT1'in en yüksek kullanım enerjisine sahip olduğu tespit edilmiştir. BT1, BT2, ve BT3'ün LCEC ve LCCE değerleri sırasıyla 102.63, 70.13, 78.07 GJ/m^2 ve 14.18, 9.75 ve 10.06 ton CO_2/m^2 olarak hesaplanmıştır. Mevcut uygulamalar ve metodolojiler ile tarihi binanın güçlendirilmesi ve restorasyonu, gömülü enerji (EE) değerini %56,6 oranında arttırmaktadır. Tarihi yapıların sürdürülebilir güçlendirme ve restorasyonu; tarihin, çevrenin ve enerjinin korunması ilkelerine uygun teknikler kullanılarak gerçekleştirilmelidir.

Anahtar Kelimeler: Enerji Tüketimi, Gömülü Enerji, Tescilli Tarihi Yapı, Karbondioksit Emisyonları, Yaşam Döngüsü Analizi.

I dedicate this thesis to my family for their endless support and selfless love. I am grateful them all that they have done for me.

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LIST OF SYMBOLS

a	Absorption Coefficient
c	Specific Heat Capacity (J/kgK)
C	Heat Capacity (J/K)
c_v	Volumetric Heat Capacity ($J/K\cdot m^3$)
f	Decrement Factor
h	Coefficient of Convective Heat Transfer (W/m^2K)
k	Thermal Conductance (W/K)
L	Considered Material Thickness (m)
q	Heat Flux (W/m^2)
q_{bb}	Energy of Radiation (W/m^2)
Q_{emit}	Radiation Emitted by a Black Body (kW)
r	Reflectivity Coefficient
R	Thermal Resistance (m^2K/W)
T	Surface Temperature (K)
U	Total Heat Transfer Coefficient (W/m^2K)
o	Opaque
c	Transparent
δ	Material Thickness (m)
ε	Thermal Effusivity ($Ws^{1/2}m^{-2}K^{-1}$)
λ	Thermal Conductivity (W/mK)
μ	Vapor Diffusion Resistance Factor
ρ	Density (kg/m^3)
τ	Thermal Time Constant (s)
τ_c	Coefficient of Transmittance
σ	Stefan-Boltzmann Constant (5.67×10^{-8} $Wm^{-2}K$)

LIST OF ABBREVIATIONS

AAC	Autoclaved Aerated Concrete
BEP-TR	Building Energy Performance Software
BIM	Building Information and Modelling
BIPV	Building Integrated Photovoltaics
BRP	Building Renovation Passports
BSI	British Standards Institution
BUR	Built-up Roofing
CFCs	Chlorofluorocarbons
CSB	Calcium Silicate Board
ECCP	European Climate Change Programme
EE	Embodied Energy
EEDMS	Embodied Energy Database Management System
EF	CO_2 Emission Factor
EIA	Energy Information Administration
EKB	Energy Performance Certificate
EP	Expanded Perlite
EPBD	Energy Performance of Buildings Directive
EPS	Expanded Polystyrene
ERMs	Energy Refurbishment Measures
ESD	Energy Services Directive
EUI	Energy Usage Intensity
FE	Fuel Economy
GDP	Gross Domestic Product
GHG	Greenhouse Gas
GIA	Gross Interior Area
GWP	Global Warming Potential
HC/A	Heat Capacity Per Unit Area (J/K m^2)

HCFC	Hydrochlorofluorocarbon
HOE	Holographic Optical Elements
ICB	Insulation Cork Board
ICE	Inventory of Carbon and Energy
ICT	Information and Communication Technologies
IE4B	Athena Impact Estimator for Buildings
IR	Infrared
ISO	International Standards Organization
LASRS	Lightweight Aluminum Standing-Seam Roofing Systems
LC	Load Carrying Capacity
LCA	Life Cycle Analysis
LCCE	Life Cycle Carbon Dioxide Emissions
$LCCO_2A$	Life Cycle Carbon Dioxide Emissions Assessment
LCEA	Life Cycle Energy Assessment
LCEC	Life Cycle Energy Consumption
LCI	Life Cycle Inventory
LCIA	Life Cycle Impact Assessment
LECA	Lightweight Expanded Clay Aggregate
LOW-E	Low Emissivity
LPG	Liquefied Petroleum Gas
LTRS	Long-Run Refurbishment Strategies
LVL	Laminated Veneer Lumber
MDF	Medium Density Fiberboard
MF	Melamine Foam
MSs	Member States
NDCs	Nationally Determined Contributions
NEEAPs	National Energy Efficiency Plans
NZEBs	Nearly Zero-Energy Buildings
OSB	Oriented Strand Board
PAC	Pumice Aggregate Concrete
PCMs	Phase Change Materials

PE	Primary Energy
PF	Phenolic Foam
PIR	Polyisocyanurate
PU	Polyurethane
PV	Photovoltaics
PVB	Polyvinyl Bitural
PVC	Polyvinyl-Chloride
RC	Reinforced Concrete
SDGs	Sustainable Development Goals
SF	Single Family
SHGC	Solar Heat Gain Coefficient
SPD	Suspended Particle Devices
SR	Solar Reflectance
UV	Ultraviolet
VIP	Vacuum Insulation Panels
VMT	Vermiculate
VR	Vaulted Roof
VT	Visible Transmittance Rate
WD	Weight of the Disposal
XPS	Extruded Polystyrene

CHAPTER 1
INTRODUCTION

1.1 General

Today, global warming is a major problem for the world. It brings out financial affairs of nations and influencing way of living, costing mankind, communities as well countries immensely at present days and much higher in time to come. Climatic regimes are modifying on ecosystem, weather incidents are occurring more violently and global greenhouse gas (GHG) emissions have arrived the topmost extent until today. To tackle such environmental problems, on 1th January 2016, the 2030 agenda for sustainable development, formally implemented. One of the target of the sustainable development was to promote the world to take immediate measures to tackle climate change [1].

The buildings and construction industry are liable for 35% of global final energy use and about 40% overall carbon dioxide (CO_2) outputs. In this regard, 2020 is a critical period for countries to enhance their Nationally Determined Contributions (NDCs), actually paying attention to additional measures to alleviate energy consumption and related greenhouse outputs in the buildings and construction industry [2].

The construction sector have crucial mission in global economy. With regard to statistics of the World Economic Forum, the sector presently is responsible from nearly 6% of the world GDP [3] and is foreseen to attain about 14.7% in 2030 [4]. Construction sector has a strategic importance for the European economy that comprising a broad category of companies and stakeholders, delivering 18 millions of employment. In case of Turkey, construction sector have leading position in national economy. Growing population of the Turkey, resulted in inevitable necessities regarding the sector for instance; need for housing, urban rehabilitation, infrastructure requirements, and renovation of existing building stock. Such needs provides consistent progress in the building and construction sector. In accordance with Turkish Statistical Institute, the number of buildings which were certified with building licence certificate in 2018 account for 104,143. Such a huge number proves the size of the construction and building sector.

Turkey being one of the most ancient settlement on the world has been the shelter of numerous old civilizations. Because of this rationale, a great deal of heritage buildings remained from these civilizations. In accordance with the report of Turkish Ministry of Culture and Tourism, the quantity of heritage building in Turkey is over 100,000 in the year of 2021. Therefore, the subjects related to renovation and refurbishment of heritage buildings have gained wide acceptance in Turkey over the years. Many studies are available in literature that concerns environmental impacts of buildings and its constituting materials to identify solutions to alleviate energy use and corresponding environmental impacts. Nevertheless, most of the researches concentrated on newly constructions and most of the researches concerns exemplary instances. There is a research gap in available literature related with the restoration and structural retrofit operations on the LCEC as well LCCE of historical constructions.

The determinant factors of environmental gains in available studies are the ‘‘use energy” depleted throughout the operation phase and ‘‘embodied energy” that is the cumulative energy imported to erect the building. Previous studies proved that historic buildings’ adaptive reuse is a profit for the ecosystem. The main goal of this thesis is to demonstrate the potency of restoration and rebuilding of historical structures on the life cycle energy use and corresponding greenhouse emissions.

In a broad perspective of view, the aim of this study to evaluate the reuse phenomenon for historical buildings as a course of action to accomplish sustainability and reveal the implementations that diminish or enhance the energy use of a historical building, throughout its’ life cycle, during and later restoration practices. The main goal of the present study is to analyze the energy use and corresponding greenhouse outputs of a historical building, make a comparison the outcomes with scenario of re-construction of the historical building, and demonstrate the impacts of restoration action throughout a 50 year period of lifespan. The outcomes of the study are anticipated to benefit the researchers, municipalities, policy makers, and technical staff conducting restoration projects on heritage building.

1.2 Outline of the thesis

Chapter 1- Introduction: The first chapter of the thesis presents the objective and scope of the study.

Chapter 2- Literature review: This chapter covers the previous studies on LCEC and corresponding LCCE of historic, newly constructed, and retrofitted buildings.

Chapter 3- Regulatory framework of building energy efficiency in EU and Turkey: This chapter presents main regulations that deals with building energy efficiency in EU and Turkey.

Chapter 4- Parameters effecting buildings' energy consumption and CO_2 emissions: This chapter explains the parameters that effect buildings' energy consumption and CO_2 emissions. These parameters are gathered under three main headings; environmental (climatic) parameters, parameters related with building, and parameters related with heating and cooling system of building. Details and sub-branches of these parameters are explained comprehensively in this chapter.

Chapter 5-Heat transfer in building envelope: This chapter submits heat transfer mechanism that occurs building envelope.

Chapter 6- Building envelope and constituent materials: This chapter focusses on both historic and modern buildings envelope and their constituent materials. Also thermal insulation materials and their properties are introduced in this part.

Chapter 7- Case study building: In this chapter properties of the studied building models are introduced. Also informations (i.e. geographic, climatic, etc.) related with the city of Gaziantep and Şahinbey district are given in detail.

Chapter 8- Methodology: This chapter presents life cycle assessment (LCA) methodology in detail. Concordantly, the implementation of LCEA and $LCCO_2A$ approaches on the studied building models are given. Also, tools and methods used in analysis are explained.

Chapter 9- Results and discussion: This chapter provides findings of the study in terms of studied building models construction phase results, operational phase results, demolition phase results, and overall results.

Chapter 10- Conclusions: This chapter submits the most proper conclusions of this study with a few noteworthy aspects for future studies.

CHAPTER 2
LITERATURE REVIEW

Iyer-Raniga and Wong [5] carried out whole building LCA for eight buildings in Australia, six of these pertain to heritage building category (B2, B3, B4, B5, B6, B7) and two of these pertain to recently built one (B1, B8). Cumulative Primary Energy (PE) was determined as 39,150 MJ/m^2, 183,720 MJ/m^2, 103,760 MJ/m^2, 100,160 MJ/m^2, 104,000 MJ/m^2, 79,890 MJ/m^2, 78,810 MJ/m^2, 81,890 MJ/m^2 respectively for B1, B2, B3, B4, B5, B6, B7, and B8 building types. Life cycle operational CO_2 outputs of the B1, B2, B3, B4, B5, B6, B7, and B8 building types were calculated as 2.9 tCO_2/m^2, 11.5 tCO_2/m^2, 6.95 tCO_2/m^2, 6.4 tCO_2/m^2, 6.8 tCO_2/m^2, 5.1 tCO_2/m^2, 4.85 tCO_2/m^2, and 5.4 tCO_2/m^2 respectively. It was stated that the cumulative PE pertinent to embodied, building, materials renewal, and landfill stages changed through 4% and 18% of the cumulative life cycle PE use of all studied buildings on a lifecycle period of hundred years. Besides, it was declared the average life cycle PE and corresponding greenhouse gas outputs alleviated by 47% and 46% respectively from 100 GJ/m^2 and 8 tCO_2 equivalents/m^2 as long as building lifecycle was diminished to a period of 50 years from a period of 100 years for historic buildings. For the 30 year lifecycle circumstance, the life cycle PE and corresponding greenhouse gas outputs diminished by an average of 66% and 64% respectively. In regard of uninsulated reference building type, the addition of floor insulation enabled a slight alleviation in the net energy demand of buildings that 1% to 16% diminishment occurred in the life cycle energy. Thermal insulation of walls reduced life cycle PE demand between 10% and 24%, with a mean value of 9% in regard of uninsulated reference building type. Combined insulation of exterior and interior walls exhibited proper effect than solely exterior wall insulation. The life cycle energy demand diminished between 11% and 32%, the mean operational energy demand diminished by 12% when compared to uninsulated reference building type. Combined insulation of ceiling and roof for the simulated building diminished life cycle PE demand between 22% and 53% in regard of uninsulated building type. Ceiling ventilator usage alleviated life cycle energy depletion from 6% to 13% in regard of uninsulated building type.

Ramesh et al. [6] reviewed from previous studies of the LCEA of buildings originated in 73 studies throughout 13 countries. The buildings subjected to study include both dwellings and office buildings that had a life time varying through 40-100 years. The results of the study demonstrated that operational phase accounts for 80-90% share, embodied phase accounts for 10-20% share in the total buildings life cycle energy use. Also it was concluded that life cycle energy (primary) use of ordinary dwelling type buildings varies through 150–400 kWh/m^2 per annum as well that of office type buildings varies through 250–550 kWh/m^2 per annum.

Piroozfar et al. [7] conducted a comparative LCA study between traditional and novel type dwellings in Palestine. The model buildings were a single house for traditional housing that was constructed with limestone and lime mortar, whereas five story building for novel type dwelling that was constructed with reinforced concrete and concrete blocks. To conclude, the results for energy use, environmental effects, and global warming potential for the novel type housing were much greater in contrast to traditional type housing that the embodied emissions of the traditional type housing and novel type housing was computed as 0.22 tCO_2/m^2 and 1.06 tCO_2/m^2 respectively for a 100 years period of life cycle .

Hu [8] conducted LCA for a historical building which is placed in Medina, New York for a life cycle period of 75 years. The Autodesk Revit tool was used to obtain the material quantity takeoffs and also the Athena Sustainable Materials Institute’s Impact Estimator (IE4B) was used in order to assess EE and operational energy usage. Historic conservation, retrofit and recent construction circumstances have been evaluated, and also six alternative objectives for energy performance were generated and evaluated. Consequently, historical construction had more life cycle energy consumption regarding “2012 ICC” Building Energy Code. Recent construction case with an Energy Usage Intensity (EUI) goal of 19000 Btu/sq ft/year is the best alternative solution, while a retrofitted building with an EUI target of 19000 Btu/sq ft/year is ranked as the second best alternative solution considering overall life cycle energy aspect. Considering primary energy demand of buildings studied, façade walls of the historic building had the greatest embodied primary energy use that corresponds to about 85% of the energy consumed through product to end of life LCA phases. Floor sections were responsible for 6% of total embodied primary energy that was ranked as second major consumer. In the retrofit case, exterior walls were responsible for 78% of the cumulative embodied primary energy demand, and the roof section was responsible of 12% of the overall embodied energy use. In the case of Global Warming Potential (GWP), recent construction case was much greater in manufacture and end-of-life phases that was approximately two times greater. In comparison, the retrofitted building had a slightly more GWP with regard to the existing building and the recent construction case. Additionally, it was declared that use energy has the highest share (90–95%) of the overall life cycle energy use of buildings, while embodied energy ranked as second order (5-10%). The contribution of destruction and other process energy was slight or inappreciable.

Koezjakov et al. [9] presented a survey on the relevancy between embodied energy and operational energy usage in Dutch dwellings. 3SCEP HEB (Center for Climate Change and Sustainable Energy Policy High Efficiency Buildings) model was employed to conduct analysis, besides for embodied calculations Embodied Energy Database Management System (EEDMS) was utilized. The lifespans subjected in the study for refurbishment and heavy refurbishment of single family and multi-family dwellings are 73.3 and 66.8 years, and also for new, advanced new, and standard single family and multi-family dwellings 58.3 and 51.8 years, respectively. It was found that embodied energy usage for twenty five Dutch dwellings varied from 52 to 106 MJ/(m^2·a), annualised throughout building lifespan and 3 to 6.4 GJ/m^2 in cumulative amount. With a respective average share of 27% and 21%, precast and reinforced concrete dwelling types had the highest embodied energy among all analysed dwelling types. The use energy demand in the Dutch building samples varied from 124 to 682 MJ/(m^2·a). In terms of use energy demands, apartments had the least values, while detached dwellings had the highest values. When the building models were evaluated, advanced new dwellings have the least specific heat consumption and standard dwellings had the highest. The share of Embodied Energy (EE) in the cumulative energy demand of buildings is least for standard dwellings with an interval of 10–12% and highest for advanced new dwellings lying between 31–46%. It was announced that with regard to scenario analysis result, a reduction resulted in cumulative energy demand in the improved efficiency scenario of 36%, in the frozen efficiency scenario of 13% in 2050, in regard of 2015. Correspondingly, it was indicated that an embodied energy rise up 26% and 35%, respectively, whereas use energy demand diminishes by 19% and 46%, respectively.

Atmaca A. and Atmaca N. [10] have investigated life cycle carbon dioxide emissions (LCCO_2A) and energy (LCEA) of two dwelling archetypes in Gaziantep, Turkey. In order to estimate primary energy demand and CO_2 outputs, Inventory of Carbon and Energy (ICE) Version 2.0 was utilized. Use energy demand was calculated by data derived from utility bill records and questionnaires. According to analysis results, it was declared that Building Type 1 (BT1) has higher EE value (15,576 GJ) and CO_2 emissions value (1473 ton CO_2). When compared to BT1, Building Type 2 (BT2) accomplished a diminishment of about seventy percent in EE (4689 GJ) and CO_2 output (453 ton) in construction stage. Additionally, operational energy in both BT1 and BT2 is remarkable and ranges from 79% to 84% of overall Life Cycle Energy (LCE), respectively. Operational energy demand of BT1 is 30.1 GJ/m^2, and this value is higher when compared to BT2 that has 24.4 GJ/m^2. Also it was found that BT1 has a 24% diminishment in CO_2 outputs because of natural gas usage for heating purposes. On the contrary, BT2 outputs more emissions (6484.9 kg CO_2/m^2) owing to the coal usage for heating energy. Regarding BT1, primary energy demand and CO_2 outputs was found to be 37.9 GJ/m^2 and 5221.9 kg CO_2/m^2, respectively. In the case of BT2, primary energy demand and CO_2 output was found to be 29.1 GJ/m^2 and 6485 kg CO_2/m^2, respectively. The energy demands and CO_2 outputs of construction and use stage correspond to 21%, 79%, and 14%, 86% for BT1; and 16%, 84%, and 7%, 93% for BT2, respectively. Throughout the dwellings fifty year lifespan, the use stage was governing phase correspondingly, 79–84% of the cumulative energy demand and 86–93% of CO_2 outputs, respectively.

Monahan and Powell [11] have analyzed the embodied carbon in a modest energy dwelling built using a innovative prefabricated panellised modular wooden frame structure (scenario 1), in Norfolk UK, with two conventional different scenarios. In the second scenario brick cladding is altered by the larch cladding and its related components, in the third scenario the wooden frame and larch cladding is altered by a conventional masonry wall construction. The LCA method was employed to perform a limited LCA, from cradle to site, of the structure. An inventory data of the materials and fossil-based energy used in the construction was used to estimate the primary energy expended and the related embodied carbon. Regarding dwelling building in scenario 1; the cumulative primary energy needed to construct corresponds to 519 GJ that is reciprocal of embodied energy of nearly 5.7 GJ per m^2 of story area, the cumulative embodied carbon was calculated to be 34.6 tonnes CO_2, the reciprocal value of that corresponds to 0.405 tCO_2 per m^2 of usable story area. The brick clad dwelling (scenario 2) had primary energy of 656 GJ with corresponding embodied carbon value of 45.6 tCO_2. This value corresponds to 7.7 GJ per m^2 primary energy and 0.535 tCO_2 m^2 per usable story area, respectively (enhances 35% of embodied energy and 32% of embodied carbon with respect to the case study model dwelling of scenario 1). Masonry wall construction case (scenario 3) was calculated to have primary energy of 700 GJ, with a corresponding embodied carbon of nearly 52 tCO_2. This value corresponds to 8.2 GJ per m^2 primary energy and 0.612 tCO_2 m^2 per usable story area (enhances of 35% embodied energy and 51% embodied carbon regarding the studied model dwelling of scenario 1).

Berg and Fuglseth [12] compared environmental loads of renovation of an ancient mansion with the newly constructed building in compliance with Norwegian LCA framework. The case study building has an uninsulated wood framed construction, exterior side vertical timber cladding as well completely concrete basement. In the scoop of study, sixty years of operation period was used in compliance with standard procedure for LCAs of constructions in Norway to enable comparison with analogous surveys. The findings demonstrated that the renovation of the ancient mansion results a decrement in cumulative greenhouse gas outputs (GHG) outputs over 60 years of nearly 295 tonnes CO_2-equivalents, corresponding to a 67% of decrement, with regard to the unrenovated case. The authors declared that the usage of construction materials throughout renovation produces some greenhouse gas outputs, however these are overshadowed by a 70% reduction in emissions from energy usage. In spite of energy-saving renovation, a newly constructed building in accordance with the latest standards will considerably have less energy demand than case study building. Thus, greenhouse outputs from operational phase is 40% less than for the newly constructed building. Over 60 years of operation period, net life cycle greenhouse gas outputs for the new construction case is only some 8% less than for the renovation scenario. It was reported that the rate of cumulative emissions related with energy demand is highest for the case study building without renovation (97%). Emissions related with energy use is responsible from 89% of the life cycle emissions for the renovated building and 60% for the newly constructed building. The energy-saving measures practiced for the case study building are estimated to diminish use energy demand about 30%. The equivalent diminution in energy-related greenhouse outputs is much higher (70%), because of the exchange from oil boiler in the unrenovated case, to a lumber burner stove as the principal heat source in the renovated building. Greenhouse gas outputs from electricity demand corresponds to a very large portion of cumulative energy related emissions (about 40% for the studied building without renovation, about 87% for the renovated building, and about 97% for the newly constructed building). The researchers concluded that intentive renovation of the historic building is profitable in a combat of climate change reduction over an analysis period of sixty-year. For the new construction case, above than 50 years was needed to compensate its environmental load.

The authors in Ref. [13] have surveyed life cycle energy (LCE) of a commercial type building located in Thailand. The LCE of the case study building was found to be 2.2 $x10^6$ GJ relied on 60,000 m^2 gross floor surface for a operation period of fifty years. The mean annual energy demand throughout fifty years of operation of the building was announced to be 0.86 GJ/m^2. The earliest embodied energy of the studied building was found to be 375 TJ. It was declared that relied on the outcomes of the LCEA, the use stage governed other life cycle phases which corresponds to 81% of the LCE demand. The LCE allocation of energy demand of the manufacture stage was also calculated to be remarkable (17%). It was pointed out that by the implementation of energy efficiency measures, 40–50% of energy (electricity) could be saved for the studied building. According to findings of preliminary analysis, recycling of construction materials could also employ extra energy savings (around 8.9%) to a buildings LCE demand.

Wu et al. [14] have presented a study that analyses life cycle energy use and CO_2 emissions of a commercial type building located in China. The building had a floor area of 36,500 m^2 and the calculations have made for a operation time of fifty years. The cumulative energy demand of the commercial building was calculated as 68,464.37 MJ/m^2. It was declared that the operational stage had the highest energy demand throughout whole life cycle period (58,870.26 MJ/m^2, 85.99%) phases and the construction materials manufacture was ranked as second major energy consuming phase (8,431.41 MJ/m^2, 12.32%). The cumulative CO_2 outputs of the studied building was found to be 15,932.05 kg/m^2. Also it was pointed out that high quantity of electricity needed throughout the use phase of the building that resulted in the highest CO_2 emissions value over the entire life cycle period (12,951.46 kg/m^2, 81.29%). The results showed that the demolition works caused nearly 2,177.44 kg/m^2 CO_2 outputs that has corresponding share of 13.67%. This was essentially induced by the high quantity of CO_2 emissions produced from groundfilling (2,161.91 kg/m^2). The construction materials manufacture phase had 715.4 kg/m^2 CO_2 outputs, the value of which corresponds 4.49% of the CO_2 outputs share. Also it was declared that that concrete is responsible from 49.18% of the cumulative CO_2 outputs, followed by the wood and steel that account for 26.10% and 16.57% regarding manufacturing phase of materials. Small quantity of diesel oil (716.52 MJ/m^2) was consumed for shipping construction materials and a little amount of CO_2 released from construction period, the construction phase caused 87.75 kg/m^2 CO_2 outputs, that corresponds to the little share of the cumulative CO_2 outputs (0.55%).

Bull et al. [15] investigated energy saving refurbishment alternatives for educational buildings in the UK regarding with life cycle cost and carbon footprints context. The case studies comprise four buildings (School A, School B, School C, and School D) which were built between 1906-1982. School A has four levels, with net interior area of 2435 m^2, gross interior area of 3841 m^2, storey elevation of 3.62 m and pitched type roofing. School B has four levels, with net interior area of 3034 m^2, gross interior area of 4532 m^2, storey elevation of 3.53 m and flat type roofing. School C has four levels, with net interior area of 3836 m^2, gross interior area of 5290 m^2, storey elevation of 3.34 m and flat type roofing. School D has one level, with net interior area of 675 m^2, gross interior area of 931 m^2, storey elevation of 3.5 m and pitched type roofing. The functional unit of the study is 1 m^2 of the buildings' gross interior area (GIA). Building geometries were designed in DesignBuilder 3.0 software tool and thereafter edited to perform energy simulation of a various energy refurbishment measures (ERMs) utilizing EnergyPlus v. 7.2 and jEPlus v. 1.4. Investigated ERMs are four alternatives for interior thermal insulation, two alternatives for exterior insulation, one alternative for window upgrading, one alternative for air-tightness upgrading, and one alternative for highly efficient boilers. The authors pointed out that remarkable decrement in use energy can be achieved for all of the studied buildings by considering envelope retrofit measures together with highly efficient heating system. Besides, it is feasible to reduce energy used for space heating about 90% by thermal insulation measures and lowering uncontrolled air leakage ratio to 0.25 air discharge per hour. Boiler efficiency constitute the highest share to heating energy demand. The average payback period for emissions of all packages, comprising ones related with air tightness enhancement is 3.9 years. On the contrary the average discounted economic payback period of just the 25% retrofit packages that pay back throughout 60 years is 32.1 years. This proves that the great majority of refurbishment measures that pay back economically will compensate their embodied emissions more rapidly.

CHAPTER 3
REGULATORY FRAMEWORK OF BUILDING ENERGY EFFICIENCY IN EU AND TURKEY

3.1 General background

Technological advancements, industrialization and growth in the population of world rapidly enhances the demand for energy. Energy, being the primary input in manufacturing , contributes to welfare of societies and is used in almost every field of the daily life. In brief, energy is described as the capability to conduct work and it can be available in chemical, mechanical (kinetics and potential), electricity, heat, and nuclear species. Energy can be transformed into other forms by proper techniques and classified in various ways [16].

Energy resources are generally categorized in terms of their usage and transformability. If the classification is made regarding their use, energy resources are renewable and non-renewable; as well if their transformability is considered, these are primary and secondary energy resources (See Figure 3.1) [16].

Energy form that has not undergone any change or transformation is called as primary energy. Oil, nuclear, natural gas, coal, biomass, hydraulic, sun, wave-tide, and wind are resources of primary energy. The energy derived by virtue of the transformation of primary source is known as secondary energy. Electricity, diesel, petrol, coke, petcoke, air gas, secondary coal and liquefied petroleum gas (LPG) are representative of such energy sources [17, 18].

Another form of classification for energy resources is, at the end of their use, by taking into account their renewability or non-renewability characteristics. With regard to this classification, renewable resources can keep the same in a natural cycle process which do not diminish even though being used and do not run out. On the other hand, energy sources that cannot renew themselves as depleted once are called as non-renewable energy sources. Among themselves, non-renewable resources are classified into two groups, those are fossil-based and atomic nuclei-sourced. Oil, coal, and natural gas are fossil-based non-renewable energy resources, besides uranium and thorium are considered as nuclei-sourced non-renewable energy resources. Wind, wave tide, hydraulic, solar, biomass, geothermal, and hydrogen are renewable energy sources [17, 18]. Figure 3.1 presents general categorization of energy resources.

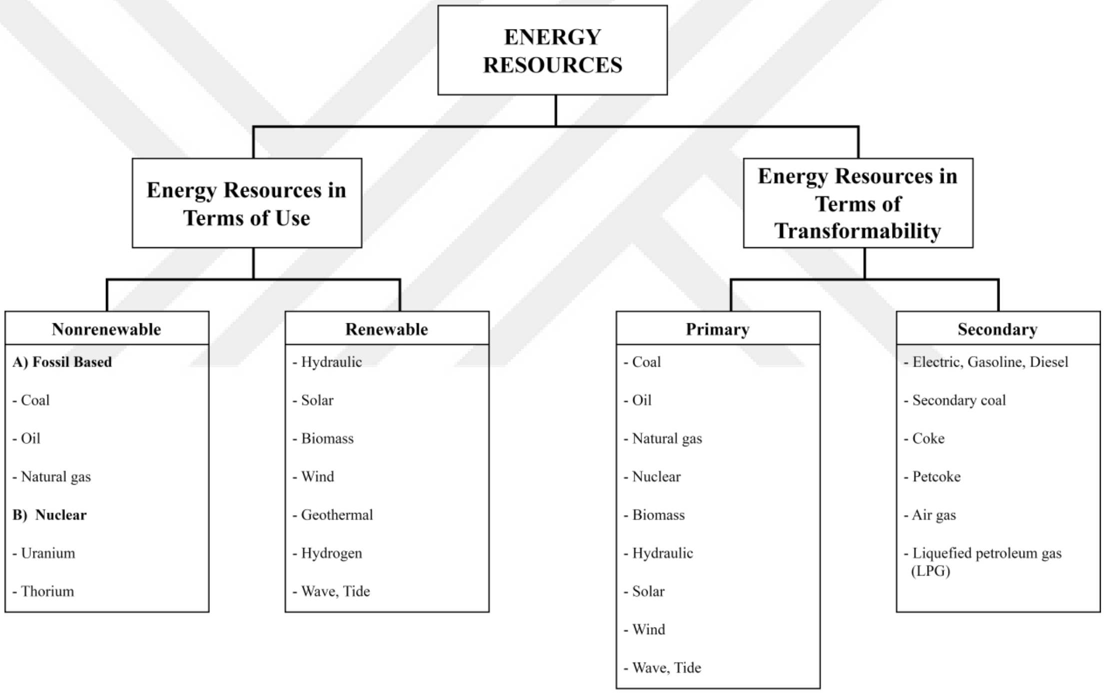


Figure 3.1 General categorization of energy resources [17]

3.2 Building energy efficiency in European Union (EU)

So as to realize how the EU energy efficiency policies have been effectual in adapting the existing buildings and in diminishing the energy use in newly constructed and existing buildings, this paper analyzes EU legislations regarding with energy efficiency. In Table 3.1, outline of primary energy efficiency lagislative acts at the EU scale through the recent 50 years is presented.

In EU member countries buildings are liable for around 40% of energy consumption and 36% of greenhouse gas outputs. The EU targets to upgrade energy efficiency by 32.5% by 2030 that would diminish primary energy demand to 1.273 Mtoe or final energy demand to 956 Mtoe [19]. The main legislative acts for realizing the energy efficiency objective are the the Energy Efficiency Directive [20] and Energy Performance of Buildings Directive (EPBD) [21]. Both of these two directives enable a national legislative framework intenting to make up eco-friendly building stock and attain remarkable energy efficiency by 2050, a encouraging ambient for energy efficiency investings, energy savings and cost savings [22]. EPBD that was put into force, and will be carried out framework given below [23]:

- December 2002: EPBD is adopted by EU; EPBD 2002,
- January 2006: Due date for transposition directive into national regulation,
- November 2008: Commission suggests amendment of EPBD (EurActiv 14/11/08),
- April 2009: First-reading position is adopted by Parliament (EurActiv 24/04/09),
- November 2009: Political agreement on directive is achieved by EU (EurActiv 18/11/09),
- May 2010: Parliament endorses new regulations,
- May 2010: EU approves (adopts) the revised (recast) EPBD 2010, EPBD Directive 2010/31/EU on the energy performance of buildings,
- End 2018: Public buildings must obey nearly zero energy standards,
- End 2020: All newly constructed buildings to be nearly zero energy.

Table 3.1 Outline of primary energy efficiency lagislative acts at the EU scale through the recent 50 years [24]

Policy specification	Date of approval	Definition	Reference
Directives	13 February 1978	Council Directive on the performance of heat generators for space heating and the production of hot water in new or existing non– industrial buildings and on the insulation of heat and domestic hot-water distribution in new non-industrial buildings	1978/170/ EEC
	21 December 1988	Council Directive on the approximation of laws, regulations and administrative provisions of the Member States relating to construction products	1989/106/EEC
	21 May 1992	Council Directive on efficiency requirements for new hot-water boilers fired with liquid or gaseous fuels	1992/42/EEC
	22 September 1992	Council Directive on the indication by labelling and standard product information of the consumption of energy and other resources by household appliances	1992/75/EEC
	13 September 1993	Council Directive to limit carbon dioxide emissions by improving energy efficiency (SAVE)	1993/76/EEC
	3 September 1996	Directive on energy efficiency requirements for household electric refrigerators, freezers and combinations thereof	1996/57/EC
	18 September 2000	Directive on energy efficiency requirements for ballasts for fluorescent lighting	2000/55/EC
	16 December 2002	Directive on the energy performance of buildings	2002/91/EC
	6 July 2005	Directive establishing a framework for the setting of eco-design requirements for energy-using products and amending Council Directive 92/42/EEC and Directives 96/57/EC and 2000/55/EC of the European Parliament and of the Council	2005/32/EC
	5 April 2006	Directive on Energy End-use Efficiency and Energy Services and Repealing Council Directive 93/76/EEC	2006/32/EC
	21 October 2009	Directive establishing a framework for the setting of ecodesign requirements for energy-related products	2009/125/EC
	19 May 2010	Directive on the Energy Performance of Buildings (recast)	2010/31/EU
	14 November 2012	Directive on Energy Efficiency, Amending Directives 2009/125/EC and 2010/30/EU and Repealing Directives 2004/8/EC and 2006/32/EC	2012/27/EU
	30 May 2018	Directive amending Directive 2010/31/EU on the energy performance of buildings and Directive 2012/27/EU on energy efficiency	2018/844/EU
	11 December 2018	Directive amending Directive 2012/27/EU on energy efficiency	2018/2002/EU
Regulations	9 March 2011	Regulation of the European Parliament and of the Council laying down harmonised conditions for the marketing of construction products and repealing Council Directive 89/106/EEC	2011/305/EU
Resolutions	17 December 1974	Council Resolution concerning Community energy policy objectives for 1985	1975/C 153/2

	9 June 1980	Council Resolution concerning Community energy policy objectives for 1990 and convergence of the policies of the Member States	1980/C 149/1
	16 September 1986	Council Resolution on new Community energy policy objectives for 1995 and convergence of the policies of the Member States	1986/C 241/01
Recommendations	4 May 1976	Council Recommendation on the rational use of energy in the heating system of existing buildings	76/493/EEC
	4 May 1976	Council Recommendation on the rational use of energy for electrical household appliances	76/496/EEC
	4 May 1976	Council Recommendation on the rational use of energy by promoting the thermal insulation of buildings	76/492/EEC
	25 October 1977	Council Recommendation on the regulation of space heating, domestic hot water production and the metering of heat in new buildings	77/712/EEC
	5 February 1979	Council Recommendation on the reduction of energy requirements for buildings in the Community	79/167/ECSE
Communications	13 May 1987	European Commission Communication towards a continuing policy for energy efficiency in the European Community	COM(1987) 223
	29 April 1998	Energy Efficiency in the European Community - Towards a Strategy for the Rational Use of Energy	COM(1998) 246
	08 March 2000	EU policies and measures to reduce greenhouse gas emissions: towards a European Climate Change Programme (ECCP). COM (2000) 88 final. Brussels	COM(2000) 88
	26 April 2000	EC, 2000. Action Plan to Improve Energy Efficiency in the European Community. COM (2000) 247 final. Brussels	COM(2000) 247
	29 November 2000	EC, 2000. Green Paper on Towards a European Strategy for Energy Supply. COM (2000) 769 final. Brussels	COM(2000) 769
	22 June 2005	EC, 2005. Green Paper on Energy Efficiency or Doing More with Less. COM (2005) 265 final. Brussels	COM(2005) 265
	19 October 2006	EC, 2006. Communication from the Commission - Action Plan for Energy Efficiency: Realising the Potential. Brussels	COM(2006) 545
	10 January 2007	EC, 2007. An energy policy for Europe. COM (2007) 1 final. Brussels	COM(2007) 1
	8 March 2011	EC, 2011. A Roadmap for moving to a competitive low carbon economy in 2050. COM (2011) 112 final. Brussels	COM(2011) 112
	25 February 2015	EC, 2015. Energy Union Package: A Framework Strategy for a Resilient Energy Union with a Forward-Looking Climate Change Policy. COM (2015) 80 final. Brussels	COM(2015) 80
	11 December 2019	EC, 2019. The European Green Deal. COM (2019) 640 final. Brussels	COM(2019) 640

3.2.1 Directive 2002/91/EC (EPBD)

The main goal of this Directive is to support energy performance upgrading of the buildings through the Community, regarding outdoor ambient climate and local conditions, in addition to indoor climate needs and cost-efficiency. The requirements are presented below with regard to "Annex I" of this directive.This Directive centres around following milestones [25]:

a) General framework for a technique to estimate the integrated energy performance of structures;

b) Implementation of minimum requisites on the energy performance of newly constructed buildings;

c) Implementation of minimum requisites on the energy performance of existing building stock which are exposed to major renovation;

d) Energy certification of buildings; and

e) Routine check up of air-conditioning equipment and boiler in buildings and additionally an evaluation of the heating installation where the boilers are dated than 15 years.

The common calculation technique should involve whole of the aspects that identify energy efficiency and not merely buildings' insulation quality. This integrated procedure should consider aspects such as cooling and heating equipments' installation, lighting assembly, the orientation and location of the building, heat recovery system, etc. The minimum requirements for buildings are estimated relying on the above technique. The Member States are liable for establishing the minimum requirements [26].

The Directive deals with the housing sector and the tertiary sector (public buildings, offices, etc.). The extent of the provisions on certification does not, nevertheless, involve some buildings, for instance industrial sites, historic buildings, etc. It encompasses whole aspects of energy efficiency in structures aiming to set up a truly integrated technique. The Directive does not stipulate measures on transportable tools for instance households' electricity appliances. Measures on obligatory minimum efficiency necessities and labelling have already been carried out or are planned in the Energy Efficiency Action Plan [26].

Energy performance certificates should be provided accessible as buildings are constructed, hired or sold. The Directive particularly points out hired buildings in order for providing that the householder, who does not ordinarily make any payment charges for energy expenses, should perform the required action. Additionally, the Directive specifies that users' of buildings should be facilitated to regulate their own energy use for heating as well hot water, in a certain extent such measures have cost effectiveness. The Member States are liable for setting the minimum requirements. Also, they will assure that inspection and certification of buildings are performed by independent and qualified staff. The Commission, with the support of a committee, is liable for customizing the Annex to technical development. The Annex involves the framework for the estimation of buildings' energy performance and the requirements for checking central air conditioning systems and boilers [26].

The Directive constitutes section of the Community enterprises on global warming (involvement as a part of the Kyoto Protocol) as well reliability of supply (the Green Paper-security of supply). First of all, the Community is growingly relying on external sources of energy and, secondly, emissions are on the raise. The Community can have slight potency on energy supply, however can effect energy consumption. Diminishing energy demand by upgrading energy efficiency is one applicable solution for both of the forementioned troubles. Energy demand for building service systems corresponds to about one third of cumulative EU energy demand. The Commission regards that, giving precedency in this area, remarkable energy savings can be attained, accordingly promoting to achieve objectives on climate change mitigation and supply security. Community-level measures must be constructed for the purpose of dealing with such Community-level challenges. The Directive is a tracing to the measures concerning boilers (92/42/EEC), building materials (89/106/EEC) and Specific Actions for Vigorous Energy Efficiency (SAVE) programme provisions on buildings. Although there is earlier directive related with the building energy certification (Directive 93/76/EEC legislated away by Directive 2006/23/32/EC), it was accepted in a distinct political status prior the Kyoto protocol and the uncertainties related with the energy supply security in the Union. It does not have the identical objectives regarding with the Directive of 2002/91/EC. The recent one is an adjunct tool, submitting tangible steps to fill any existent gaps [26].

3.2.2 Directive 2010/31/EU (EPBD-recast)

In 2009, the Commission introduced the recast of the EPBD (2010/31/EC, EPBD Recast) for the purpose of strengthening some earliest EPBD provisions and enabling further energy savings as specified in the 2006 Action Plan. The primary target of the recasting EPBD was to assure that national Minimum Energy Performance Requirements accepted by Member Nations had comperable ambition grades in respect of energy savings and ecological impacts mitigation. The reason for this is some national standards were not cost-efficient and ambitious enough [27]. For this purpose, Article 5 of the EPBD recast presented the cost-optimal method as the leading precept in order to set building energy uses and Article 9 introduced the aspect of ‘‘nearly zero-energy buildings” (NZEBs) pursuant to which whole newly constructed private-ownership buildings will have to conform to nationally described NZEB standards until January 2021 [24]. The requirements are given below with regard to “Annex I” given in this directive [21];

a) The common widespread framework for a method in order to estimate the integrated energy performance of building units and buildings,

b) The implementation of minimum necessities to the energy performance of new building units and buildings,

c) The implementation of minimum necessities to the energy performance of:

i. Building elements, building units, and existent buildings which are exposed to major retrofit,

ii. Building elements which constitute part of the building envelope and that have a remarkable effect on the building envelopes’ energy performance as they are replaced or retrofitted,

iii. Building service systems whenas they are mounted, replaced or improved,

d) National plans in order for enhancing the figure of nearly zero energy buildings;

e) Energy certification of building units or buildings,

f) Routine check up of air-conditioning and heating equipments in buildings,

g) Autonomous control mechanism for energy performance certificates and check up reports.

3.2.3 Directive 2018/844/EU

In order for implementing the Energy Union Strategy, in November 2016 the Commission introduced a series of measures (the Winter Package) to amend the EPBD and EED and coordinate them to the latest 2030 objectives of energy and climate. The EPBD amendment process initiated at the late of 2016 and finished on 30 May 2018 with the acceptance of Directive 2018/844/EU. As well, the Commission introduced database for new structures– the EU Building Stock Observatory – in order to monitor the energy performance of buildings through Europe. For the purpose of enhancing and stimulating the amount of direct investment for the refurbishment of the existing buildings, the Commission also introduced financial plan that targets to launch an extra 10 billion € for private and public funds. The novel Directive (2018/844/EU, EPBD) was published on 19th June 2018, and on 9th July 2018 the updated provisions come into force. This update presents focused amendments to the ongoing EPBD intended to speed up the cost-effective refurbishment of existent buildings, so as to possess eco-friendly building stock until 2050 and the mobilization of investments to attain this target [28]. The update also brings out novel provisions to improve smart technologies and building service systems, involving building automation technology. It was declared for Member Countries to integrate the Directive into their national regulations until 10th March 2020. Particularly, the 2018 EPBD involves the below provisions [24]:

a) Member States shall develop more efficient long-run refurbishment strategies (LTRS), determining a sufficient set of economic measures and making consultation with stakeholders in the providence and application of their strategies.

b) Encourage cost-efficient deep refurbishment stimulating more holistic approaches in projects of energy refurbishment. The potential of employing Building Renovation Passports (BRP) and trigger points (key instants such as; sale, rental, change of usage, extension, maintenance or repair) in the lifetime of the building is also provided. It is necessary for Member States to describe these trigger points in the context of their LTRS and in compliance with national implementations. The concept of an optional plan for peculiar BRP is comprised for the first-time in the LTRS framework of the necessities which Member States organize for their existing building stock.

c) The Commission will evolve joint European plans for evaluation the smart readiness of structures, that will be noncompulsory for Member States.

d) Information and communication technologies (ICT) and smart technologies in buildings will be supported, for instance through necessities on the installation of building control and automation systems and on instruments which regulate the internal temperature from the building scale below to the room scale enabling that buildings serve in use efficiently.

e) E-mobility will be promoted by presenting minimum necessities for electric recharge locations over a definite measure of the building and other minimum infrastructure are presented for lower sized buildings.

f) National energy performance necessities of Member States shall be declared in ways which enable cross-national comparability; enhancing the quality and transparency of the EPCs.

g) Health and wellness of building occupants' will be supported, for example through an enhanced consideration of ventilation and air quality.

h) Combatting energy shortage and alleviating the household energy invoice by retrofitting older structures.

3.2.4 The Energy Services Directive (ESD) and Energy Efficiency Directive (EED)

The Energy Services Directive (ESD – 2006/32/EC) is commonly regarded as tracker of the SAVE Directive and the antecessor of the EED. The ESD, adopted in 2006, set up the basis for establishing indicative national objectives corresponding to minimum 9% of energy savings by 2016 and presented reporting compulsories through the formation of National Energy Efficiency Plans (NEEAPs) [29, 30]. Although the ESD did not contain any typical focus on constructions, it involved some provisions on billing and metering, energy performance contracts and financing. These provisions were consolidated in the following EED, reviewed below [24].

The regulatory foundation of the 2020 objectives and other related provisions agreed in the Energy Efficiency Action Plan-section 4 (2011) was built up in the Energy Efficiency Directive (EED, 2012/27/EU) that was accepted in December 2012 within the framework of the European Energy and Climate Package [31].

The Directive determined the 20% energy efficiency objective in respect of final and absolute primary energy use levels by 2020 and needed Member States (MSs) to provide EU objective by building their national own energy efficiency targets. Whereas these objectives are of indicant nature, the Directive establish various obligatory EE policy measures to assist achieving the objective, paying attention of whole phases of the energy string from manufacture to end use. The most significant EED articles on structures involved the regulations for the public sector to retrofit its central administration buildings (Article 5), the setup of billing and metering regulations (Articles 9–11) [32] and development of long-term policies for retrofitting national buildings (Article 4). As well, the Directive also involved provisions to support public sectors' energy performance contracting (Article 18) [33], to eliminate split incentives (Article 19a) and to set up obligatory audits for major companies (Article 8) [34]. Finally, the Directive forced to open up energy marketing to demand-side response (Article 15) and establish Energy Efficiency Obligation Schemes obligating energy firms to accomplish 1.5% energy savings per year for end users

(Article 7) [35, 36]. EED was amended in 2018 (2018/2002/EU) to enable a statutory framework for the 2030 energy efficiency objectives and spread article 7 to 2030 [24].

3.2.5 Long-term renovation strategies (EED Article 4/ EPBD Article 2.a)

In order to benefit cost effective energy-saving facility of energy retrofits within the EU, Member States were demanded to generate long-period retrofit policies with the perspective of mobilising energy saving investments in commercial and residential buildings. These policies, that denoted the first policies of this type, had a leading mission for Member States to make up eco-friendly building stock. The EED did not obligate particular strategy measures/interventions to be involved in the policies nor did it necessitate forming retrofit objectives. The policies were drawn up to ensure [24]:

1. A survey of the states' building stock;

2. Determine key strategies to encourage retrofit;

3. Ensure an assess of the potential energy savings amount and wider advantages;

4. Identify cost-efficient methods by building type and climatic zone;

5. Encapsulate a prospective concept to investing decisions.

Whereas high rate of conformity with the forementioned 5 factors was mostly attained in both the basically presented national policies in 2014 and following updates in 2017 [37, 38], scope, the ambition grade, and depth of analysis changed remarkably within the member countries . Principally, gaps in data regarding non-residential sector were determined besides absence of modelling and ambitious and clear targets. The updated policies of 2017 enabled a more thoroughly examination of countries building stock as well as more stringent scenario analysis of potential intervention alternatives. Otherwise, the evaluation and monitoring of applied strategies and the improvement of particular monitoring indicators kept shortcomings of the policies [144].

As mentioned above, with the revision of the EPBD and EED in 2018, Article 4 partaking in EED was shifted into the amending EPBD Article 2a. In order to solve some of the above weak points, the amended EPBD presented various key changes with the intention of improving the function of these policies as ‘roadmaps’ together with an action plan concerning how to modify their building stock to an immensely energy saving and eco-friendly building stock until 2050, as well favoured breakthrough for the years 2030 and 2040. Despite the novel policies are not necessitated to comprise quantifiable objectives, they must be promoted by appreciable advancement indicators and must describe how they assist to the cumulative 32.5% energy saving objectives for 2030 (in the context of the application of the EED). It advances further by highlighting that the policies must enable the cost-effective modification of existing building stock into nearly zero energy buildings (NZEBs), moreover a provision comprised in Article 9.2. A special attention is also paid for segments of the national building stock that has poor energy performance, measures to diminish energy poverty and combats to speed up energy efficiency profits in public structures [24].

3.2.6 Central government buildings (EED Article 5)

In order to strengthen the function of the public sector in the green energy conversion, Member States were demanded to retrofit 3% of the cumulative floor area of cooled and/or heated constructions occupied and owned by their central government every year for the purpose of satisfying the minimum energy performance necessities determined in implementation of EPBD Article 4. In order to ensure more pliancy to Member States, the EED enabled an alternating path under the case that comparable energy savings to the ones produced by obligatory retrofits are attained through else cost-effective measures involving behavioral change measures and deep retrofits [24].

3.2.7 Split incentives (EED Article 19a)

In regard of addressing split incentives in the construction industry, the EED Article 9a asked for Member States to make evaluation and, if needed, adopt proper measures to eliminate regulative and nonregulative impediments against energy efficiency.

Whereas the EED does not obligate particular measures to strive split incentives, it points out various feasible solutions involving precepts for sharing costs and profits between owners and hirers and measures arranging decision-making steps in multi-owner premises. Measures for tackling split incentives involve regulative measures - e.g. minimum energy performance requirements in hired premises and rent law amendments, administrative regulations (e.g. revisions in administrative organization of commonly-owned apartments) and several fiscal and financial incentive plans [39-41]. Since the EED did not specify any compulsory actions, an evaluation was performed to determine the development towards practicing EED Article 19, has demonstrated unsteady improvement by Member States in addressing the matter of split incentives [39]. Several member states still have no pertinent measures in valid measures, emphasizing the necessity for further strategy action in this field [24].

3.2.8 Metering and billing (EED articles 9–11)

In order to support energy savings by means of behavioural change, the EED (2012/27/EU) presented an obligatory requirement of consumption-depending cost share and billing of cooling, heating, and hot water in multipurpose and multi-apartment buildings with common cooling/heating systems. Even though the EU has supported energy use metering for energy consumption since 1976/1977, the EED constitute the juridical framework for precise metering and billing in order to monitor individual energy use in multipurpose and multi-apartment buildings in the EU. Pertinent articles involve: Article 9 on energy use metering, Article 10 on energy billing data and Article 11 on price of accessing to metering and billing data. Owing to the fact that variances in climatic environment, user habits and building stocks, EU Member States accepted seperate allocation principle which induced, in some situations, to a sequence of legal, technical, and user safeguard subjects [40]. Thereafter, these were handled in 2018 together with the provisions of the amended EED, which presented more robust principles on metering and billing of heating energy by providing clients more obvious rights to obtain more often and more beneficial data on their energy use [24].

3.3 Building energy performance standards and regulations used in Turkey

3.3.1 TS 825 Thermal Insulation Requirements for Buildings

In order to determine and explain the rules of thermal insulation in buildings TS 825 was revised by taking into account EU standards and published in the Turkish Official Gazette on 14 th June 1999 with number of 23725 by Ministry of Public Works and Settlement, as well entered into force on 14 th June 2000. The standard was revised in 2008 and published in the Turkish Official Gazette with number of 26979 and it has been included in the scope of mandatory standard. The revised standard was amended in 2009 and published in the Turkish Official Gazette with number of 27291.

The target of the standard is to limit the amount of energy consumed in the heating of the buildings, thus to enhance the energy savings and to identify the standard calculation technique and values to be employed during the estimation of the energy demand. The standard can also be employed for the below targets:

a) By implementing the calculation technique and values detailed in the standard to the several design alternatives pertaining to the structure to be built newly, identifying the design alternative which will ensure the favorable energy performance,

b) Identifying the net heating energy demands of the existing structures,

c) Before the implementation of a refurbishment project to a existing structure, identifying the amount of energy savings that the energy saving measures which can be implemented will ensure,

d) By estimating the energy demand of the various structures which will typify the building sector, calculating the future energy of building sector at the nationwide.

3.3.2 Building Energy Performance Regulation

The regulation prepared by the Ministry of Public Works and Settlement and published in the Turkish Official Gazette on 5 th December 2008 with number of 27075, as well entered into force on 5 th December 2009. The concepts in the Energy

Efficiency Law are explained in detail within this regulation. The regulation was prepared based on EUs Energy Performance of Buildings Directive (2002/91/EC), with the entry into force of this regulation, Thermal Insulation Regulation in Buildings (published in the Turkish Official Gazette 09 th October 2008 and numbered 27019) has been repealed.

In the regulation, procedures and principles related with avoidance of energy wastage, efficient and effective usage of energy in buildings, and protection of the environment have been detailed. Besides the regulation involves authorizations and regulation of authorizations, building architectural design and applications concerning building energy performance, thermal insulation and air-tightness, heating and cooling system design and applications, air conditioning and ventilation system design and applications, mechanical installation, automatic control systems, lighting systems and electrical installation, use of renewable sources and NZEB, Energy Performance Certificate (EKB) , building inspection and periodic maintenance, annual energy demand.

Within the scope of the regulation, energy performance certificate was defined in order for classifying energy performance and greenhouse emissions of buildings. Energy performance certificate involves seven energy performance and greenhouse emissions grades (from A to G, A represents highest energy performance grade while G is the lowest). Building Energy Performance Software (BEP-TR) was used in the creation of energy performance certificate for buildings. The first version of the software was BEP-TR1, and it was valid until November 1, 2017. Then, updates were made in the software, BEP-TR2 was put into use. BEP-TR software requires for the buildings, that have received building license certificate after the date of January 1, 2011, must have at least ‘C’ grade energy consumption and carbon dioxide emissions. Energy performance certificate is valid for 10 years from the date of approval. It is essential that energy performance certificate must be prepared for entire volume of the building. Certificate of permission for building use can not be assigned any building that do not have energy performance certificate. After the date of January 1, 2020, Energy performance certificates must be provided as buildings or detached unit of the buildings are bought, hired or sold.

3.3.3 Energy Efficiency Law

The law published in Turkish Official Gazette on 2 nd May 2007. The target of the law is usage of energy efficiently, avoidance of waste, to diminish the charge of energy prices on the economy, as well enhancing efficiency in the usage of energy resources and energy in order for protecting environment. In the Energy Efficiency Law; the Ministry of Energy and Natural Resources, the Ministry of Environment and Urbanization, the Ministry of Science, Industry and Technology, the Ministry of Transport, Maritime Affairs and Communications, and the Ministry of National Education have been given responsibilities regarding the regulation of sub-legislation [41]. As well, after the presentation of the law, many lagislations have been entered into force correlating with the law. The main articles in the law regarding the housing sector are as follows [42];

a) Owners of the buildings that have cumulative building area of at least 20,000 m^2 or with an annual energy consumption of 500 TOE or more are appointed as energy managers.

b) In residential buildings with central heating system, the heating cost should be shared according to heating energy consumption rate.

c) A regulation to be collectively developed by the General Directorate and Turkish Standards Institution and entered into force by the Ministry of Public Works and Settlement shall lay down the procedures and principles for the buildings' energy performance which includes norms, standards, criterias for minimum performance, data gathering and control phases on architectural design, hot water, cooling, heating, thermal insulation, lighting, and electrical installation in buildings used for residential purposes (having cumulative construction areas as stated in the regulation), service buildings, and commercial buildings. In event of acts conflicting to the provisions of the regulation, the responsible administration shall not allow the usage of such buildings.

3.3.4 Regulation on Increasing the Efficient Use of Energy Resources and Energy

The regulation published by the Ministry of Energy and Natural Resources, in 2008, in order for suggesting procedures and principles of enhancing the efficient utilization of energy sources and energy, to avoid wastage of energy, to diminish the charge of energy expenses on the economy and to preserve environment. The regulation has been amended in 2014. The Regulation encompasses procedures and principles relevant to empowering professional chambers, universities, and consulting companies of energy efficiency in managing and spreading energy efficiency services and activities, energy administration implementations, responsibilities and tasks of energy administrator and energy administration departments, education and certification affairs pertinent to energy efficiency, energy efficiency projects, sustentation of projects and implementation of voluntary agreements, governance of demand side, improving energy efficiency in the production, conveyance, distribution, storage and use of energy, waste heat recovering, improving energy efficiency at open fields enlightening, incentives related with the usage of alternative fuels such as hydrogen and bio-fuel, and governmental sanctions. In the regulation, the articles related to the buildings are included under the title of 'Measures to Improve Energy Efficiency'. These articles are;

a) Management of commercial and service buildings (in the absence of building management; the building owner), that have cumulative construction area of more than 20,000 m^2 or a cumulative yearly energy consumption of more than 500 TOE, as well management of public sector buildings that have cumulative construction area of equal or more than 10,000 m^2 or yearly energy consumption of at least 250 TOE have made survey to energy efficiency consulting companies , if there are personnel with building survey-project certificate among its employees, the personnel performs the survey itself,

b) Attaining the highest energy efficiency in cooling, heating, air conditioning, and heat transfer,

c) Implementing thermal insulation on cold and hot surfaces in compliance with standards, reducing unwanted heat losses or gains by insulating all units which produce, distribute and use heat,

d) Analyzing heat pump, renewable energy, and cogeneration systems,

e) Using highly efficient lighting systems and utilizing more daylight,

f) Using double glazed window systems having low-emissivity.

3.3.5 Communique on the of National Calculation Method of Energy Performance Certificate

The Communique was published in the Turkish Official Gazette on 7 th december 2010 with number of 27778 and amended on 1 th January 2017. It was prepared within the scope of the Regulation on Energy Performance in Buildings (published in the Turkish Official Gazette on 5 th December 2008 with number of 27075) in order for evaluating the impact of all parameters affecting the energy consumption of existing and newly constructed buildings such as dwellings, offices, schools, health facilities, hotels, shopping and commercial centers. Also it was aimed to enable the publication of the building energy performance computation technique developed to evaluate and determine the energy performance class. In the determination of energy performance of structures, the calculation procedure presented in the annex of the Communique is applied. Energy Performance Certificate is prepared in the form and content attached to the Communique. Furthermore, in order for determining the principles and procedures regarding the trainings to be given to experts and trainers who prepare energy performance certificates, ‘The Communique on Training and Audit of Energy Performance Certificate Experts’ has been entered into force by Turkish Official Gazette on 7 th January 2021.

CHAPTER 4
PARAMETERS EFFECTING BUILDINGS’ ENERGY CONSUMPTION AND CO_2 EMISSIONS

Energy consumption in buildings is a numerical expression representing the level of building energy performance predicted in new buildings and measured in existing buildings for the buildings’ energy requirements such as heating, cooling, electricity devices, ventilation, lighting and hot water. Parameters affecting building energy consumption and CO_2 emissions can be evaluated in two categories as environmental parameters and building-related parameters [43].

4.1 Environmental (Climatic) parameters

The climatic parameters related with the location of the buildings are one of the most significant factors influencing the amount of energy used and hence the amount of CO_2 outputs. Temperature, humidity, wind speed and direction, precipitation amount, sunshine period, solar radiation, atmospheric pollution are important climate parameters [43].

4.1.1 Parameters related with exterior ambient

4.1.1.1 Exterior ambient temperature

Long-term average hourly outside temperature (˚C) is used as data. Hourly temperature values is used to calculate the amount of heat passing through envelope of the building, via conduction and convection, by considering the hourly thermal behavior and the hourly operating schedule of the building. Exterior ambient temperature is one of the important climatic parameters that influences instantly heating and cooling load calculations [43].

4.1.1.2 Solar radiation

The solar factor, one of the most crucial determinants affecting the building energy balance, is calculated hourly. Hourly solar radiation on the horizontal plane (W/m²), obtained as meteorological data, is used to calculate the hourly solar radiation incident on the surfaces in all directions (360˚) and all inclination angles with the algorithm included in the calculation method. The solar altitude angle and solar azimuth is calculated for each day and each hour of the year relying on the latitude of the building [44]. Solar radiation is important in heating and cooling periods owing to the solar gain propery. The amount of solar radiation varies through the direction and location of the building, the angle of the surface, roughness of the material surface, the heat absorption and reflection capacity of the material and the pollution of the atmosphere [43].

4.1.1.3 Outside humidity

Relative humidity value is used to evaluate the effects of humidity value of fresh air taken into building with natural ventilation on interior comfort conditions and the latent air conditioning loads that will come into mechanical system. Relative humidity value is the daily average value for each day considered [44].

4.1.1.4 Wind

Wind is a current of air, always transferring from a high pressure zone to a low pressure zone. Wind should be utilized properly to save energy. Wind flow enables to enhance comfort level by means of its cooling and moisture reducing property in hot climates, as well it causes heat loss in cold climates by leaking from the building envelope [45].

4.1.2 Parameters related with indoor ambient

Since the resultant of optimum values of indoor climatic parameters creates climatic comfort, indoor climatic variables are considered as outputs of the design. These parameters are indoor air temperature, interior surface temperatures, indoor air movement and indoor air humidity [46].

4.1.2.1 Indoor ambient temperature

The dry-bulb temperature of the ambient air is the most important parameter that determines the amount of heat exchange by convection between the indoor environment and people. Heat exchange between the people and surrounding environment continues until temperatures of a body surface and ambient air are balanced. As a consequence, it can be said that the body surface temperature is one of the most important parameters affecting the climatic comfort of the people [47].

4.1.2.2 Inner surface temperature

The long-wave thermal radiation governs the heat exchange of a human with surrounding environment. As thermal radiation owing to the temperatures of the surfaces surrounding environment comes to the fore in indoor areas, the effect of solar radiation is important in open areas. Since, heat exchange occurs by radiation between the surfaces surrounding a closed volume and the environment within the volume, inner surface temperatures that are determining factor in indoor air temperature, are the most crucial factors influencing climatic comfort [46].

4.1.2.3 Indoor air flow

Since the speed of air flow affects the heat transfer coefficient between any surface and the air, it is a parameter that governs the amount of transferred heat via convection between people and their surrounding environment [48].

4.1.2.4 Indoor air humidity

Humidity level in the air is an environmental parameter that affects the amount of heat lost from the human body by the diffusion of water vapor from the skin, the evaporation of perspiration from the surface of the skin, and the breathing [48].

4.2 Parameters related with building

Parameters relevant to the building control the development of indoor climatic conditions relying on the external climatic conditions. Therefore, these parameters have a common aspect such as being the determinants of indoor climatic conditions and air conditioning loads as well as genereated CO_2 outputs. Designing energy-efficient buildings and reduction of related CO_2 outputs can be achievable only if proper values of these parameters [49].

4.2.1 Building ranges

Design criterias such as solar radiation and wind/air flow incidents should be regarded in the design of open fields between buildings. In order to profit from these criterias in passive climate design, optimum spacings between buildings should be determined relying on the dimensions of the buildings. So as to obtain the maximum benefit from solar radiation, building spacing should be equal or greater than adjacent buildings' and other obstructions' the longest shadow length . When determining the building spacings, intermediate hours (out of sunrise and sunset times) should be considered in terms of land slope, land direction and settlement density. Building spacings in the direction of the prevailing wind should be determined by taking into account the trace distribution behind the buildings regarding heat loss from the building surface depending on the speed of the wind [50].

4.2.2 Building form

Building form is a crucial determinant that affects heat loss and gain. Building form can be described such geometric parameters which are important design factors; building height, the ratio of the building length to building depth (shape factor), the ratio of building height to building length, facade slope and protrusions, roof type and slope, etc. The amount of heat loss-gain for the buildings varies through surface to volume ratio forming the spaces. The selection of the form of the buildings relies on several parameters and the building designs must performed with regard to these parameters. Principal parameters are; latitude, solar radiation and wind factor (prevailing winds, pace of winds) [45]. In general, buildings having small form factor rates are favorable as the surface area value is quite low with regard to building volume which results in compact buildings to be approved. These kinds of constructions have less energy demand due to fact that lower surface area causes to low heat dissipation from the walls, roofing and floor to the ground. Mainly, in the mild and hot climatic conditions, these kinds of constructions have been highly demanded [51]. In Figure 4.1, volumes of the same size were created with various geometric forms. The surface area of the cube was accepted as 100% and compared with the surface areas of other geometric forms. The lowest outer surface area (96%) is that of the hemisphere. Round (spherical and dome-like) forms have the least surface area per unit volume and thus they have the highest energy saving capacity [52]. But, if the concerns related with construction and use of spherical and dome-like forms is considered, the smallest surface area/volume ratio is achieved in the cube [53]. In the volume where the cube is halved, the surface area increases by 33%, as well where the cube is divided into 8 cubes, the surface area increases by 100%.

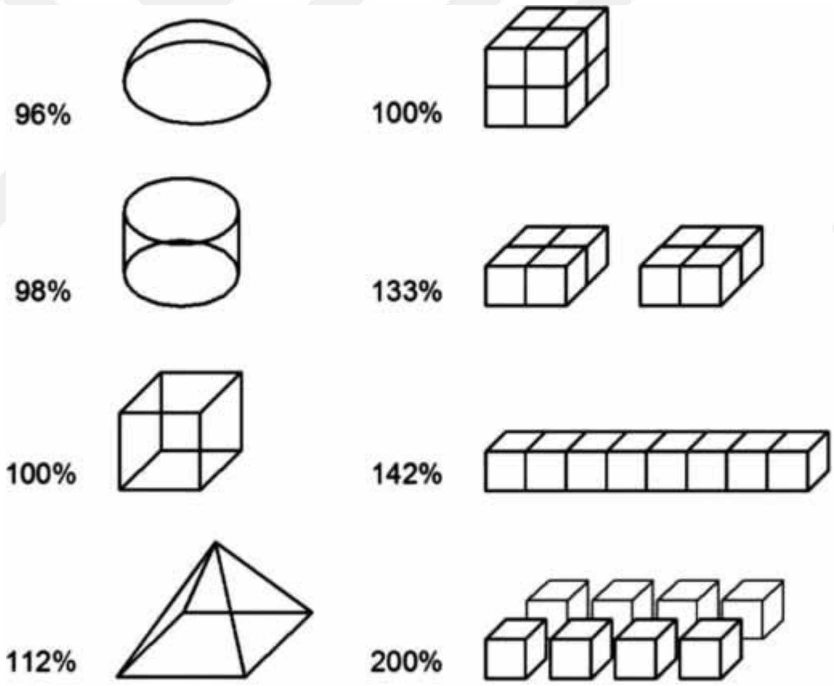


Figure 4.1 The exterior surface areas of buildings of several three-dimensional forms with the equivalent volume [52, 54]

In the design of building, the excessively moving exterior contours in the plan increases the building surface unnecessarily causing it to grow, so that the heating energy for cold climatic regions increase. All architectural design forms oriented in the north-south axis should not be preferred due to fact that those have wide east and south facade in winter and summer conditions (See Figure 4.2). Almost in all climatic zones and latitudes the buildings oriented east-west direction provides controlled solar gain in their wide southern facade, while on the northern facades in order to minimize heat loss they offer the most suitable solution (See Figure 4.3). Optimization of form length depends on climate type [50].

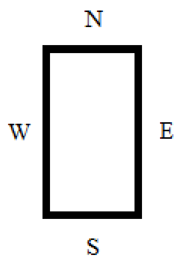


Figure 4.2 Building forms oriented in the north-south axis [50]

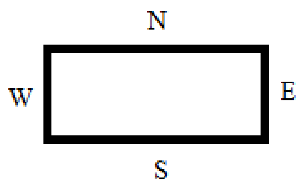


Figure 4.3 Building forms oriented in the east-west axis [50]

4.2.3 Building orientation

Since external climatic factors such as solar radiation and wind vary according to direction of the building, the orientations of the envelope components enclosing the building volume will control the extent of solar radiation hitting to the building envelope and therefore the mean radiative temperature. This case will have an influence on the amount of heat crossing through the building; the interior surface temperature of the envelope and thus the interior ambient temperature also vary. As the interior ambient temperature varies relying on the solar radiation potency on the exterior surface of the envelope and the amount of heat crossing through the envelope, it is one of the most substantial artificial environmental parameters which influence the energy use required to sustain climatic comfort and thus the amount of CO_2 outputs [55]. Benefits gained from optimal orientation of buildings as given below [56]:

- It is a low-cost energy efficiency measure which is applicable in the beginning phases of project design.
- It diminishes the energy consumption.
- It diminishes the need for more complex passive solutions.
- It enhances the performance of other sophisticated passive technologies.
- It enhances the amount of daylight gained, alleviates the energy use for artificial lighting, and contributes less to the interior heating energy demand of the building.
- It boosts the performance of PV collectors.

4.2.4 Location

The location of building specifies the coordinates of the building on the earth plane. It is essential for proper energy performance analysis, especially in terms of solar gains, to identify accurately buildings' location, latitude, longitude and altitude values [43].

Building location is influential design parameter with the impact of sub-variables such as the slope of the ground, the direction it faces and vegetation cover for climate control and preventing air pollution. Properties related with topography of the land causes modification in the effects of climatic elements and the period of those, consequently the impacts of the climate on the buildings. Such effects of topography on the climate control the energy demand for heating and cooling and thus, the amount of CO_2 outputs. Due to fact that these parameters, that vary according to distinct climatic regions, are determined by the climatic conditions prevailing in those regions and the climatic demands of the people, enables to minimize the energy consumptions and accordingly the amount of CO_2 outputs [55].

4.2.5 Optical and thermophysical properties of the building envelope

The climatic conditions within the interior volume and heating and cooling energy loads vary depending on the cumulative amount of heat gain and loss from the building envelope. Thus, the optical and thermophysical properties of the building envelope also affect both interior climatic conditions and heating and cooling energy loads. The optical and thermophysical features affecting heat transfer of the building envelope, consisting of transparent and opaque components, can be reported as; total heat transfer coefficient of transparent and opaque components, time lag and decreament factor, transmittance, absorption and reflectivity coefficients of opaque and transparent components against solar radiation, and transparency ratio.

4.2.5.1 Total heat transfer coefficient of transparent and opaque components

Total heat transfer coefficient (U) of the building envelope is a thermophysical property of both opaque and transparent components, and expressed as the total amount of heat flow of two parts of a building component that separates two different environments while the temperature difference between the surfaces is 1 °C, per m² of surface area in 1 hour [49]. Total heat transfer coefficient for opaque components can be calculated by the Eqn. (4.1) [57]:

$$U_0 = \frac{1}{\frac{1}{a_i} + \frac{d_1}{\lambda_1} + \frac{d_2}{\lambda_2} + \cdots + \frac{d_n}{\lambda_n} + \frac{1}{a_d}} \tag{4.1}$$

U_0 : total heat transfer coefficient of the opaque component, W/m²°C

a_i ,a_d : internal and external surface thermal conductivity coefficients, W/m²°C

$d_1, d_2, \dots, d_n$: thicknesses of materials which constitute the opaque component, m

$\lambda_1, \lambda_2, \dots, \lambda_n$: the thermal conductivity coefficients of the materials which constitute the opaque component, W/m°C

4.2.5.2 Time lag and decreament factor

At the cross-section of the exterior wall of a building, various temperature figures are existent throughout any moment of a one-day interval. These figures are function of exterior temperature, interior temperature and components of the wall layers. As the exterior temperature variates periodically throughout a one-day interval, there will be new temperature figures at any moment of the day. In the course of transient phase, a heat wave propagates within the wall from exterior ambient to inside and the amplitude of the these waves indicates the temperature extents, as well wavelength of the waves indicates the time. The wave amplitude on the exterior surface of the wall is relied on convection and solar radiation between the exterior surface of the wall and ambient weather. During the wave propagation within the wall, its' amplitude will diminish relying on the material property and the wall thickness. As this wave contacts with the interior surface, the amplitude of which will be significantly lower than the magnitude it has at the exterior surface. The time required for the heat wave to spread from the exterior surface to the interior surface is called as ''time lag'' and the lowering ratio of its amplitude throughout this phase is called as ''decrement factor'' [58, 59]. Decrement factor can be stated by the Eqn. (4.2) [48]:

$$f = \frac{t_{oim} - t_{oio}}{t_{odm} - t_{odo}} \tag{4.2}$$

t_{oio}, t_{odo} : daily average values of interior and exterior surface temperatures of opaque elements, °C

t_{odm}, t_{oim} : maximum temperature values on its inner and outer surfaces of opaque elements, °C

4.2.5.3 Transmittance, absorption and reflectivity coefficients of opaque and transparent components against solar radiation

Transmittance, absorption and reflectivity coefficients correspond to the ratio of solar radiation transmitted, absorbed and reflected by the component, respectively to the total solar radiation on the components' exterior surface. These coefficients are unitless in the building envelope [60]. Coefficients of transmittance (τ), absorption (a) and reflectivity (r) are unitless and can be calculated by the Eqn. (4.3):

$$\text{For the opaque envelope components; } a_o + r_o = 1 \qquad (4.3)$$
$$\text{For the transparent envelope components; } a_c + r_c + \tau_c = 1$$

Where a_o denotes to absorption coefficient of opaque components, r_o denotes to reflectivity coefficient of opaque components, a_c denotes to absorption coefficient of transparent components, r_c denotes to reflectivity coefficient transparent components, τ_c denotes to transmittance coefficient of transparent components.

4.2.5.4 Transparency ratio

It is the ratio of the buildings' transparent component surface area to the whole envelope surface area. Since the amount of heat transferring within transparent and opaque components is different, it is a parameter which affects the amount of heat transferring within the envelope of building [60].

4.3 Parameters related with heating and cooling system of the building

The heating and cooling system of the building is one of the most significant design parameters that straightly affects the energy consumption of the building and the related CO_2 emissions. The type and efficiency of heating and cooling device, type of fuel, type of distribution system, the type of fluid that transmits the heat are basic variables that control the amount of energy consumption and CO_2 emissions of the building. The accurate decisions about these variables will diminish energy consumption so that allows decrement of CO_2 emissions [46].

CHAPTER 5
HEAT TRANSFER IN BUILDING ENVELOPE

5.1 General

The flow or transport of energy in the state of heat is usually called as 'heat transfer'. Heat transfer will proceed provided that there is a temperature imbalance in the ambient (or between two media) and terminates as the system has attained thermal equilibrium. Heat transfer occur in three distinct ways; conduction, convection, and radiation [61].

Considering time criteria, heat flow can eventuate in accordance with either transient or steady state conditions. Steady state conditions occurs both the heat flow and the temperature at any particular position in the physical system keep constant with regard to time [62]. A model of steady state heat transfer is a response of building on a cold day whose rate of heat loss balances the rate upon which it is heated, thus its interior temperature is maintained. On the other hand, heat flow is expressed as transient as its direction or magnitude variates with regard to time. In accordance with transient conditions, heat inputs and releases the physical system at varying ratios, and the spatial dispersion of temperature through the physical system also remains fluctuating with time. Representation of transient heat flow case is the thermal behaviour of the formerly indicated building in free-running state (i.e. when its heating device is deactivated); the temperature steadily declining prior to ambient temperature reaches equilibrium [63].

5.2 Steady state heat conduction

Conduction is the flow of energy within the matter from more energetic molecules to less energetic ones by virtue of contact between the molecules. It takes place in solids, liquids and gases. Conduction in solid materials is caused by a combination of the energy transferred by free electrons and molecular lattice vibrations. In liquids and gases it is caused by the impingement and diffusion of the molecules throughout their random movement [61].

Analyzing a homogeneous floor slab having a thickness of L, a surface area of A and varying temperatures on each face. The one-dimensional steady-state conductive heat flux through the slab can be stated by the Fouriers' law (see Figures 5.1 and 5.2):

$$q = -\lambda \frac{T_1 - T_2}{L} \tag{5.1}$$

Fourier's law can be stated in a differential form as:

$$q = -\lambda \frac{dT}{dx} \tag{5.2}$$

Assessment of the thermal conductivity of gases and liquids necessitates stable medium (no radiation or convection).

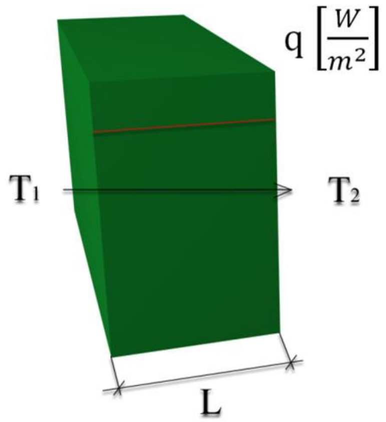


Figure 5.1 Conduction of heat within a slab [61]

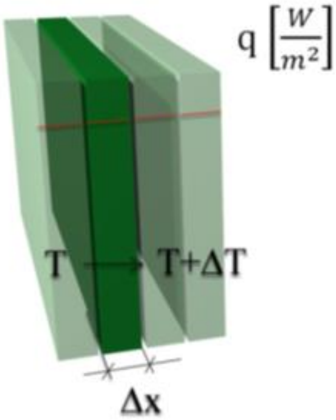


Figure 5.2 Portion of a slab [61]

5.3 Heat capacity

Thermal mass, or heat capacity, in Eqn. (5.3) corresponds to the buildings' heat storing capacity, in the per unit area approximation this becomes Eqn. (5.4). For composite sections, i corresponds to each homogeneous section with n homogeneous sections in the system [64].

$$C = \sum_{i=1}^{n} m_i c_i \tag{5.3}$$

$$HCA = \frac{C}{A} = \sum_{i=1}^{n} \rho_i c_i \delta_i \tag{5.4}$$

where C denotes to heat capacity (J/K), c denotes to specific heat capacity (J/kgK), HCA denotes to heat capacity per unit area (J/K m^2), m denotes to mass (kg), δ denotes to wall sublayer thickness (m), and ρ denotes to density (kg/m^3).

Relied on its location, thermal mass of buildings can be categorized into two main types, i.e. the exterior thermal mass and the interior thermal mass [65]. The exterior thermal mass exposes straightly both indoor air and ambient. More clearly, the exterior envelope components such as roofs and exterior walls fall into this classification. They contact the indoor environment and the outdoor environment. The interior thermal mass, such as interior concrete partitions and furniture does not expose straightly to the outdoor air but only to the interior environment [66].

5.4 Heat balance

In the present context the heat content and the heat flux denoted by e(x,t) and q(x,t), respectively. Figure 5.3 shows the heat balance through a definite thickness ($x < x' < x + \Delta x$) of a body at a time period of t and t + Δt. In the figure below the heat flux reaching the left boundary is bigger than the heat flux moving out the right boundary; hence the heat content of the body will enhance [67].

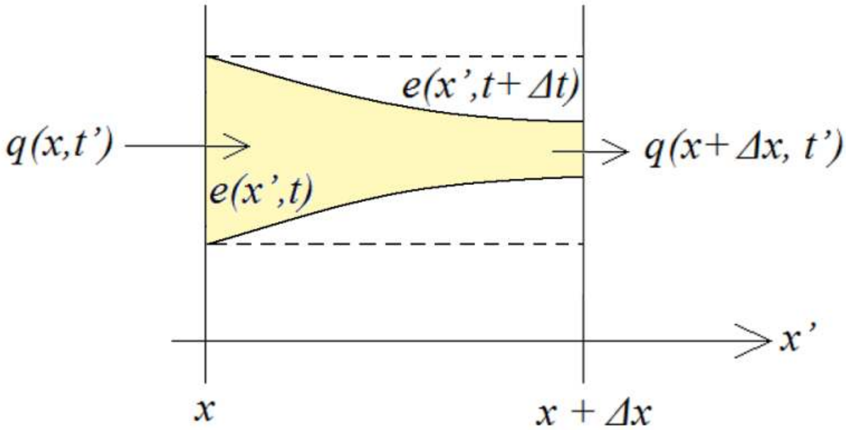


Figure 5.3 Graphical representation of a spatial change in heat flux that results in a change in the heat content [61]

The one-dimensional (1-D) energy balance for a slab section having thickness of Δx is a correlation between the variation of the captured heat and the difference between the input and output fluxes [61].

$$\int_{x}^{x+\Delta x}[e(x',t+\Delta t)-e(x',t)]dx' = \int_{t}^{t+\Delta t}[q(x,t')-q(x+\Delta x,t')]\,dt' \quad (5.5)$$

The correlation for lower values of Δx and Δt can be represented as an approach of the two integrands at their median values:

$$x' = x + \frac{\Delta x}{2} \quad and \;\; t' = t + \frac{\Delta t}{2} \tag{5.6}$$

The correlation then becomes:

$$\left[e\left(x + \frac{\Delta x}{2}, t + \Delta t\right) - e(x + \frac{\Delta x}{2}\ , t)\right] \cdot \Delta x \\ \cong -\left[q\left(x + \Delta x, t + \frac{\Delta t}{2}\right) - q\left(x, t + \frac{\Delta t}{2}\right)\right] \cdot \Delta t \tag{5.7}$$

Equation of heat balance can now be obtained by dividing $\Delta x \cdot \Delta t$ with the preceding formula, and letting $\Delta x \to 0\ and\ \Delta t \to 0$. The formula of general heat balance is then becomes the subsequent partial differential equation:

$$\frac{\partial e}{\partial t} = -\frac{\partial q}{\partial x} \tag{5.8}$$

The left part of the equation is the rate of change of captured heat as a function of t, and the right part denotes the change in heat flux through the x-axis.

Since it is difficult to measure captured heat, it is feasible to work out with temperature instead. The correlation between a change in temperature and a change in captured heat is the volumetric heat capacity:

$$\frac{\partial e}{\partial T} = C_V \tag{5.9}$$

Replacing Eqn. (5.9) into Eqn. (5.8), then we obtain:

$$\frac{\partial T}{\partial t} = -\frac{1}{c_v}\frac{\partial q}{\partial x} \tag{5.10}$$

Combining Eqn. (5.10) with Fourier's heat conduction law of Eqn. (5.5), we obtain the general heat conduction law (for constant thermal properties):

$$\frac{\partial T}{\partial t} = \frac{\lambda}{c_v} \frac{\partial^2 T}{\partial x^2} \tag{5.11}$$

This is the general formula for one-dimensional heat conduction which has to be analyzed under seperate conditions for various thermal problems. Relying on the conditions (boundary and initial values), alternative solutions to Eqn. (5.11) will be derived [61].

5.5 Diffusivity and effusivity

The thermal diffusivity is a material specific property which states how quickly the temperature changes in a material that undergoes a temperature variation on its boundaries. The thermal diffusivity can be formulated as:

$$a = \frac{\lambda}{c_v} \tag{5.12}$$

A material that has a small volumetric heat capacity and a high thermal conductivity value will have a high thermal diffusivity. Moreover, The thermal diffusivity is the relevance between how quickly the temperature shifts in a position, as well how precipitously the heat flux shifts in the path of the flux [61].

A crucial aspect concerning sensible energy storage is the effective material thickness that can be used for storing energy on a certain time period. This value can be estimated in respect of a penetration depth x that relies on materials' thermal diffusivity [61].

$$d = \sqrt{at} \tag{5.13}$$

The penetration depth is the location in a material by which nearly 50% of a temperature variation at the surface has penetrated [61].

The thermal effusivity can be regarded as a measure of how readily a material carries out heat exchange with its ambient. The temperature at the interface of two contacting materials is controlled by the effusivities of the two materials. As an example, if we touch steel or timber, we perceive that steel is colder with regard to timber, because heat is transmitted from our hand to the steel at a greater rate due to fact that steel has a greater thermal effusivity with regard to timber [61].
Thermal effusivity ε can be formulized as:

$$\varepsilon = \sqrt{\lambda c_v} \tag{5.14}$$

5.6 Convection

Convection implies the movement of molecule groups at a distinct temperature. Convection is caused by nature an outcome of displacement (transfer of enthalpy) and appears in a pronounced procedure about to the contact between gases and liquids at one side, as well solids at the other [68]. Two types of convection are existent, those are natural convection and forced convection. Forced convection is arised from an external airstream and can be triggered by, for instance, attic ventilation. On the other hand, natural convection happens because of variation in density between warm and cold air [69].

The amount of transferred heat at a surface caused by forced convection is stated as [61]:

$$q_{conv} = h(T_s - T_\infty) \tag{5.15}$$

Where h denotes to coefficient of convective heat transfer in W/m^{2}K, T_s denotes to surface temperature, and T_∞ denotes to temperature of the fluid fairly distant from the surface.

5.7 Radiation

Radiation relates to heat transfer mechanism sourced by the emission and absorption type of electromagnetic waves. Heat transfer via radiation does not necessitate a medium. Conversely, it is least hindered in vacuum and follows physical laws which diverge strongly from conduction and convection. Thermal radiation diverges totally from convection and conduction. Indeed, radiant heat transfer is arised from electromagnetic waves, that are radiated by every plane warmer than 0 °K and whose sorption by other planes leads to thermal agitation of electrons and atoms in them. Thermal radiation terminology encompasses all electromagnetic waves having a wave length varying through 10^{-7} and 10^{-3} m: Ultraviolet (UV), light (L) and infrared (IR) [68].

The radiation induce energy flow from a warmer to a cooler object. Distinct objects absorb and radiate disparate rate of energy per unit surface area, even when they are in the same circumstances, which means that all materials have certain emission and absorption factors. Absorption denotes to the capability to absorb radiation. Emissivity denotes to the capability to release radiation. Identification of these type of variables involves describing an idealized body, termed as black body. All of the incident radiation is absorbed by black body. The energy of radiation released by a black body can be represented by Stefan-Boltzmann law given in Eqn. (5.16) [61].

$$q_{bb}(T) = \sigma T^4 \tag{5.16}$$

where $\sigma = 5.67\times10^{-8}$ $\mathrm{Wm^{-2}K^{-4}}$ is the constant of Stefan-Boltzmann and T is the absolute temperature of the plane. At equal temperature values, the radiation released by real planes is lower with regard to the radiation released by a black body as:

$$Q_{emit} = \varepsilon \sigma A_s T_s^4 \tag{5.17}$$

where ε denotes to the emissivity value of the surface. The value of emissivity lies in the range of $0 \leq \varepsilon \leq 1$, moreover is an estimate of how closely a surface converges a black body for which ε=1 [61].

The net value of radiated heat which arrives the plane A_1, that interchanges radiation with a much greater plane of A_2 (A_1<<A_2) is:

$$Q = \varepsilon A \sigma T^4 - T_0^4 \tag{5.18}$$

Among two parallel planes, this equation change into:

$$Q_{12} = \varepsilon_{12} A_1 \sigma_s (T_1^4 - T_2^4) \tag{5.19}$$

in which ε_{12} is described by

$$\frac{1}{\varepsilon_{12}} = \frac{1}{\varepsilon_1} + \frac{1}{\varepsilon_2} - 1 \tag{5.20}$$

5.8 Thermal time constant

The thermal inertia can be identified by its thermal time constant τ which identifies the duration for the temperature of the building to variate if the cooling/heating of the building is terminated. The thermal time constant is described as the proportion of a thermal mass of a building and its cumulative heat loss coefficient. Both cumulative heat losses and the thermal masses are complicated parameters to describe in a precise way, however the approximation given below can be used [61]:

$$\tau = \frac{\sum c_v \cdot v}{\sum k} \tag{5.21}$$

In the equation given above, $\sum c_v \cdot v$ is the summation of entire heat capacities within the thermal envelope (each materials' volumetric heat capacity multiplied by its

volume), and $\sum k$ is the summation of entire thermal conductances within the envelope components of the building. The time constant can be employed in a equation in order to determine how the temperature within a building variates if, e.g., the heating system of a building is terminated in the winter.
Variation in temperature is then determined by an exponential equation [61]:

$$\Delta T_t = \Delta T_0 \cdot (1 - e^{-t/\tau}) \tag{5.22}$$

In the equation given above ΔT_0 is the difference in temperature at time zero, and ΔT_t is the internal temperature at a instant t afterwards the heating was terminated. As a basis, the time constant may be identified either by based on calculation regarding construction design data or conducting measurements on building [61].

The particular time constant explanation has own limitation, as it accepts that whole components of a building within the thermal envelope have the identical temperature value. Immediate temperature variations will solely have an impact on the surface layer of materials, as slow variations will have an impact on the entire mass of even massive buildings, and therefore enable an improved thermal storage capacity. Nevertheless, if we evaluate temperature variations which occurs throughout comparatively lasting time intervals, e.g., days, whole components within the thermal envelope will have about the identical temperature value. Another drawback related with the single time constant is that ventilation heat losses has not been involved, however an approximate modification of τ can be produced to involve such effects [61].

Figure 5.4 presents that how the temperature will diminish in a building experienced a 21 °C outer temperature decrease. It is apparent that the temperature of a building with small time constant value will alleviate rapidly, causing the building unconfortable for occupation within shorter than one-day period, while a building with greater time constant, for instance 100 h, can still be confortable for occupation later 2 days. It is important to note that there are two identical circumstances for which Fig. 5.4 and Eqn. (5.21) can be employed: A) The exterior and the interior temperatures are same, however at time zero the exterior temperature is lowered. B) The exterior temperature is low and the building is warmed up till time zero as the heating system is switched off. Circumstance B is more factual for a building in a cool climatic conditions, nevertheless this kind of problems is frequently formulated algebraically like circumstance B [61].

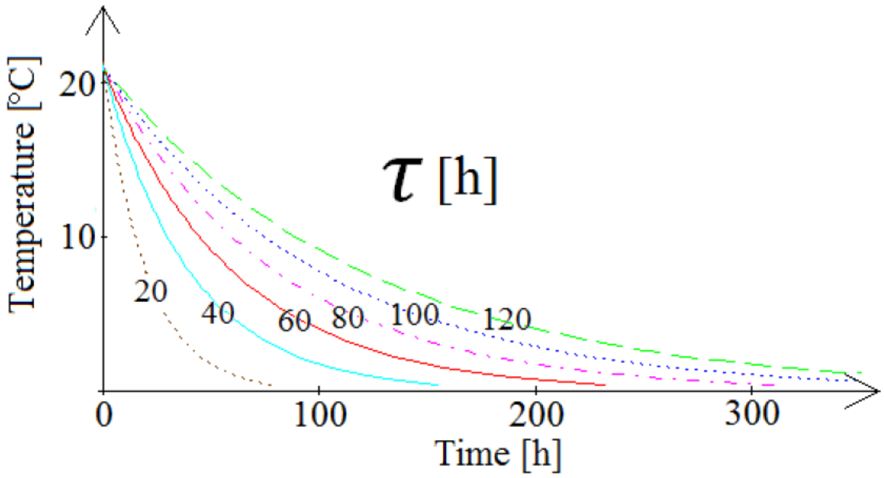


Figure 5.4 The temperature drop of several buildings with various time constants (presented in the figure) as the exterior temperature is 0 °C and the heating system is switched off at time zero (as the interior temperature was 21 °C) [61].

The subsequent reformulation of Eqn. (5.22) can be employed to estimate the instant at which the temperature of a building has diminished to T_i afterwards a switch-off of the heating system [61]:

$$t(T_i) = -\tau \cdot \ln(\frac{T_i - T_e}{T_{i,0} - T_e}) \quad (5.23)$$

in which T_i is the temperature at instant t, $T_{i,0}$ the earliest interior temperature and T_e the exterior temperature.

CHAPTER 6
BUILDING ENVELOPE AND CONSTITUENT MATERIALS

6.1 General

The building envelope, or "shell", or "skin", comprises constructional materials and finishes which encircle space, isolating interior volume from outside. This encompasses floor surfaces, walls, doors, fenestrations, openings and roofs. The envelope must balance needs for daylight and ventilation whereas ensuring moisture and thermal protection suitable to the climate of the region. Envelope design is a crucial determinant for identifying the amount of energy that will be consumed by a building during its' operation [70, 71].

Climate is one of the most significant determinants that affects envelope design. Cold, temperate, hot/dry or hot/moist climatic zones will present distinct design policies. Another significant determinant affecting envelope design is what happens within the building. If the equipment and activity within the building produce a remarkable amount of thermal energy, the heat loads might be mainly sourced inside (generated by equipment and people) instead of outside (generated by the sun). This influences the ratio at which a building captures or dissipates heat. Occupancy and volume of building also have remarkable effects on the requirements and efficiency of the building envelope [71].

Openings are positioned in the envelope to ensure entry to a building, generate sight to the exterior environment, receive solar energy and/or daylight, and provide natural ventilation. The dimensions, form and position of the openings change relying on the task they fulfill in the building shell. Windows can be utilized to control cooling and heating demands and users' comfort by regulating the amount and sort of light which transfers within windows [71].

Decisions regarding construction details have an important task in building envelope design. Construction materials conduct heating energy at various rates. Constituents of the envelope for instance, foundation walls, joists, sills, connectors and studs, among others, can generate pathway for heat energy conveyance, called as thermal bridges which conduct heat throughout the wall assembly. Moreover ground surfaces encircling the structure have an important mission regarding building envelope efficiency [71, 72].

6.2 Traditional envelope materials

Stone, Earth and wood is probably the most ancient known construction material in the earth. It has been utilized in many fields and by most of the communities in history, the oldest use of those in the construction works dating back about 10,000 BC, in Mesopotamia region [73]. Another important materials in traditional construction are Pozzolanas, lime and fired clay based construction materials.

6.2.1 Stone

The authors in Ref. [74] stated that stone is the earliest, abundant and durable construction material which is obtained from nature. When it is obtained near to construction field, it is a low-cost construction material. Various construction materials can be manufactured via processing stone. Stone used in building construction can be categorized into three geological formations: (i) Igneous rocks (for instance; volcanic stones and granite), (ii) Sedimentary rocks (for instance; limestone and sandstone) and (iii) metamorphic rocks (for instance; marble, quartzite, and slate). Among the stone types obtained from nature, ashlar used for regular course masonry works, impermeable stone (e.g., granite) used for damp proofing courses; as well as exterior cladding of walls, rubble is used for foundations, slate utilized for roofing, stone and gravel chippings are used as aggregate for concrete and terrazzo, granular stones used for surfacing bituminous mats, powders used for extending paint, limestone utilized for lime and cement manufacturing. Some of the benefits of stone regarding construction sector can be summarized as; abundantly availability in nature, easily accessibility in highland areas, low investment price for extraction, durability and strength, impermeability of most of stone species to rainfall, and suitability to arid regions and highland due to its' high thermal capacity. Some of the drawbacks can be outlined as; low resistance to seismic events hence possibility of demolition and threatening lives, decay might occur as a result of atmospheric pollution (e.g., as sulphur compounds dispersed in rain water generate sulphuric acid that reacts with carbonate minerals within limestone, causing blisters and skin formation), spelling and efflorescence catalyzed by sea spray and certain kind of salts, damage caused by thermal movement of some type of stones (particularly when fastened rigidly to components with distinct thermal movement, such as concrete), surface damage caused by water that gradually dissolves limestones; or by prolonged cycles of wetting and drying in certain kind of sandstones; or by freezing of water captured in fissures.

The main reasons for the usage of stone as the main construction material in Gaziantep heritage buildings can be stated as [75];

- Stone is a locally obtained material, besides it is very durable and suitable for processing,
- The region is very hot in summer and cold in winter. Masonry buildings enable improvement of interior climate so that inside of the buildings cool in summer and warm in winter.

Masonry types mined from Gaziantep region are Havara stone, Keymık stone, Topaktaşı stone, Minare kayası stone, Karataş stone, red marble. The quarries in the city were Topaktaş region (20 km away) , Gaziantep Karakuyu region (20-25 km away), Bostancık region (40 km away) [75].

The constant width of the stone rows (called kor) in Gaziantep historic buildings is 27 cm. Within the wall, mortar consisting of havara (a kind of limestone) powder, lime and water is used. In the joints between the stones a mixture of lime, keymık powder, ash and hemp fibers were used [75].

6.2.1.1 Havara stone

Havara stone has a small porous structure, the pores of which can not be seen with naked eyes. It has rapid water absorbent property, besides it is not hard so that can be easily mined and processed. Hardness of the stones used in Gaziantep historic buildings is presented in Table 6.1. Havara is lighter than Keymık stone and it has low thermal conductivity. It is light cream colored. It has dust producing property, hence within the building the surface of the stone was covered with wood (called nacar) or it was plastered. It was used in interior spaces with lower building loads and vaults with less openings. At the same time, it is preferred because of its ability to absorb the smoke formed during indoor cooking and tandır stove [76]. Photo of the Havara stone is presented in Figure 6.1.

Figure 6.1 Photo of Havara stone [76]

6.2.1.2 Keymık stone

Keymık is a type of limestone which has started to be dolomitized. It has very few pores and absorbs less water. It has hard structure, extracting it from the quarry, processing it into blocks is laborious process so that it is costly. It was used in exterior environment because of its' load bearing capacity, impact resistance and ability to withstand the factors arising from climatic conditions (frost, rain, temperature differences, etc.) [76]. Keymık stone was used in most of the exterior facade of historic dwellings, stairs, perimeter walls, religious buildings, dome structures, minarets and arches of buildings. The carvings and inscriptions on the exterior facades of historic buildings were made on keymık stone as well as marble [77]. Photo of the Keymık stone is presented in Figure 6.2.

Figure 6.2 Photo of Keymık stone [76]

6.2.1.3 Minare Kayası stone

Minare Kayası stone got its' name because it was used in minarets and mined from Hacı Arap region near to Nizip district. The author stated that the pedestal part of the minarets was constructed with mostly Keymık stone and the upper parts were with the Minare Kayası stone, starting from this point of view Keymık stone is harder than Minare Kayası stone. On the other hand, Minare Kayası stone can be easily shaped when obtained from the quarry, but hardens over time [76]. Photo of the Minare Kayası stone is presented in Figure 6.3.

Figure 6.3 Photo of the Minare Kayası stone [76]

6.2.1.4 Topaktaş stone

Topaktaş stone was obtained from Topaktaş region, located in Gaziantep - Maraş road, during the construction of the Gaziantep railway. Initially, the stone was used primarily in the construction bridge and railway station. Later, the stone was also used by the public buildings [78]. In late period structures of Gaziantep, especially in the buildings of post-Republican period, roughly chipped form of the stone was used [76]. Photo of the Topaktaş stone is presented in Figure 6.4.

Figure 6.4 Photo of the Topaktaş stone in Gaziantep railway station [76]

6.2.1.5 Red marble (Çarpın stone)

The stone is mined in the form of 5-6 cm thick layers from village of Çarpın, located in 20 km west of the city. It was used entrance of dwellings, courtyard, sofa and workbench of shops (see Figure 6.5). It is actually one of the most durable stone for covering building facades [78]. Besides these uses, the stone usually used in floors, monumental structures (mosques) and facades (for decorative purposes). This stone is harder and more durable than Keymık and Havara stones. It is locally known as red marble and called by the name of the region (Çarpın) where it was mined. However, according to petrographic analysis report of the stone samples, it was declared that the stone is fossiliferous limestone [76].

6.2.1.6 Karataş (basalt)

It is called as Karataş because its' color is close to black (see Figure 6.5). It has small porous structure and high specific gravity, also it is hard and resistant to impacts. By using it with Keymık stone, mostly at corner points on the facade in a certain order, a visual richness was given to the facade. The use of the stone especially at the corner points originated from its high strength. This feature of stone enabled jointly use with of white marble and sometimes Çarpın stone, that have similar properties, in order to provide both functional and decorative purposes [76]. The stone has volcanic origin and being one of the hardest stones. It was used in building foundations, facade corners, vertical load bearing members, as well street and floor paving [78]. Currently, the stone is being used for road and pavement paving.

6.2.1.7 White marble (Araban Beyazı)

It is an off-white colored stone that has hard and ribbed structure. Processing of the stone is difficult, as well it can be polishable. The stone does not exactly have marble property, but it was named as white marble in the city because it is harder than the other stone types. It it is known as "Araban Beyazı" in the local dialect. Some stone types in the city are called as the name of the region where it is obtained. From this perspective of view, the stone was probably obtained district of Araban [76]. Table 6.1 presents hardness of the stones used in Gaziantep historic buildings (Note: The figures given for the hardness of the stones are given in order to be able to sort them among themselves. Number 1 refers to the softest type of stone and number 6 refers to the hardest type of stone).

Table 6.1 Hardness of the stones used in Gaziantep historic buildings [76]

Type of stone	Hardness grade
Havara	1
Keymık	4
Minare Kayası	3
Topaktaş	2
Red marble (Çarpın stone)	5
Basalt (Karataş)	6
White marble (Araban Beyazı)	5

Figure 6.5 Sample photo demonstrating Araban Beyazı**,** Çarpın stone and Karataş masonry types [76]

6.2.2 Earth

Earth (soil) is obtained by the degradation of rocks caused by mechanical, chemical and biological processes such as thermal cycles, frost, dew, rainwater, plants and microorganisms. The material originating from the initial decay of the rocks experiences further metamorphosis when it is carried away, deposited as a sediment, compacted by further sedimentation, or altered by biological colonization or chemical processes (diagenesis) [79].

Earth utilized for construction must contain plenty of clay to be plastic when wet and hard when dry, however a surplus of clay must be abstained since it would induce shrinkage and cracking as the wet substance dries [79].

The earth used in construction must contain clay and silt 20-30%, and sand 70-80%. Since old times, other substances have been supplemented to the mixture to enhance the ultimate features of the hardened material. Plant fibers, for instance hay or straw shredded to 5 to 10 cm in length, in order for enhancing mechanical properties of the mixture, particularly tensile strength. Besides manure enhances resistance to damp, obstructing the disintegration of clay particles in a surplus of water. Cement or lime in current earth construction technique enhances both water resistance and mechanical properties. The material acquired by the mixture of up to 10% cement, or 20% lime is termed stabilized earth [79].

6.2.3 Fired Clay Products

Clay is obtained by the grinding and degradation of rock. Clay can be represented as $Al_2O_3 \times 2SiO_2 \times 2H_2O$ in a dry form, that implies vast amount of silicon dioxide. Increase in water content of clay, makes it more workable [80].

Clay can be formed and burned up to 1000 celcius degree. Thereby, water is completely evaporated so the chemical formula changes into $Al_2O_3 \times 2SiO_2$, and this reaction is irrecoverable, more clearly water cannot be remixed into the clay. It has turned into a ceramic substance, with the usage area that have been identical over the time, in construction, on roofs and floors, as tanks and water pipes. As the inside temperature of kilns is raised to further degrees, the clay initiates to swell, transforming into expanded pellets of clay, that in previous years have turn into a lightweight aggregate for concrete production and a noteworthy thermal insulation material [80].

The fired clay products and their manufacture started with bricks in Mesopotamia had been evolved by Assyrian, Sassanian, Islamic and Persian cultures, afterwards spread to Anatolia and then to Europe. While the usage of fired bricks was maintained, the necessity for roof material emerged. This necessity was fulfilled in 4th century BC together with concave formed tiles that is still being used. These tiles were manufactured by Chorint, pounding and ramming clay pastes and shaping them thicker and greater items. Over the years the Greeks manufactured tiles with various dimensions and initiated to use Greek tile products. Then, Romans manufactured novel, more round and smaller dimensioned products. Consequently, tiles comparable to the Ottoman types were manufactured and started to use in buildings. Romans brought the first norms to tiles and bricks. In our country, occurance of fired clay products initiated with Turkish (Ottoman) style roof tiles. Currently, restoration of historic structures is performed same tile to preserve the originality [81]. Some of the advantages of fired clay products: high thermal capacity, great compressive strengths, porosity to facilitate the building to respire, fire resistance, reutilization of low quality and crushed products and weather resistance. Some of the drawbacks are: energy intensivity of firing process, the elevated cost to minor sized manufacturers and by this way lower quality brick manufacture, an attenuation or failure of bricks named as 'lime blowing' that is induced by the hydration of quicklime fragments [74].

6.2.4 Wood

The usage of wood as a construction material is much older than steel and concrete. Development of wooden building systems and more extensive usage of wood in the load bearing members enhances with the turn of the 20 th century. In this period, mechanical and physical properties of the wood material were investigated, the joint elements (nails, bolts, etc.) were examined, materials and methods that enable protection of wood against environmental factors were developed [82].

Compared to other building components, wood is completely compatible with nature and easy to recycle. It has remarkable strength compared to its density, as well it is compatible with other building materials. Wood is a sustainable material that may be long lasting when used properly. Regarding these positive features, it has an important ranking in traditional Turkish architecture. Although wooden building elements used in the past had not undergone any protective treatment most of the time, it can maintain its durability today. In order for wooden structures to maintain its' serviceability, it is necessary to use the proper materials, protect the material from moisture conditions and satisfy cross-sectional adequacy of structural elements [83].

Since wood is an anisotropic and heterogeneous material, its mechanical properties are different from other building materials. For this reason, the mechanical behavior of wood is investigated from micro to macro level. The direction and structure of the fibers should be determined by experimental studies and numerical analyzes taking into account heterogeneous structure of wood. The hardness and shrinkage properties of the wood should be determined by applying forces in parallel and vertical directions. In order for designing qualified wooden structures, it is important to investigate mechanical behaviour of wood by performing experimental and numerical studies. When investigating the mechanical behaviour of wood; elasticity, tensile and compressive strength , splitting tensile and shear strength parameters should also be examined.

The mechanical properties of wood material can be called the resistance of wood against external forces. Wood having orthotropic properties three different directions are existent; parallel to the fibers, radial (running from the core to the shell) and tangential (running parallel to the rings). Due to its orthotropic properties, the mechanical properties of wood may also affect its physical properties. This situation proves that woods' elasticity modulus and strength depends on the direction. The modulus of elasticity has the highest value in the direction parallel to the fibers, while in radial and tangential direction direction it decreases [84].

Some of the advantages of the wood can be summarized as [82]:

- It has remarkable strength value, as well it is lightweight material. As a result of lightweight property, wooden structures have less dead load so that the dimensions of the foundation and other load-bearing elements are reduced.
- Due to its lightweight property, it has less transportation cost and it is easy to assemble.
- Wooden structural elements, which are easy to assemble, can be interlocked with each other; can be glued; can be combined with nails, bolts, screws or metal elements.
- Since the joint elements can be easily dismantled, the wooden structures can be disassembled and wooden building elements can be reused .
- It has good thermal insulating property.
- It requires less workmanship and it can be shaped even in the construction site.
- Dried wood has favorable electrical insulating property.
- It can be easily obtained from nature and it is more preferred by architects due to warm property.

On the other hand, some of the drawbacks of the wood can be summarized as [82]:

- It is weak against water and humidity. When it is not protected from water, it easily absorbs water into its body. After drying, it shrinks and cracks. For this reason, dried wood products should be preferred in construction sector.
- It is an anisotropic material (material properties at each point and direction are not same). Due to its fibrous structure, it has higher compressive and tensile strength in the fiber direction, while in other directions is lower. This should be taken into account in the calculations.
- Because of its fibrous structure, knots and cracks are not evenly spread throughout the section.
- Insects, woodworms, bacteria and fungi can cause wood to deteriorate and rot. For this reason, protective measures should be applied.
- Sound insulation performance of wood is poor.
- Wood is an easily flammable material.

Regarding heritage buildings in Gaziantep, wood is used as an auxiliary material behind stone. The reason why wood is used less than stone is shortage of wood and the wood material is brought from other regions. Wood types used in the construction of ancient buildings were pine, walnut, poplar, oak and linden trees. Among the wood types, poplar wood was used in ceiling and floor beams; pine, walnut, oak and linden wood were used in doors, windows and wooden cabinets. Also, roof was constructed among these wooden materials. In the protrusions constructed with bagdadi technique (lath and plaster) and some of trusses located in front of windows wood material was used [75].

6.2.5 Lime

Lime is the binding material that used all of the mortar types. Lime (CaO) is produced by calcining limestone (mainly formed by calcium carbonate $CaCO_3$) in kilns around 900 °C temperatures. As water is appended to calcium oxide, hydrated lime also termed as slaked lime is obtained. Mixture obtained from water and calcium oxide (quicklime) is an exothermic process termed as slaking that produces calcium hydroxide, ($Ca(OH)_2$) [85].

Lime mortars are commonly utilized in historic structures. They present low rates of physically bound water (the amount of absorbed water usually <1% w/w), relatively low rates of structurally bound water (amount of chemically bound water <3% w/w) and significant carbon dioxide quantity (CO_2 > 32% w/w). The rate of CO_2 to structurally bound water, that inversely denotes the degree of hydraulicity, is mostly over 10, as aggregates are primarily calcareous, while when the silicoaluminate property of the aggregates governs the above ratio varies through lower figures (7.5–10), in accordance with the structurally bound water of the aggregates fraction and the rate of the binding substance. These mortars have a binder to aggregate ratio (per weight) that varies through 1:4 and 1:1 [86].

6.2.6 Pozzolanas

Pozzolanas can be described as natural or artificial substance that include silica and /or alumina which are not cementitious themselves, however when finely grinded and blended with lime, in the existance of water, the blend will set and harden at any temperatures [87]. Basically, two types of pozzolanas, namely artificial and natural are exist. Natural pozzolanas are generated from geologically recent volcanic activity whereby the material has experienced remarkable alteration following deposition [88]. Artificial pozzolanas are either calcined clays or byproducts of several agricultural and industrial phases by way of calcination has developed [89].

The basic feature of a pozzolana is its capability to combine with cement or alkaline lime to generate a material with enhanced performance. Besides, the addition of a pozzolana leads to a basically distinct setting phase. Lime mortars reformed with either natural or artificial pozzolanas generate a relatively indissoluble and durable substance which vary from lime mortars. In general, lime-contained mortars involve long durations for setting or hardening and have lower resistance to destructive factors involving water, salts in solution and freeze/thaw cycles with regard to those modified with pozzolanas [89].

6.3 Modern envelope constituents and materials

6.3.1 Foundation

Foundation is a primary element of the building envelope that is anchoring the construction and preserving the enclosure from water incursion from the ground and thermal losses [90]. For this reason it is crucial that the foundation is initially, designed and sized properly, thermally insulated to diminish heat loss and damp-proofed to sustain healthy and comfortable of interior ambient [91]. Reinforced concrete and damp-proofing materials are main constituent materials forming the foundation.

Concrete, a composite human-made material, is the most commonly used construction material in the building market [92]. It comprises a rationally selected blend of binding substance for instance cement or lime, fine and coarse aggregates having well-gradation, water, and typical admixtures (to manufacture concrete with particular features) [93]. Since concrete has a quite low tensile strength, it is mostly reinforced with steel rods or bars that is hence denoted as reinforced concrete [92]. Concrete has been the principal material because of its formability, longevity and ease of transportation [92, 94].

Steel bars are high strength material and might have textured surface to enhance bonding with concrete. They are regarded as being the most proper construction material amongst metallic category. This is because a combination of mechanical and physical features they possess. By properly controlling the alloying elements, carbon content and heat treatment; a appropriate combination of strength, hardness and ductility can be attained in steel. Steel is commonly employed in a broad category of structures, because of its superior strength to weight ratio, relatively low price and pace of construction. Hot-rolled ribbed bars are the most commonly used type of reinforcement for RC buildings. Hot rolling is carried out in the mills that requires implementation of deformations on its' surface; i.e. ribs thereby it can constitute bond with concrete [95].

A damp-proofing material is the one which impedes ingression of water from one ambient to another [96]. Even though concrete is primarily water resistant material, variations in constituents blended to make concrete can change the extent of porosity and water resistance of concrete. It occurs since a grid of capillaries and pores exist in concrete that enables the ingression of potentially hazardous materials causing disruption. Therefore, the interaction between the concrete and environment is determinant factor for its long-term durability performance [97]. Classification of damp-proofing materials relied on their implementation technique shows that they could be either (i) Surface coating type material to be implemented on hardened concrete and/or (ii) Mixture blended additives to be implemented as blending concrete. Surface coating type materials are the waterproofing techniques implemented on the surface either by brushing, dipping, and/ or spraying. They can be silanes, polymers, and siloxane-based materials. Mixture blended additives are implemented while mixing concrete. These are mainly polymer-based and/or silane-based additives [98]. Details for development of waterproof concrete are presented in Figure 6.6.

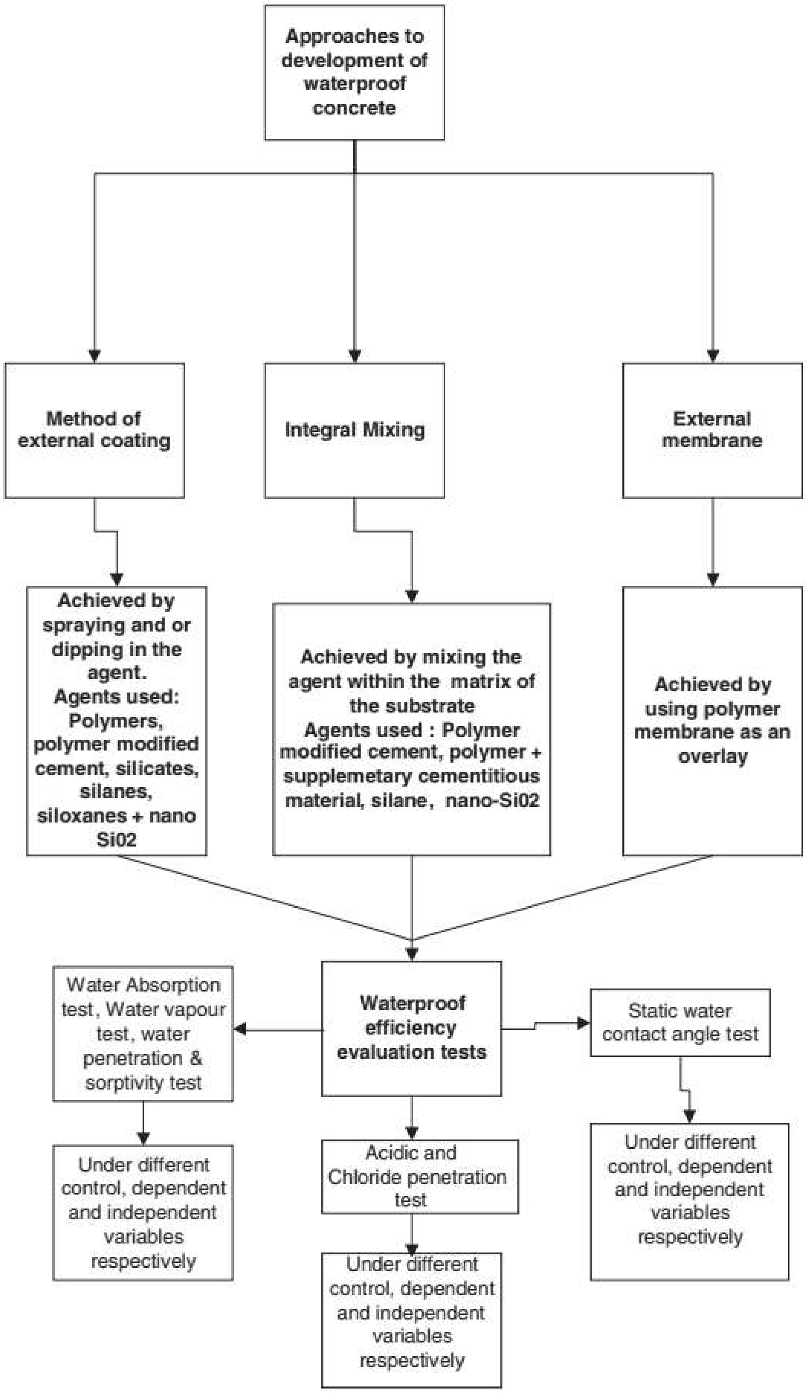


Figure 6.6 Development of waterproof concrete [98]

6.3.2 Wall components

Walls are a principal part of a structures' envelope and are anticipated to ensure acoustic and thermal comfort within a structure, devoid of compromising the aesthetic property of the structure. The R-value (thermal resistance) of the wall is important, since it affects energy consumption seriously, in particular in high rise structures in which the percentage between wall and cumulative envelope surface is high [99].

Some factors should be considered regarding wall construction. These can be listed as follows [100];

- Walls should show high thermal resistance and prevent air leakage. In this regard, selection of wall material and calculation of wall thickness should be made correctly.
- Walls should regulate condensation by controlling moisture transfer.
- Walls should satisfy thermal comfort during heating and cooling season.
- Walls should resist cracking caused by shrinkage and stresses, that is induced by temperature change.
- Wall construction should not be affected from bad air pollutants (dust, gas, acid, etc.).
- Wall construction should be economical, besides effortless in terms of maintenance and repair.

Typically, relied on the materials employed in construction, walls can be categorized as masonry-based walls, metal-based walls and wood-based walls. There are other categories of sophisticated building wall forms which are implemented to enhance comfort levels [99]. However, according to statistics of building licence documents supplied by Şahinbey Municipality, the mostly constructed wall type in the city is declared to be masonry-based autoclaved aerated concrete block, pumice aggregate concrete block, and clay brick type walls. In this regard, autoclaved aerated concrete block, pumice aggregate concrete block, and clay brick type modern wall components are discussed in the thesis.

6.3.2.1 Autoclaved Aerated Concrete (AAC)

Autoclaved aerated concrete is a blend that contains lime, cement, gypsum, finely grinded sand, and aluminum powder as an aerating constituent resulting expansion in bulk of the blend up to three times [101].

AAC has many benefits for instance; good thermal insulation, being lightweight, easy transportation, durable nature and favorable fire resistance so that it has gained widespread usage in the building sector. As a result of its' porous texture, it has low weight, low density and proper thermal insulation properties. Even though it is a lightweight construction material, its' mechanical properties may satisfy the durability norms of lightweight concrete [101]. According to standard of TS EN 771-4, wall built with ACC blocks will have calculated coefficient of thermal conductivity (λ) of 0.11-0.29 W/mK and mass per unit volume of 350-800 kg/m^3 [57].

As well as its insulation capacity, AACs' fire resistance capacity is a good property for dwelling and commercial buildings. A wall constructed from AAC panels or blocks can withstand a temperature gradient up to 2000 °F (1100 °C) no less than for four hours. Rate of change in compressive strength against raising temperature is demonstrated in Figure 6.7 [102]. At almost 800 °F (427 °C) temperature, compressive strength reaches highest value and its' strength diminishes after this stage in accordance with the tests performed standard of ASTM E 119 (ANSI UL 263). Industrially manufacturing process of AAC products reduces the possibility of construction defects as well as enhancing speed [101].

The AAC products are encouraged because of its energy efficiency, ecological attribute and low price. Figure 6.8 demonstrates that the consumption of raw materials and energy needed for the manufacture of clay bricks, clay bricks masonry units, calcium silicate masonry units, and AAC masonry units [103]. This figure proves that AAC is the most energy efficient building material within the four masonry products [101].

Production of ACC initiates with the grinding of gypsum and sand into powder. This powder is then blended with portland cement, water, lime, and aluminum powder in an automated weighing mixer. This blend is afterwards cast into molds. The reinforcing mesh with anti-corrosion treatment, if there is any, should be situated before to casting. Reaction takes place between aluminum and cement slurry to produce hydrogen gas, that enhances the volume of the blend and forms the porous texture. Meanwhile, lime and water reaction generates heat leading to rapid initial setting of cement in nearly four hours. Following this pre-curing phase, the semi-solid and self-supporting material is split in wet form for the desired item sizes. Then, the ACC components are cured in autoclaves until 8-12 hours. Afterwards, the ACC components are taken from the autoclaves, packaged and dispatched to the storage field. The most frequently used AAC components are the lintels and blocks as the filler walls. Also, the elements in desired patterns like blocks (normal, round, and U), panels (cladding, load carrying partition, roof, horizontal, and floor) and lintels can be manufactured for commercial usage [101]. Various products of ACC is given in Figure 16.

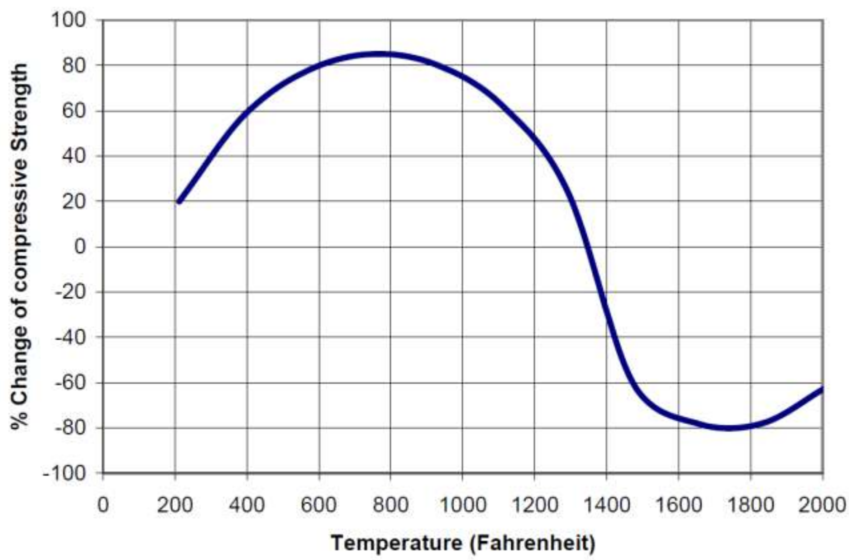


Figure 6.7 Change in compressive strength against raising temperature [101]

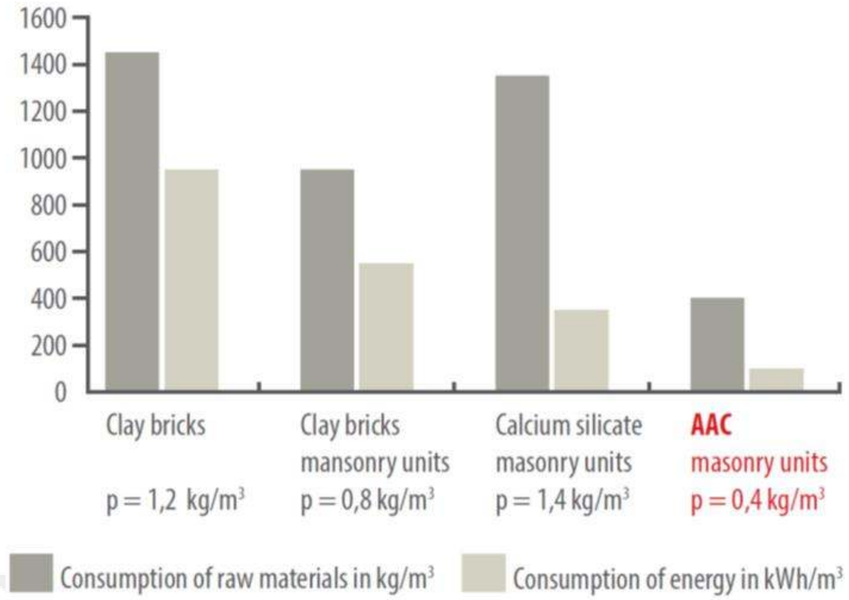


Figure 6.8 Consumption of raw materials and energy needed for manufacture [101]

Figure 6.9 Various AAC products [104]

The most significant drawbacks of AAC are its fragility and water absorption. As ACC is subjected to water, it immediately absorbs water because of its porous structure and may experience fracture. Thus, plastering or water coating should be implemented to the surfaces which can be exposed to water or dampness. Because of its fragility, the manufacturers have evolved particular coating, reinforcing mesh and plaster agents [101].

6.3.2.2 Pumice aggregate concrete (PAC) block

Pumice is a type of rock with glassy and porous structure, and formed by virtue of a series of volcanic activities. Pumice aggregate can be obtained in many areas around the world in which volcanoes have been present. In its' chemical composition, 52-75% silicon dioxide (SiO_2), 11-17% aluminum oxide (Al_2O_3) , 0.5-5% iron oxide (Fe_2O_3) , 1-8% calcium oxide (CaO), 0.5-3% magnesium oxide (MgO), 3-9% sodium oxide - potassium oxide (Na_2O-K_2O) and also very small amounts of titanium oxide (TiO_2) and sulfur trioxide (SO_3) are exist [105].

Pumice is divided into two categories, namely acidic and basic. Acidic pumice, being the most common type, is white and off-white in color. Its hardness is 5-6 with regard to the Mohs scale and its density is 0.5-1 gr/cm³. Basic pumice (Scoria) is brown and black in color, its' hardness grade is 5-6. Scoria is heavier than acidic pumice and its' density is 1-2 gr/cm³ [106].

World pumice reserve is around 18 billion m³ and about 40% of the reserves exist in Turkey. Regarding pumice quarries processed in our country, Central Anatolia region leads the way, while the Mediterranean and Eastern Anatolian regions have a significant amount of production activities [105]. The quality of the pumice stone mined in Turkey is being evaluated as hard and soft. The pumice described as hard is mined from Kayseri Develi and the pumice being soft is mined from Ürgüp, Nevşehir, and Aksaray regions [106].

Pumice is used in various fields in the construction sector. These can be stated as [107];

- In the production of lightweight concrete,
- In the production of lightweight building components,
- In the production of prefabricated structural members,

- In the production of lightweight ready to use plaster and mortar,
- As an insulation materials for roof and floor slabs,
- In the production of decorative coating elements.

Among the usage fields of pumice, it is mostly used in the production of lightweight building components, namely PAC cavity blocks. PAC cavity blocks have following advantages [108];

- Good thermal and sound insulating property
- Lightweight
- Excellent bonding with plaster
- High resistance to climatic conditions

Production of PAC cavity blocks are generally performed in seven stages. These stages are; pumice quarrying, preparation of concrete mix, molding, drying, packaging, storage, and distribution. Initially, pumice aggregate, water, and cement are blended in mixer in appropriate proportions. The prepared mixture is poured into the molds under vibration and pressure in order to prevent voids within wet mortar. Later semi-solid blocks are transferred to setting rooms by conveyors in order to gain its initial set. The blocks remain in the setting rooms for 72 hours. In summer, blocks are dried in ambient temperature, while in winter minimum temperature of the setting room should be 15ºC [109]. The dried blocks are then transported for packaging. During this phase, broken blocks are removed. Later, blocks are waited in storage fields for 28 days to gain its' final strength [106]. Blocks produced from pumice aggregate can be categorized into five groups according to their dimension, shape, and geometry; cavity wall blocks, cellular wall blocks, filled wall blocks, cavity block for slabs, special slotted filled wall blocks [105]. Figure 6.10 presents various PAC block products.

The mass per unit volume of blocks vary according to types of material produced. For one sequence cavity block mass per unit volume is 800 kg/m^3, regarding two sequence cavity block mass per unit volume is 900 kg/m^3, for three sequence cavity block mass per unit volume is 1000 kg/m³. Minimum compressive strength value of PAC blocks should be 20 kgf/cm², average value should be 25 kgf/cm² or more [110]. Walls constructed with the filled blocks made of natural PAC (with DDB type blocks conforming to TS EN 771-3) have thermal conductivity calculation value of 0.28-0.74 W/mK, walls constructed with the filled blocks made of natural PAC by using mortar conforming to TS EN 998-2 and whose density is less than 1000 kg/m³ (made with the DDB type blocks conforming to TS EN 771-3, without adding quartz sand) have thermal conductivity calculation value of 0.23-0.35 W/mK, walls constructed with the special slotted filled wall block made of natural pumice without adding quartz sand (with the SW type blocks conforming to TS EN 771-3) have thermal conductivity calculation value of 0.18-0.32 W/mK, walls constructed with the special slotted filled wall blocks made of concrete made with the natural pumice without adding quartz sand by using mortar conforming to TS EN 998-2 and whose density is less than 1000 kg/m³ (with the SW type blocks conforming to TS EN 771-3) will have thermal conductivity calculation value of 0.16-0.29 W/mK [57].

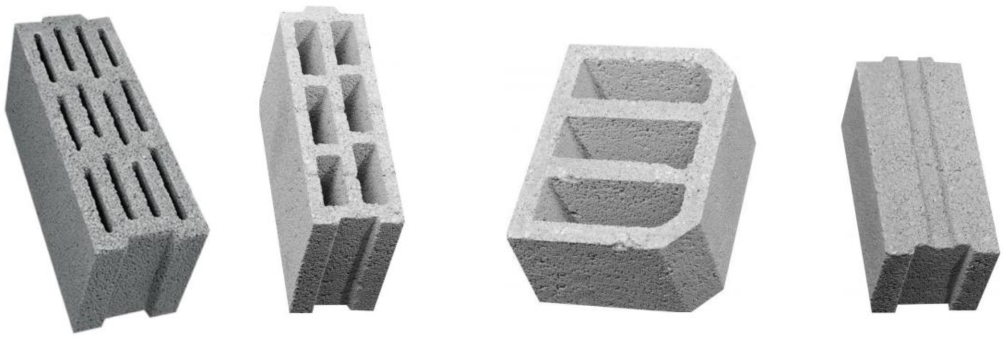


Figure 6.10 Various products of PAC blocks [111]

6.3.2.3 Clay brick

Clay bricks are made up of clay minerals and non-clay materials along with supplementary minerals such as carbonaceous substance and water. In industrial manufacturing, the production of clay bricks is consist of various phases such as mining of raw materials, preparation of the clay paste mixture, molding of the bricks, drying, burning, and curing after burning [112].

Clay raw materials mined from open quarries are carried to plant depots. Materials are blended in order to obtain more uniform mixtures from raw materials. Grinding process is not required for production. More clearly, the raw material is used as is. The arrangement of clay raw material involves various steps, for instance taking out of stones and other impurities (scraps, root); shreding the clay to receive needed grain size; homogeneous mixing of several additives; homogenizing and moisturizing to attain the proper plasticity. Water amount within the paste is controlled and the dampness content of paste going on the molding step varies through 15 to 30% relying on the clay material. The molding technique relies on the sort of raw material and specifically water amount and sort of brick that will be manufactured. Molding of bricks is generally made with these methods: stiff-mud (extrusion) technique, soft-mud technique, and dry-pressing (or semi-dry pressing) technique [113, 114].

In stiff-mud (extrusion) technique, water about 15–20% is blended into the clay in a pug mill to contribute plasticity. The clay paste passes through a de-airing chamber to eliminate air holes so that the clay paste will have enhanced workability and plasticity, contributing to higher strength. Then, the clay paste is extruded through a die to form a column of clay paste. As the paste leaves the die, surface coatings or textures may be implemented. An automated blade then cut the clay paste column to produce the individual brick. In soft-mud technique, clay is blended with 20–30% water and subsequently shaped into brick in molds. This technique is appropriate for clays comprising excessive water. Bricks are manufactured by hand or machine. Dry pressing technique is specifically appropriate for clays having low plasticity. Clays are blended with water up to 10%, and afterwards pressed into molds under a pressure ranging from 3 to 10 MPa in hydraulic machine. Prior to burning process, shaped moist bricks are dried in drying chambers at temperature values ranging through 38-200°C utilizing waste heat obtained from the cooling segment of the kilns. The required time for drying varies through 24 to 48 h. In whole situations, humidity and heat must be cautiously controlled to prevent fracture of the bricks [112].

The clay brick products are typically classic solid bricks which have a rectangular form, bricks with vertical perforations, besides roof tiles relying on the usage purposes. The perforations in the brick products amend firing and drying, as well diminish the amount of raw materials needed; they also improve the thermal insulation performance of the bricks [113].

Products in the brick tile industry can be sorted as ;

- horizontal perforated brick (TS EN 771-1) ,
- vertical perforated brick (TS EN 771-1),
- vertical perforated exterior brick (clinker brick) (TS EN 771-1),
- masonry outer chimney brick (TS EN 771-1),
- handmade brick (TS EN 771-1),
- hollow floor filling brick (TS 1261),
- hollow floor beam brick (TS EN 15037-3),
- facade facing brick (TS EN 1304),
- curtain wall brick (TS EN 1304),
- base brick (TS EN 1344),
- roof tile (TS EN 1304).

Generally, the thermal conductivity value of bricks was declared to be about 1.0+/-0.4 W/(m·K) relying on raw material features besides the bricks processing technique [115]. However, innovative approaches in fired clay brick design and/or production will lead to have lower thermal conductivity value for brick products. Figure 6.11 shows various perforation arrangement for brick products. As well, Figure 6.12 shows the the impacts of vertical perforation arrangement on thermal conductivity value of bricks. In Figure 6.12, different vertical perforation arrangement in brick causes different thermal conductivities (a) solid brick devoid of perforations, (b) perforations in a regularly formed array, and (c) perforations with a zigzag form which augmented the route passed by heat. Direction for flow of heat is demonstrated with an arrow. Notice the profit gained from the zigzag form.

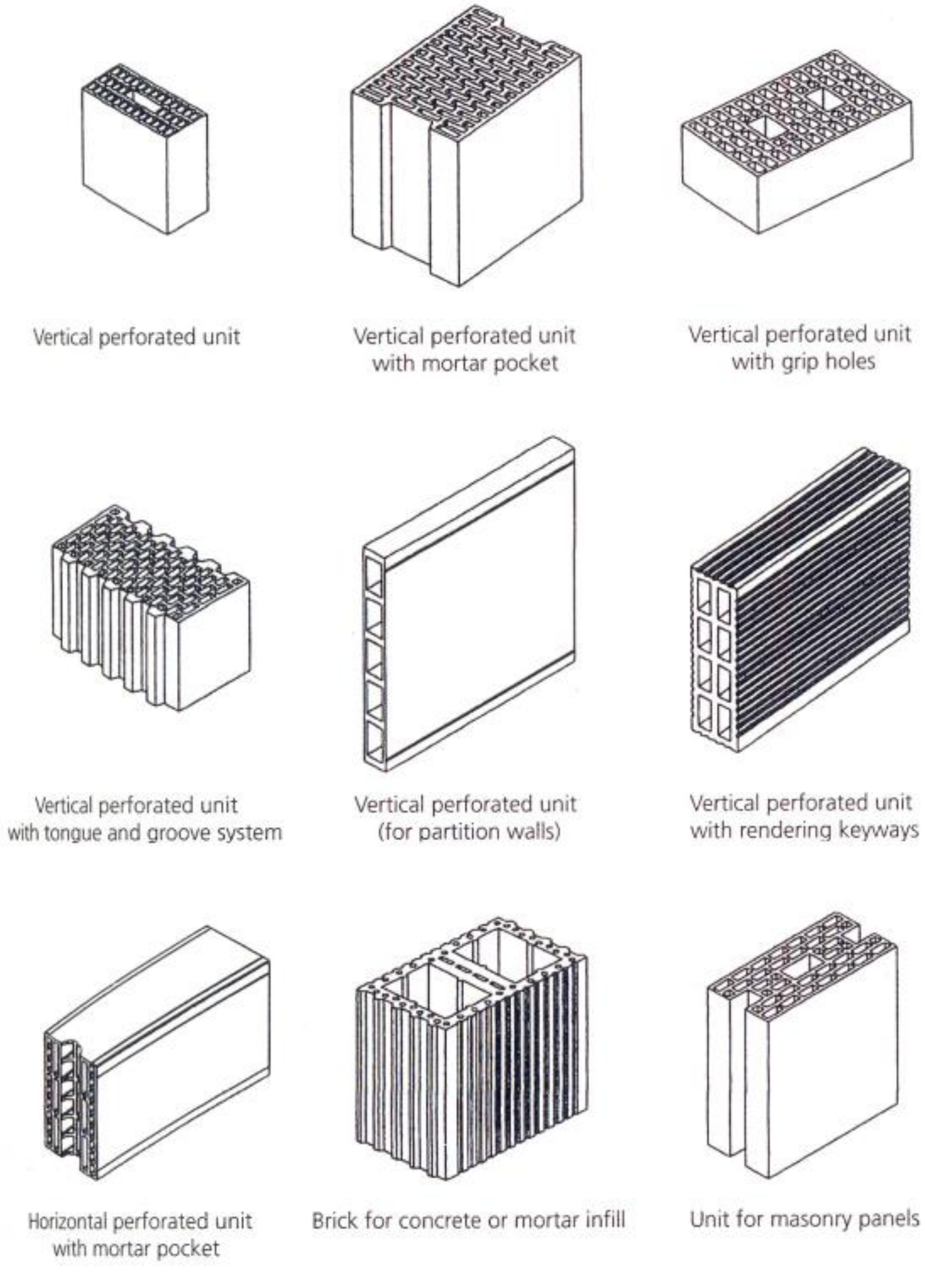


Figure 6.11 Bricks with various perforations [112, 113]

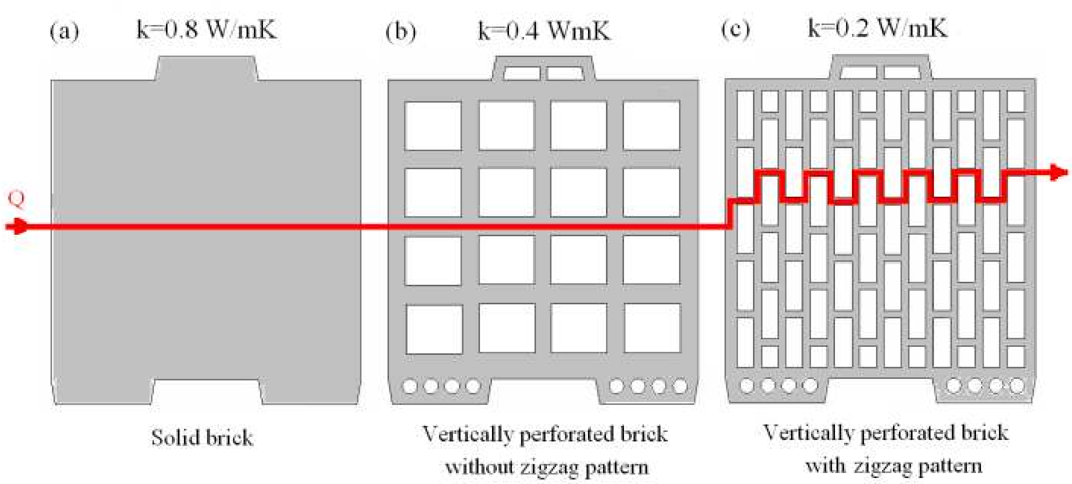


Figure 6.12 Different vertical perforation arrangement in brick [112]

6.3.3 Plaster

Plaster is a coating material, that protects the building components (i.e. wall, ceiling, and load bearing members) from external factors, consists of a binding material, fine aggregate, and water. Plaster is applied to building component as it is in plastic consistency via trowel or plastering machine [116]. As a finishing material, plaster enables for rough and uneven surfaces to be made smooth. It regulates moisture balance between interior and exterior environments, as well it contributes thermal, sound and fire insulation [117].

The thermal conductivity value of exterior plaster varies through 0.81-1.51 W/mK relying on the type of plaster mortar and humidity of the plaster, while interior plaster it varies through 0.46- 1.05 W/mK. The thickness of exterior plaster is about 20 mm, the thickness of the interior plaster is about 15 mm, thus, in practice the thermal insulation property of the plaster is lower compared to other factors [117]. Plaster provides effective sound insulation for walls built from perforated blocks. Cement and lime-cement based plasters (e.g. plasters on exterior walls) generally have better sound insulation property with regard to gypsum based plasters. Considering ordinary wall constructions made of porous sheets the sound insulation property of the plaster is much more effective [116].

Plaster has fire protection property according to DIN 4102 norm for all structural elements. Thus, some materials (e.g. wood wool boards) have only fire securing property when covered with plaster. In reinforced concrete ceilings, the ceiling plaster has great significance in terms of fire resistance. Reinforced concrete ceilings provided that covered with a minimum of 15 mm lime-cement based plaster, have fire resistance three times longer than unplastered ceilings [117]. Plasters can be categorized into four different groups regarding production method, chemical binder, field of application, and type of wall on which it is applied [116].

6.3.3.1 Plaster with regard to production method

Plasters regarding to production methods are divided into two groups, namely traditional plaster and ready to mix plaster. Traditional plaster includes cement, lime and gypsum as binding material, also various grade of sand is used as an aggregate. Blend of traditional plaster is prepared when it is to be applied. Ready to mix plaster is prepared as a dry blend at manufacturing plant and it is prapared to use by mixing with water and it can be implemented by traditionally by trowel or machine. Ready to mix plaster is very convenient for construction works regarding standard implementation technique and mass production. Ready to mix plaster can be applied directly to the surface, by virtue of its' texture and color alternatives, it is also used on interior surfaces [118].

6.3.3.2 Plasters with regard to the wall surface on which they implemented

Plasters are implemented to surfaces such as concrete, brick, aerated concrete and insulation materials that have different chemical, physical, and mechanical properties. Plasters can present different properties depending on various implementation surfaces and surface properties [116].

6.3.3.3 Plaster with regard to binding property

Plasters are divided into two groups regarding binding material, these are plasters with synthetic binder and plasters with mineral binder. Mineral binder based plasters includes inorganic binder materials such as cement, lime, and gypsum. These binder materials can be used separately or it can also be used as a mixture of them [119]. Synthetic binder based plasters include various synthetic materials (i.e. polystyrene, polyurethane, and epoxy) [120]. Synthetic based plasters are generally used for coating mineral-based surfaces. Synthetic based plasters hardens faster and are more elastic with regard to mineral-based plasters. As well, synthetic-based plasters have higher water impermeability and vapor diffusion resistance factors with respect to mineral based plasters [119].

6.3.3.4 Plasters with regard to usage area

Plasters can be categorized into two groups according to place in which they are used, these are interior plaster and exterior plaster. Interior plaster is applied the interior side of spaces enclosed by the walls. As well as its protection function for interior surfaces, it enables to obtain more smooth, easy-to-clean, and decorative surfaces. Also, it has repellent property against dust and dirt. It provides to obtain a suitable surface for a more aesthetic finishing material than itself. Exterior plaster is applied to the outer surfaces of the buildings' facade. It contributes protection of the wall elements and therefore the entire structure exposed to atmospheric effects. Also it ensures to obtain aesthetic aspect reflecting architectural characteristics of the building [121].

6.3.4 Fenestration (doors and windows)

Fenestration denotes to holes in a building envelope which are mainly doors and windows. The fenestrations have an important function for ensuring ideal illumination levels and thermal comfort in a structure. They are also crucial from an architectural perspective in providing aesthetics to the structural design. In last years, there have been major developments in glazing industry. These developments comprise insulated glazing systems, solar-control glazing, low emissivity (low-e) coated glass, gas cavity fills and aerogels, evacuated glazings in addition to developments in spacer and frame designs [122].

In windows sector, various alternatives are available considering the arrangement of glazings. A single-pane window is no more used in newly constructed buildings.

Moreover multiple-pane window systems have various advantages for instance; prevention of condensation, sound insulation and sunlight controlling, and the most prominent one is thermal insulation. Even though, it enhances the cross section of glazing, windows having double and triple glazing have become mostly demanded type for the building industry as they diminish the rate of heat flow. A quadruple glazed windows are not preferred much due to difficulty of usage and high cost [123]. Properties of some types of glazing are presented in Table 6.2.

Table 6.2 Properties of some types of glazing [80]

Types of glazing	U-value (W/m^2K)	Transmission of daylight (%)
Single glazing	4.6-5	89-90
Double glazing	2.6-2.9	80-82
Double glazing having one low emissivity coating	1.4-1.8	74-78
Double sealed glazing having argon filling	2.5-2.6	80-82
Double sealed glazing having argon filling and one low emissivity coatings	1.2-1.4	74-78
Triple glazing	1.9-2	74-76
Triple glazing having two low emissivity coatings	1-1.1	62-67
Triple sealed glazing having argon filling	1.7-1.9	62-67
Triple sealed glazing having two low emissivity coatings and argon filling	0.8-0.9	62-67

6.3.4.1 Insulated glazing systems

Insulated glazing systems rather than standard glazing can diminish the heat dissipation from window by up to 80%. Insulated glazings are generally constitute two or more glass spaced away with a spacer. The glass sheets are then sealed to constitute a single unit together with one or more air spaces within it. The spacer can be comprised of composite plastics, aluminum, etc. The spaces within glasses comprise heavy inert gases or dry air. These inert gases are generally krypton (Cr), argon (Ar), and xenon (Xe) have a lower thermal conductivity value than air. These gently-moving, viscous gases minimize the coefficient of convective heat transfer efficaciously. Dry air is the mostly preferred alternative as an infill gas by the sector.

Also argon gas is commonly used as an infill gas as it is easily accessible and low-priced than xenon and krypton. Moreover, argon is non-toxic and clear gas [123, 124].

6.3.4.2 Solar-control glazing

Solar-control glazing is preferred for diminishing the adverse impacts of solar incidence on the interior environment for instance glare troubles and overheating. It will be analyzed under three headings; Solar low-e – spectrally selective glass , tinted glass, and glass with reflective coating [123].

Solar low-e – spectrally selective glass

This type of glazing is particularly advantageous for employing in warm climatic environment. It is a sort of glass which obstructs dissipation of heat during cold period of year and alleviates the thermal gain in hot period. It enables solely visible part of spectrum of solar incidence to influx, reflects the IR rays. Thus, it has superior visible transmittance rate (VT) however low solar heat gain coefficient (SHGC). Double glazed solar low-e glass has better performance with regard to ordinary double glazed glass in terms of heat retention capacity (14%) and solar control (42%) [123, 125].

Tinted glass

Tinted glass is produced by appending metal oxide to the glass. Colour of glass varies in accordance with type of metal appended. It is generally manufactured in blue, smoked, green, and bronze colors. Light transmittance, reflectivity, and solar heat gain coefficient properties varies with regard to colour of glass [124]. Tinted glass ensure privacy, it prevents appearance of interior ambient from outside. Besides it obstructs immoderate glare and sunlight. The major drawback of tinted glass is that it limits the natural lighting [123].

Glass with reflective coating

This type of glass has high reflection coefficient. Thus it is grouped in the solar-control glazing category. It is primarily used in office type buildings. This coating can be implemented to float or tinted glass. There are various coating alternatives in metallic colors for instance bronze, gold, and silver. These colour alternatives also alter the other physical characteristics of the glass. Glass with reflective coating has very low rate of daylight transmissivity. Also it has 50% less solar heat gain value with regard to ordinary glass [123].

6.3.4.3 Low emissivity (Low-e) Glass

Low-e coatings efficaciously alleviate the thermal transmittance of a glass by limiting thermal radiation [126]. These coatings should be implemented on the inner (cold climates) or outer (hot climate) glass surfaces in touch with the air chamber to acquire more improved performance when implemented to double-glazed fenestration [127]. Low-e coatings can be grouped into two category: soft type coating and hard type coating. The hard coated low-e glass involves a thin layer of tin oxide while the soft coated type involves generally a thin layer of silver encompassed by dielectric protecting layers. Generally, soft silver type coatings have greater infrared reflectance and lesser solar transmittance with regard to hard tin oxide type coatings [128].

6.3.4.4 Aerogel glazing

Aerogel glazing took part in modern glazing sector since 2006 and basically, aerogel in a granular form embedded between polycarbonate panels which weigh lower than 20% of the corresponding pane unit, besides they have 200 times greater impact strength. U-value and light transmission of aerogel systems correlate with panel thickness. Their low density, superior performance and remarkable light diffusing characteristics bring them a proper alternative for roof-light implementations [129].

6.3.4.5 Vacuum glazing

Vacuum spacing is formed within two glass units to suppress the convective and conductive heat transmission between the glass units lowering the center-of-pane U-value to as low as 1 W/m^2K. Frequently, low-e coating is implemented on one or both of the glass units to lower the re-radiation into the indoor volume [130]. Even though, the technology confronts some difficulties in sustaining vacuum for prolonged terms, it is yet a commonly utilized energy efficacious glazing alternative [129].

6.3.4.6 Switchable reflective glazing

Switchable reflective glazing is basically a mutable tint pane, moreover this glazing type is generally appropriate for cooling energy demand dominant structures having high solar exposure [130]. In some sorts of this innovative product, the optical features vary as a function of the solar radiation incident, either by implementing a low-voltage DC or by utilizing hydrogen to alter from uncolored to colored case. In other sorts, light guiding constituents reflect solar irradiation [129].

6.3.4.7 Suspended particle devices (SPD) film

A SPD film is encapsulated between two sheets of glass. The SPD film has light absorbent particles which are desultory dispersed in their ordinary case constituting a translucent barrier. As voltage is implemented, the particles align orthogonal to the surface of the pane forming a transparent glass. This innovative product is affected by some drawbacks for instance glare, radiant temperature, clearness, colour rendering, and lifetime [129].

6.3.4.8 Holographic optical elements (HOE)

HOE technology are light guiding components containing a holographic film embedded within two sheets of glass. The solar irradiance incident is redirected, at a predetermined angle by means of diffraction at the holographic film sheet, generally onto the ceiling of the structure inside. This can be utilized as a potential daylighting implementation. This technology is affected by drawbacks for instance light dispersion, glare effects, milky clearness, restricted exposure range of zenith and azimuth angles, etc. [129].

6.3.4.9 Fenestration frames

As the transparent components of the building are considered, 10-30% of the total area of the fenestration constitutes frame. The selection of material and design of the frame is important to exhibit good thermal performace for fenestration elements. PVC, wood, and aluminum are main materials used in the construction of the frames. These materials exhibit different thermal performances according to their material properties and design features [100, 131]. Composite frame systems manufactured by combination of various materials are available in the construction market. These composite systems usually produced by plating the exterior surfaces of wooden frame with vinyl or aluminum material [123].

Aluminum frame has greater thermal conductivity with respect to other frame materials, so that it has lower thermal performance with regard to wood and PVC frames (U value of aluminum frame is 11.86 W/m²K) [132]. By improving the thermal insulation properties of aluminum frame, aluminum frame with heat retention property is produced. Aluminum frame with heat retention property enables 8-15% reduction in U value when compared to ordinary aluminum frame [133].

Wooden frame has more favorable properties with regard to aluminum frame in terms of thermal performance. Wood has much lower thermal conductivity value (U value of wood frame 1.85 W/m²K [132]) with regard to aluminum. By embedding some materials, that have lower thermal conductivity than wood, such as polyurethane (PU) within wood frame, innovative frame type with a lower thermal conductivity can be manufactured [100, 131].

Polyvinyl-chloride (PVC) is a type of advanced synthetic plastic. During manufacture phase of PVC frame, PVC material stabilized by lead, cadmium and tin compounds as well mixed with colour pigments. Steel is always employed as a structural core [80]. PVC frame is durable, resistant to impacts, and easy to shape. It has good thermal performance as much as wooden frame . PVC frame has cellular structure that is advantageous for its thermal performance (U value of unplasticized type PVC frame is 2.11 W/m²K [132]). PVC frames are also robust to dampness. For such reasons, it is the mostly used sort of frame in dwellings [123, 124].

6.3.5 Roofs

Roofs are immensely susceptible to solar incidence and other environmental events, thus, affecting the users' indoor comfort. Roofs are responsible for great deal of heat (captured or dissipated), particularly, in buildings having large roof surfaces for instance; auditoriums, sports complexes, exhibition halls etc. Roofs can be grouped into various categories; i.e. masonry roofs, vaulted and domed roofs, lightweight roofs, ventilated and micro-ventilated roofs, cool (solar-reflective) roofs, green roofs, and photovoltaic roofs regarding roof construction [99]. On the other hand, there is a broad category of roof types and the preference might be be controlled by some factors, such as appearance, shape and size of building, economy, other aspects (ease with which type of services can be located in roof space, condensation, weatherproofing, maintenance, and such matters). Roofs alternate from flat type roofs of timber or concrete, coated with one of a various type of materials, to pitched roofs of several structural forms that are usually coated with tiles or slates [134]. The principal constituents of a roof system are the roof deck, air/vapor barrier, thermal insulation, and a covering or membrane. Various roof forms are presented in Figure 6.13.

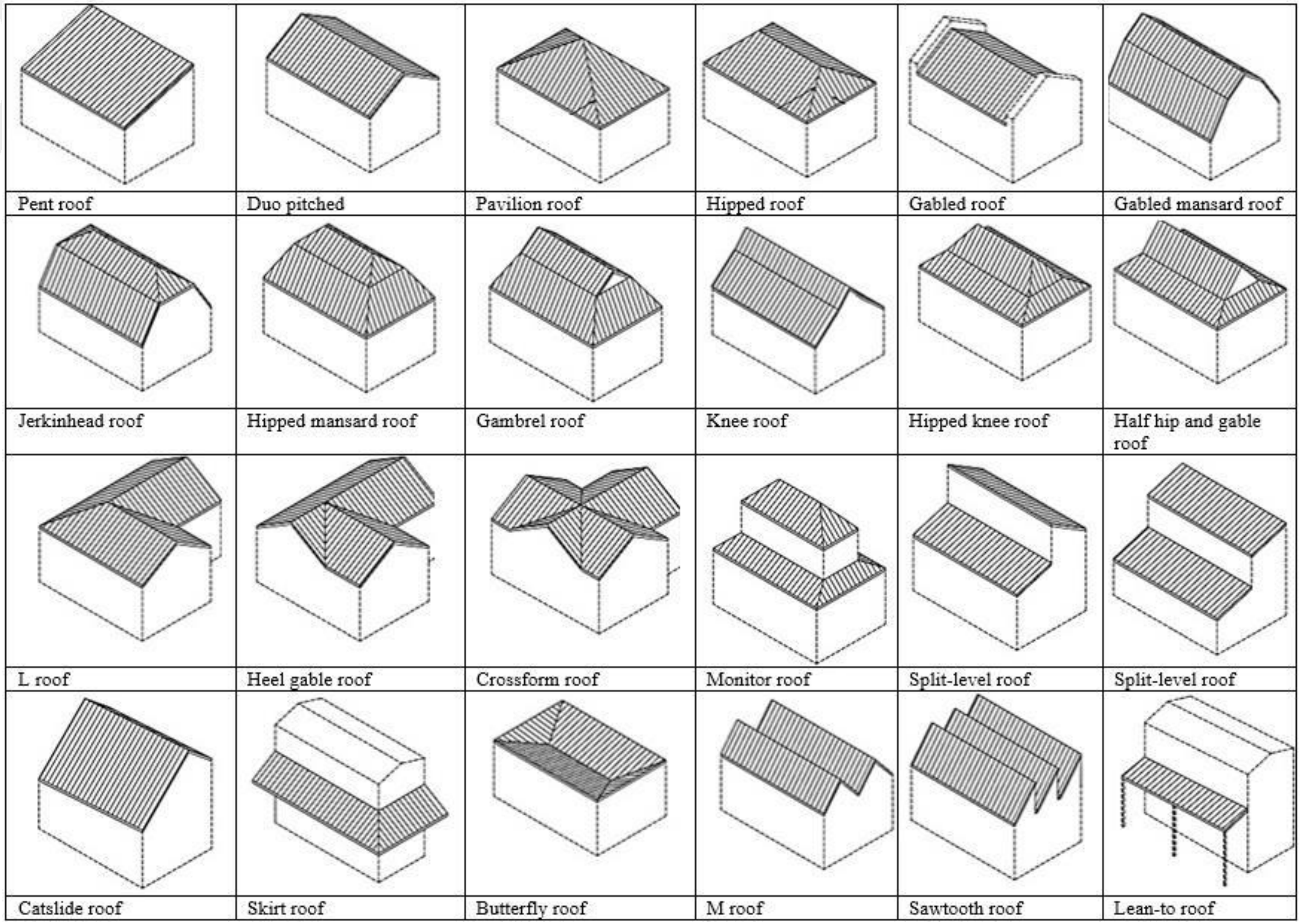


Figure 6.13 Various roof forms [135]

6.3.5.1 Masonry roofs

In the developing nations of the Middle East and South Asia , masonry dwellings with reinforced cement concrete roofing are prevalent because of their pest resistance, natural disaster (hurricane) resistance, availableness, and cost-efficiency of concrete elements [136]. In the course of tropical summers, masonry roofs are slant to demonstrate adverse thermal performance such as elevated soffit temperature as well prolonged heat retention potential which influence the indoor thermal comfort and raise energy expenditure [137].

6.3.5.2 Lightweight roofs

Lightweight aluminum standing-seam roofing systems (LASRS) are commonly implemented on government and commercial buildings, since they are affordable. Nevertheless, they are vulnerable to wind because of slender seam-clip fitting and also they have poor thermal performance. Two simple techniques to upgrade thermal performance of these roof systems are implementation of light coloured paint and using thermal insulation. It was specified that the lighter coloured planes for instance, green, brown, off-white, and white resulted in 1.3%, 2.5%, 8.8%, and 9.3% decrement in cooling energy demands with regard to an black coloured LASRS plane [138].

6.3.5.3 Ventilated and micro-ventilated roofs

The ventilated roof arrangements are basically two slabs restricting a duct whereby air discharges. This air flow/air gap alleviates the heat transfer over the roof into the structure. Ventilated type roofs can be either an active category, with fan-assisted ventilation or a passive category, with chimney effect pushing the air flow. These type of roofs more prevalent in regions having hot climate characteristics and are specifically beneficial in moderate elevation and large roof surfaced buildings [99].

6.3.5.4 Vaulted and domed roofs

Vaulted and domed type roofs are prevalent in the vernacular style of the Middle East in which the climatic ambient are hot and arid. The authors in Ref. [139] carried out finite element analysis for both flat roof and vaulted roof (VR) to evaluate their thermal characteristics in several climatic zones. The semi-rim angle of a VR should be bigger than 50° for it to demonstrate beneficial effect on the indoor thermal comfort. South–north directed VR design is more favorable than east–west directed one. As well, they are only appropriate for hot and dry climatic environment, because of the existence of larger beam element of the solar incidence that is efficaciously reflected by the arched roof plane, and not so much for hot and humid climatic environment. Even though, VRs absorb more thermal energy throughout the daytime with regard to flat type roofs, they also disperse more thermal energy by means of re-radiation and natural convection [139].

6.3.5.5 Solar-reflective (cool) roofs

Cool roofs demonstrate superior infrared emittance and solar reflectance property. They sustain lower roof facet temperature and restrain the conduction of thermal energy into the construction. Two surface characteristics which influence the thermal behaviour of these roof facets are infrared emittance (or emissivity) and solar reflectance (SR) (albedo or reflectivity). SR value of ordinary roofing materials is between 0.05–0.25. Cool coatings can enhance the SR value to beyond than 0.60. Infrared emittance value for most of the roofing materials 0.85 or higher, aside from metals, that have an inferior infrared emittance of approximately 0.25. Thus, despite metals are quite reflective (i.e. SR value higher than 0.60), metallic roof coatings and plain metal roofs prone to become hot as they cannot radiate the absorbed thermal energy efficaciously as radiation. Particular roof coatings can enhance the infrared emittance of plain metal type roofs [140].

6.3.5.6 Green roofs

A building roof which is either partly or fully overlayed with plants is termed as a green roof. Green roof is a layered composite arrangement made up of a watertight membrane, ambient for growing of plants and a plant layer itself. Commonly, green roofs comprise of a layer of root barrier , drainage layer, and alternatively an irrigation system (according to climate property of region). Two sorts of green roof are available:

extensive and intensive, the extensive type has limited substrate layer enables to farm shallow rooted plants for instance sedum or lawn, whereas the intensive type has a thicker substrate layer and enables to farm deeper rooted plants for instance trees and shrubs. The green roof system not merely reflect the solar incidence, but also serve as an additional thermal insulation layer. Green roof is just able to enhance thermal protection of a construction and should not interchange with the roof insulation [141].

6.3.5.7 Photovoltaic roofs

In last years, there have been growing demand in installing photovoltaics (PV) over the envelope of building. Particularly in countries facing limited land-use, building integrated photovoltaics (BIPV) technology present a powerful solution by the utilization of building envelope area meanwhile enabling energy output, moreover keeping envelope of building from weather action. PV roofing tiles are mounted straightly on to the roof structure instead of roofing material. Fibercement roof slates and ceramic tiles have solar cells (made from crystalline silicon) pasted straightly on them. Another sort of roof assembled technology has a PV constituent (glass-glass laminate) placed in a plastic supporting platform fastened to the roof. Other sorts of PV roofs comprise sandwich PV roofing that presents more benefits such as thermal insulation and electricity production [142].

6.3.5.8 Roof construction materials

Wood

Details related with wood are explained in the section 6.2.4 in this paper.

Plywood

Plywood is manufactured by laminating thin wood layers so that the material possess the desired thickness. Plywood is available in construction market in the form of sheets, box beam or I-sections. It has high shear capacity and its box form is generally used in arched or pitched type roofs. Plywood can be mounted to long spans as the softwood is bonded jointly and generates I or T shaped beam. As the thickness of the material is about 8-10 mm, it can be used for sheeting [143]. Photo of plywood sheets is presented in Figure 6.14.

Figure 6.14 Photo of plywood sheets [144]

Laminated veneer lumber (LVL)

LVL is a flat-pressed multilayered timber panel comparable to plywood comprised of oriented timber veneers however apart from plywood all the elements directed in identical orientation in whole the layers and fastened together via hot-pressing by employing thermosetting adhesive type of resins [145]. This material is appropriate for beams, columns, trusses, and purlins. I-section joists can be manufactured with LVL that is also a suitable material for flanges and webs in flat and pitched type roofs [143]. Photo of LVL sheet is given in Figure 6.15.

Figure 6.15 Photo of LVL sheet [146]

Particleboard

A flat timber composite layer that is made up of randomly oriented timber chips fastened by thermosetting adhesive type of resins via hot-pressing technique. The board is commonly made up of three seperate layers; the surface ones being made up of finer timber chips rather than the coarser core sheets. The board is commonly made up of three distinct layers; the surface ones being made up of finer timber chips than the coarser core sheets. The board usually has a density of 650−700 kg/m^3 [145]. Photo of particleboard sheets is given in Figure 6.16.

Figure 6.16 Photo of particleboard sheets [147]

Oriented strand board (OSB)

A flat timber composite (having three layers) board is made up of oriented timber wafers fastened by thermosetting adhesive type of resins via hot-pressing technique. The very fine wafers (width and length are very much greater with regard to in particleboard and of the order of 20 mm × 100 mm, respectively) are directed in the identical orientation within the same layer and at 90° of each other in adjoining layers generating a particularly robust panel very proper for building implementations[145]. Photo of OSB sheets is presented in Figure 6.17.

Figure 6.17 Photo of OSB sheets [148]

Hardboard (high density fiberboard)

A flat-compressed timber composite board made up of randomly directed timber strands acquired via thermomechanical timber pulping and conventionally fastened devoid of any binder by hot-pressing technique at very high density (900–1100 kg/m^3) and the high-temperature-forced flow of the lignin element of the strands. Boards involving a small quantity of binders (2–3% binder solids on dry strand), mostly phenolic resins, are frequently manufactured nowadays to enhance the properties of the board [145]. Photo of hardboard sheets are given in Figure 6.18.

Figure 6.18 Photo of hardboard sheets [149]

Medium density fiberboard (MDF)

A hot-pressed composite flat board made up of timber strands acquired via thermomechanical timber pulping and conventionally bonded together with adhesive to density of about 750–800 kg/m^3. MDFs having much lower densities are also available in the market. It is a board mostly fastened by urea–formaldehyde resins and utilized for interior use and furniture work [145]. Photo of MDF sheets is demonstated in Figure 6.19.

Figure 6.19 Photo of MDF sheets [150]

Steel

Each sort of steel products have different qualifications and a broad category of them are accessible in the building market . Various sorts of steel can be manufactured by modifying the amount of alloying, carbon, or the heat. Steel constructions can become fire resistant by implementing insulation or the second technique is to implement fire engineering procedures. Oval, circular, rectangular, and square hollow sections are commonly obtained from flat sections that are gradually bent up to almost round [143]. Typical steel sections available in the market is presented in Figure 6.20.

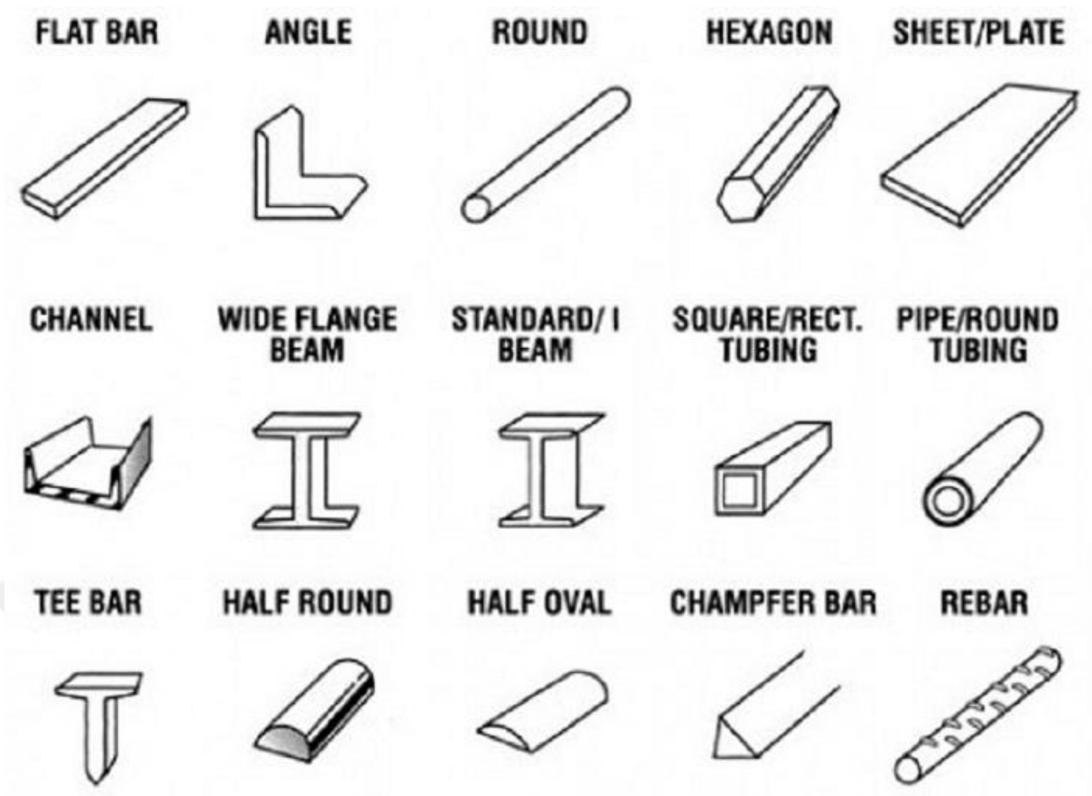


Figure 6.20 Typical steel sections [151]

<u>Vapour barrier</u>

Vapour barriers are generally manufactured from polymer or bituminous material (see Figure 6.21). They prevents water vapor coming from the interior ambient to transfer to the open-pore thermal insulation material for terraced roofs [152].

Figure 6.21 Photo of bituminous vapour barrier [153]

6.3.5.9 Roofing materials

Roofing materials can be grouped according to their constituent materials as; clay based roofing materials (clay roof tile), cement based roofing materials, metal roofing products, bituminous roofing products, polymer roofing products, glass roofing products, natural slates, and plant based materials [154].

Clay roof tile

The manufacturing procedure of the clay roof tile is the same clay brick except for molding. In Turkey, after Ottoman style roof tile was introduced to construction market; Margaritas, Mediterranean, Valencia, Torino, Granada, Venice, and Marseilles style roof tiles have been produced. The Marseille style has become the tile markets' most demanded product because of its practical implementation, stable locking property to impede water leakage and robust texture resistant to harsh climatic conditions, for instance freezing and frosting. The Mediterranean type tile is similar to Marseilles tile in aspects and by the courtesy of their particular production technique additional water flow canals added to the docking portion, it has an excellent insulation performance in comparison with other tile products. Side and upper overlay and particular water flow canals enable Mediterranean roof tile excellent insulation performance. The locking mechanism provided by the side and upper clamping canals yields a safe solution on the roof with regard to installation and insulation criterias.

The Granada style tile is known as the Portuguese tile and presents nostalgic ambiance of the Ottoman architectural style on roofs. By virtue of its' curved form; when the canals in the laying are entirely closed, it provides perfect water tightness. The Valencian tile is smaller cast of German 'Frankfurten Pfanne' style tile and provides a new perspective to roofing with its neo-classical design. It is the most frequently used tile type in developed and intensive rainy countries such as Germany. It has large rain surface which drains the precipitation and greatly durable structure that secures the roof even in windy weather [81]. Figure 6.22 presents some examples of clay roof tiles.

Figure 6.22 Some examples of clay roof tiles [155]

<u>Cement based roofing materials</u>

Corrugated fibre cement sheets and concrete tiles are the roofing materials that fall into this category.

Corrugated fibre cement sheets are roofing products that are formed by shaping the mixture, that is obtained by blending inorganic long fibers, cement, water, and coloring pigments (if desired) with special molds [156]. This roof system can be applicable both continuous or intermittent roof deck. Corrugated fibre cement sheets are aligned perpendicular to the slope on the roof surface. They are attached to each other at a certain extent [157]. Photo of corrugated fibre cement sheets is given in Figure 6.23.

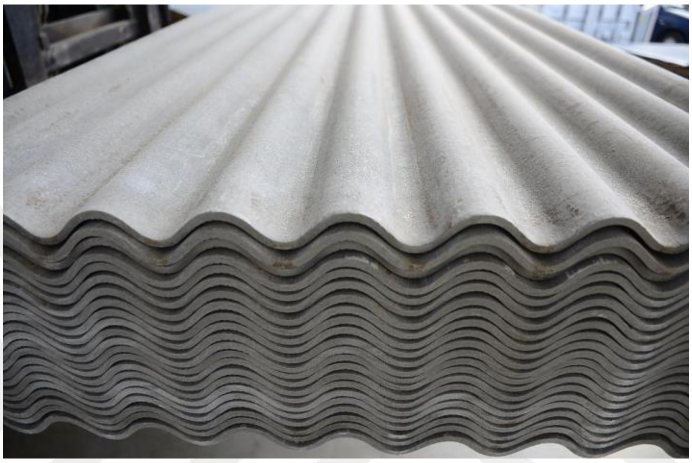


Figure 6.23 Photo of Corrugated fibre cement sheets [158]

Concrete tiles, made up of sand , cement, water, and additives, formed by shaping the materials in special molds. Color pigments can be added to the blend during production. These products have about 65% more load bearing capacity than clay tiles. The production of concrete tiles performed at low temperatures so that deformations like warping is prevented. Concrete tiles are being manufactured in greater size than clay tiles [157]. Photo of concrete tiles is given in Figure 6.24.

Figure 6.24 Photo of concrete tiles [159]

Metal roofing

Metal roofing is primarily aluminum or steel, whereas copper and other type of metals are occasionally used. Bare steel and aluminum might have a solar reflectance of around 60 %, and a low emittance. The emittance and reflectance of bare metals are quite sensitive to the evenness of the surface and the existence or deficit of oil film, surface oxides, etc. Generally, bare metal products are not very cool when exposed to sunshine. Metal roofing is also available with pigment-filled polymeric coatings (resembling to paint) which are factory implemented. These type of coatings are used for preserving the metal sheets, and for visual satisfaction; moreover they can enable the roof remain cooler [160].

Aluminum roofing products are available in the form of flat sheet, trapezoidal sheet, and sandwich panel. Flat aluminum sheets are manufactured in certain sizes or they are manufactured in desired special sizes depending on the roof surface to be implemented. They can also be manufactured in colored form. They can be implemented in two alternative forms; standing seam metal roof or slatted roof. However, flat sheets can be applicable for only continuous roof deck [161]. Flat aluminum sheet implementation on the dome of a mosque is presented in Figure 6.25.

Figure 6.25 Flat aluminum sheet implementation on the dome of a mosque [162]

Trapezoidal sheets formed by flat aluminum sheet by giving them channel shape (see Figure 6.26) to enhance their load bearing capacity so that enabling them to use in larger span. Trapezoidal sheets can be produced in different thicknesses and shapes, as well they can be produced in colored form by means of painting [163].

Figure 6.26 Photo of trapezoidal sheets [164]

Sandwich panel is a composite roofing product manufactured by embedding insulation material between two flat shaped sheets or trapezoidal sheets (see Figure 6.27).

Insulation material that is usually polyurethane or mineral wool can be in different thicknesses [157, 165].

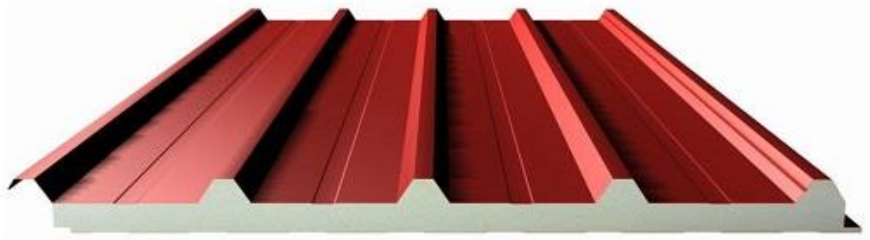


Figure 6.27 Photo of a sandwich panel [166]

Steel roofing products are available in the market as; galvanized metal sheets, metal tiles, and sandwich panel. Steel is always galvanized by the implementation of a zinc/aluminum or zinc coating, that greatly diminishes the rate of oxidation. Galvanized metal sheets can be produced in different thicknesses. Also, they can be produced in two alternative shapes; wavy (corrugated) or trapezoidal forms [157]. Photo of galvanized metal sheets is presented in Figure 6.28.

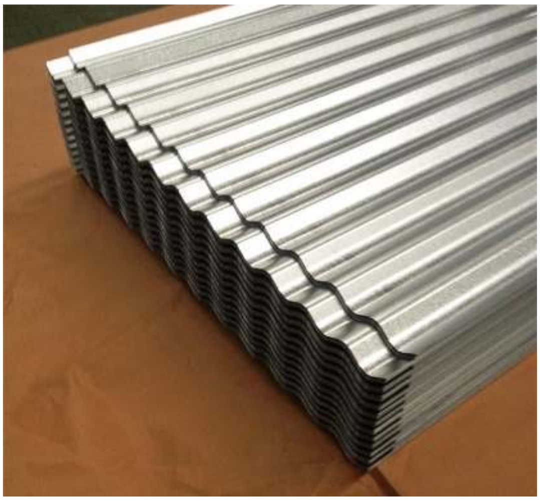


Figure 6.28 Photo of galvanized metal sheets [167]

Metal tiles have recently been manufactured and used in Turkey. They comprises several layer of materials namely; galvanized steel, primer, polyester, and paint. They are in the form of sheets obtained by pressing steel plates in the shape of adjacent tiles (see Figure 6.29). They are lightweight and durable material; resistant to cracking and rupture [157].

Figure 6.29 Photo of metal tiles [168]

Sandwich steel panels have similar properties and manufacturing process with sandwich aluminum panels except for outer material that is made up of steel plates (see Figure 6.30) [157].

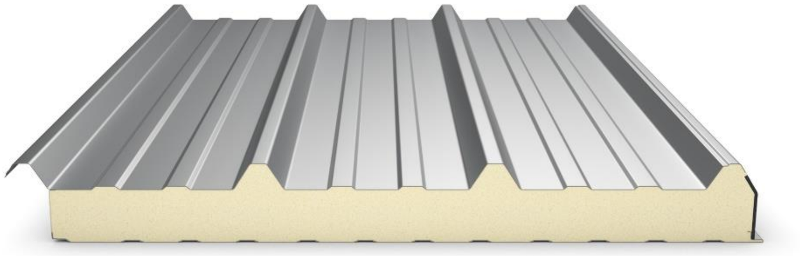


Figure 6.30 Photo of a sandwich steel panel [169]

Flat copper sheets are manufactured in certain sizes or they are manufactured in desired special sizes depending on the roof surface to be implemented. Copper sheets can be easily processed even at low temperatures so that it can easily adapt to complex roof shapes. Copper roofing is the most expensive product among the roofing elements. But considering the service life of product, it becomes advantageous. Copper sheets are durable material; as a result of weathering, the case known as patina, they becomes quite resistant material against environmental agents [157]. It is mainly used at dome of mosques. Photo demonstrating flat copper sheet implementation on the dome of a mosque is given in Figure 6.31.

Figure 6.31 Flat copper sheet implementation on the dome of a mosque [170]

Bituminous roofing materials

Bituminous roofing products are available in the market as; asphalt shingles, roofing membranes, and bituminous corrugated sheets.

Asphalt shingles are low-cost roofing material, which have a remarkable share in the building market, comprising most dwellings with sloping roofs. They are made up of tar saturated mats fabricated from fiberglass or organic felts. The tar is secured from ultraviolet rays by granular stones pressed into the shingle as it is hot and soft form. These granular stones have about 1 milimeter size (e.g., of crushed granite), that are covered with an inorganic silicate type of material. The covering comprises microscopic pigment elements, like to those used in paint, to give color. The solar reflectance asphalt shingles in the market is quite low. White colored shingles are around 30% reflective, and other colors are less reflective [171]. Photo showing asphalt shingle implementation is presented in Figure 6.32.

Figure 6.32 Photo of an asphalt shingle implementation

Roofing membranes are manufactured from strong and pliant waterproof materials. They can be implemented in multiple overlays, as in the Built-Up Roofing (BUR) system, or they can comprise a single-ply roofing membrane. Membranes generally include a fabric made from fiberglass, felt, or polyester for providing strength, that is impregnated with or laminated to a pliant polymeric substance. The polymeric substance may diversify from bituminous hydrocarbon products such as synthetic rubber known as EPDM, to asphalt, to synthetic polymers for instance PVC. The topmost surface of the membrane can be covered with a pigmented substance that determines solar reflectance and the color, or it can simply be ballasted by a layer of gravel. As a dark membrane is coated with a layer of gravel, it has the solar reflectance and appearance of asphalt shingles [172]. Photo of roofing membrane implementation is presented in Figure 6.33.

Figure 6.33 Photo of roofing membrane implementation [173]

Bituminous corrugated sheets are manufactured by blending plant based and mineral fibers with bitumen and a special resin, thereby shaping them. They have high mechanical strength. They are manufactured in certain sizes and thicknesses, with various color alternatives (see Figure 6.34). These products can be applicable both continuous or intermittent roof deck. The flexibility of these products, enables to use them on curved roof surfaces [154].

Figure 6.34 Photo of bituminous corrugated sheet [174]

Polymer based roofing materials

Polymer based rofing materials are available in the market as; PVC roofing, polycarbonate roofing, acrylic glass roofing, and glass-reinforced polyester roofing.

PVC roofing products are produced as transparent or opaque elements, formed by compressing polyvinyl chloride polymers or heating them under pressure into thin layers. They are produced in two alternative forms being corrugated sheet and trapezoidal sheet. These products can be applicable intermittent roof deck. Transparent products are used for utilizing daylight [157]. Photo illustrating PVC roofing implementation is given in Figure 6.35.

Figure 6.35 Photo illustrating PVC roofing implementation [175]

Polycarbonate roofing products are produced from polycarbonate, a special type of thermoplastics that softens as heated and hardens again as cooled. They are transparent, thus a wide range of use available in places that require the best use of daylight. The products are lightweight, resistant to impacts, as well they preserve their strength even in high ambient temperature differences. The products are available in market as in the form of flat sheet, corrugated sheet, and trapezoidal sheet [157]. Photo illustrating polycarbonate roofing implementation is given in Figure 6.36.

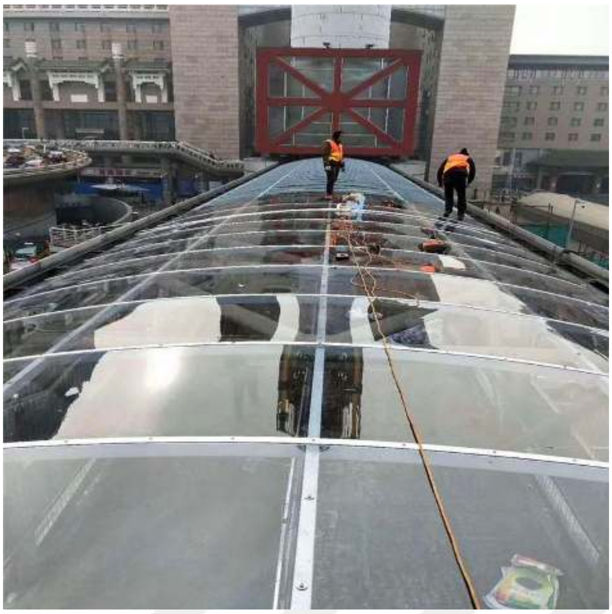


Figure 6.36 Photo illustrating polycarbonate roofing implementation [176]

Acrylic glass roofing products are manufactured by molding or compressing the liquid transparent acrylic resin. They are easily shaped thermoplastic roofing material with high light transmittance and they are six times more resistant to impacts than normal glass. These products are available with alternating visual properties such as opaque , transparent, coloured, or colourless. They are used in intermittent roof deck in order to utilize daylight [157].

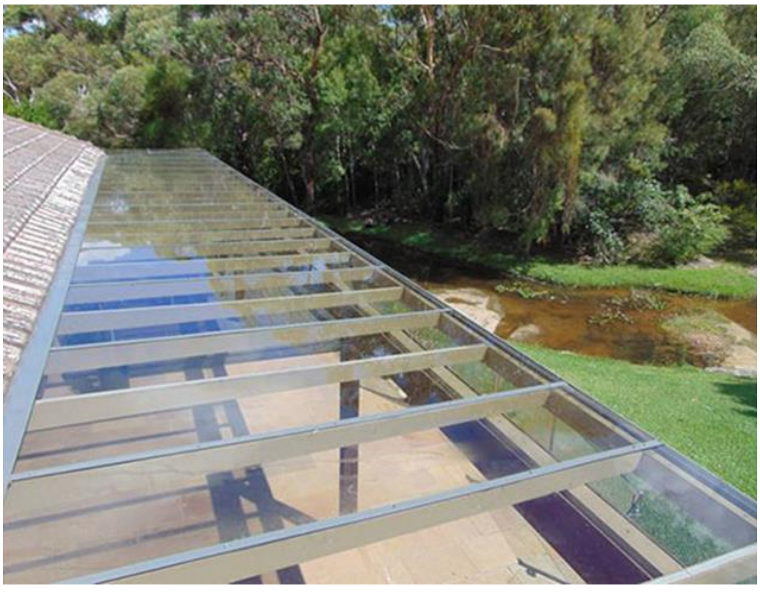


Figure 6.37 Photo illustrating acrylic glass roofing implementation [177]

Glass roofing products

Currently, with the developments in materials and building technology, glass is contemporary building material that is used in many building components from facade to roof. It can provide thermal and sound insulation, as well it controls the harmful effects of the sun and secures the building. Glass roofing products are available as glass tiles, prestressed (tempered) sheets, and laminated sheets [178].

Glass tiles are manufactured via shaping the glass, which is melted at elevated temperatures, by applying pressure in special molds. Glass tiles are used in intermittent roof deck in order to utilize daylight [157]. Photo illustrating glass tile implementation is presented in Figure 6.38.

Figure 6.38 Photo illustrating glass tile implementation [179]

Prestressed (tempered) glass sheets are produced by heating the flat glass sheets to a degree close to the melting temperature, thereby suddenly cooling in order to increase their resistance against impact, pressure, and heat. They are used in intermittent roof deck in order to utilize daylight [157]. Photo illustrating prestressed (tempered) glass implementation is given in Figure 6.39.

Figure 6.39 Photo illustrating prestressed (tempered) glass implementation [180]

Laminated glass sheets are produced by combining two or more glass layers that contain polyvinyl bitural (PVB) or a similar plastic product within layers under pressure. These products are resistant against breakage and impacts. The PVB material between the layers keeps the glass layers undispersed in case of breakage or cracking. They are used in intermittent roof deck in order to utilize daylight [157]. Photo illustrating laminated glass implementation is given in Figure 6.40.

Figure 6.40 Photo illustrating laminated glass implementation [181]

Natural slate sheets

Slate is natural schist type stone having dark gray – bluish color. It is dense and homogeneous textured material, by virtue of its' characteristics, slate can be separated in thin layers. Slate roofing sheets are manufactured by cutting and shaping slate stone in layers having 5-10 mm thickness. Usually products have square or near-square or equilateral form (see Figure 6.41). It has long service life, fireproofing, and waterproofing property. Color and other properties of slate sheets remain unalterable, over the years with no necessity of maintenance [157].

Figure 6.41 Photo illustrating slate roofing implementation [182]

Plant based materials

The plant-based roofing materials are made up of wood (called 'hartama' or 'bedavra'), or plants (i.e. thatch or reed), or small plants that constitute green roof systems (see Figure 6.42) [157]. Except for green roofing plants, plant based materials are being rarely used in the city.

Figure 6.42 Photo illustrating planted roofing [183]

6.3.6 Thermal Insulation Materials

Thermal insulation is a substance or combination of substances that as appropriately implemented, delay the rate of heat flow into or out of a building because of its high thermal resistance. The appropriate implementation of thermal insulation in structures diminishes the energy consumption one the one hand, downsizes the HVAC system in the course of design phase on the other hand [184]. The most effective implementation of thermal insulation is to position it nearest to the surface of inlet of heat; i.e. in fields where heating energy demand is prevailing, insulation material should be positioned near to the interior side of the building shell. Whereas in fields where cooling energy demand is prevailing, insulation should be positioned near to the exterior surface [99].

According to Turkish Standards TS 825 and German norm of DIN 4108, the materials (i.e. expanded polystyrene, extruded polystyrene, rock wool, glass wool, polyurethane, polyethylene, glass foam, phenol foam) whose thermal conductivity coefficient (λ) lower than 0.065 W/mK is called as thermal insulation materials, otherwise they are called as building components [124].

The thermal inertia and thermal conductivity are practically the most crucial determinants which influence the selection of the insulation material. The raise in moisture content and temperature of the thermal insulation enhances its thermal conductivity, thus lowering its performance. Indeed, studies have demonstrated that water in the state of liquid or vapor has a damaging impact on the material behaviour of fiberglass and mineral wool fibers [185]. Environmental and health effects are also crucial determinants in selecting an proper insulation material. The hydrochlorofluorocarbons (HCFCs) and chlorofluorocarbons (CFCs) progressively emitted over the life cycle of several foam category insulation materials for instance polyisocyanurate (PIR) and extruded polystyrene (EPS) prove harmful to the ecology because of their heavy global warming and ozone depletion potential. Insulating foam that includes isocyanates acts as a robust irritant on skin and eyes. Frequently, glass-fiber batt kind insulation material is declared to create medical ailments, particularly respiratory problems, to the anybody working on it. Flammability is also a serious determinant in material choice. Rigorous tests check fuel contribution, flare spread, and smoke growth rates to categorize the flammability of the insulation materials accordingly [99].

Considering various usage areas, proper thermal insulation materials should satisfy following criterials, it is important to note that not being possible for a single material to have all these and similar requirements [186]:

- High resistance to heat transfer (low thermal conductivity coefficient),
- Have sufficient tensile strength,
- Have sufficient compressive strength (in order to prevent collapse),
- It should not deteriorate at the ambient temperature, it should be incombustible and flame-proof,
- It should not react with surrounding used materials,
- It should resist water and humidity, as well it should be odorless, lightweight and economical,
- It should not be moldy,
- Ease of application and workmanship,

- Have dimensional stability,
- It should not harm human health and the environment,
- It should not be harmed by various insects and microorganisms.

Insulation materials can be categorized with regard to their physical or their chemical structure. The most commonly used insulation materials classified by author in Ref. [184] as shown in Figure 6.43. On the other hand, a group of insulation materials that is not discussed by the author in Ref. [184] is presented in sections through 6.3.6.20-5.3.6.25.

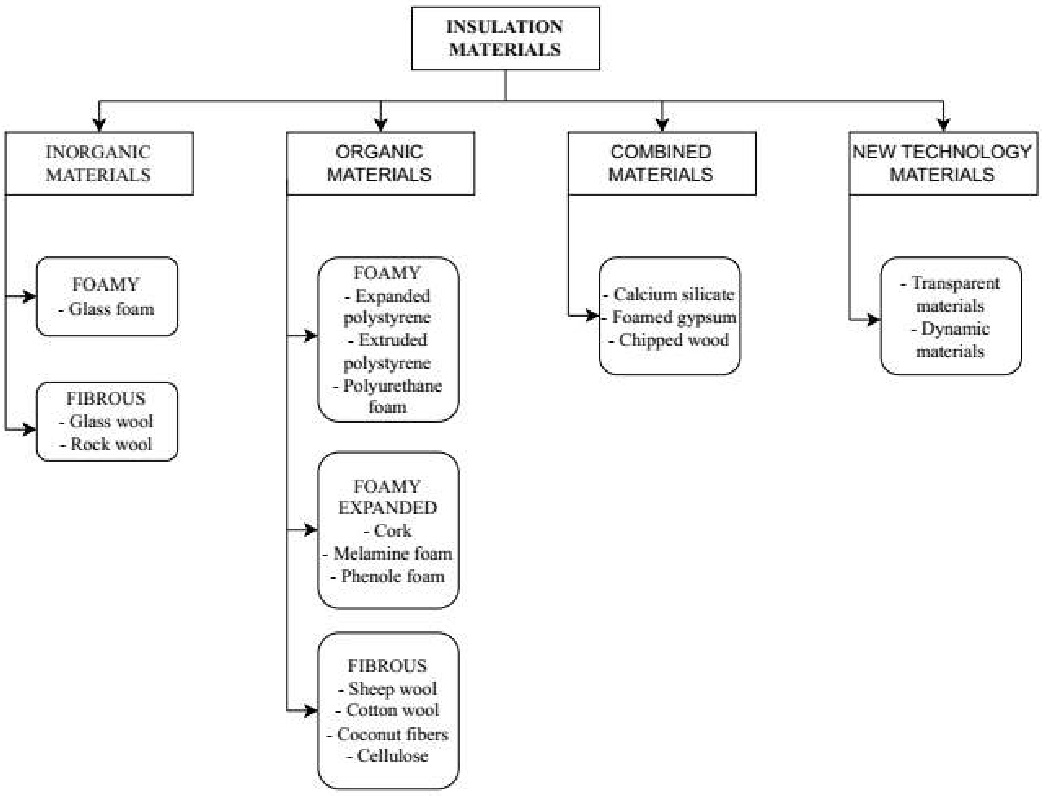


Figure 6.43 Various types of thermal insulation (adopted from [184])

6.3.6.1 Glass foam (Cellular glass)

Cellular glass are demanded for their lightness and potential of acoustic and thermal insulation integrated with favorable mechanical properties, substantially better than those of polymeric foams. Furthermore, as they are waterproof and incombustible they are enhancingly considered for usage as insulating or lightweight filling materials in civil engineering. The manufacture of glass foam generally relies upon the sintering by viscous flow of fine glass dusts, that generates a pyroplastic mass capable of foaming by the action of certain substances (foaming agents), as heating at 850–1000 °C. Foaming develops due to the discharge of CO, CO_2 or SO_3 gases, produced from the oxidation or decomposition of the additives [187]. Glass foam sheets are very hard, easily broken, resistant to pressure, not resistant to friction (its' surface can be easily dusted by friction), as well it is the only vapor-proof ($\mu = \infty$) insulation material. Glass foam does not absorb water, it is not hygroscopic and capillary. However, if it is continuously exposed to water, it may undergo corrosion because of hydrolysis event [188].

Glass foam can be used up to 500ºC, it has thermal conductivity value of 0.052 W/mK at temperature of 20ºC, and density of 120–150 kg/m³. Glass foam has cellular structure, it is resistant to chemicals, it is durable, rot-proof, non-combustible, mildew-proof, vermin-free. It is commercially available as a shell, sheet, board, block or cut piece [189]. Photo showing glass foam products is given in Figure 6.44.

Figure 6.44 Photo of glass foam products [190]

6.3.6.2 Glass wool

Glass wool is manufactured from heating silica sand at around 1200˚C - 1250˚C and modifying it into fibers. Glass wool is non-toxic, non-flammable, and robust against corrosion. It has low thermal conductivity, low weight by volume, consistent chemical property, and low moisture sorption value because of its perfect hydrophobicity. It can be manufactured in the pattern of board, blanket, loose, and pipe in various size and with differing technical features, with different coating materials regarding usage purpose. It is used for sound and thermal insulation, fire safety as well as acoustic comfort [191]. According to Turkish Standard of TS EN 13501-1, glass wool is certified in the "A" class non-combustible construction materials group so that it provides fire safety. The operating temperature of glass wool is between -50/+250 °C. As well special type of glass wool products, operate through -200/+550 °C, can also be produced. Glass wool is manufactured in densities between 14-100 kg/m^3. Thermal conductivity calculation value of glass wool is 0.040 W/mK, water vapor diffusion resistance factor μ=1 [186, 192]. Glass wool is not hygroscopic. It is chemically neutral and resistant to atmospheric conditions. Except for hydrofluoric acid, it is generally resistant to acids [186]. Photo of glass wool batt is given in Figure 6.45.

Figure 6.45 Photo of glass wool batt [193]

6.3.6.3 Rock wool

Rock wool is manufactured from rocks such as basalt or diabase by melting at 1350°C - 1400°C and modifying it into fibers. It can be manufactured in the pattern of board, blanket, loose, and pipe in various size and with differing technical features, with different coating materials regarding usage purpose. It is used for sound and thermal insulation. According to Turkish Standard of TS EN 13501-1, rock wool is certified in the "A" class non-combustible materials group so that it provides fire safety. The operating temperature of rock wool is between -50/+750 °C. Rock wool is manufactured in densities between 30-200 kg/m^3. Thermal conductivity calculation value of rock wool is 0.040W/mK, water vapor diffusion resistance factor is μ =l. Rock wool insulation material has 100% dimensional stability. As it is exposed to heat and humidity, its' dimensions do not vary. It is not hygroscopic and capillary. It does not deteriorate over time. It cannot be destroyed by insects and microorganisms [186]. Photo demonstrating rock wool samples is presented in Figure 6.46.

Figure 6.46 Photo of rock wool samples [194]

6.3.6.4 Expanded polystyrene (EPS) foam board

Expanded polystyrene is manufactured from the raw matter of polystyrene. It is manufactured by employing the pentane gas so as to expand the granules and bind to each other. It can be produced in the pattern of board (see Figure 6.47) in various sizes and with differing technical features regarding usage purpose [195].

Density of the EPS foam board varies through 15-30 kg/m^3. The thermal conductivity value is $\lambda \leq 0.040$ W/mK, besides water vapor diffusion resistance factor $\mu = 20\text{-}100$. The operating temperature of EPS foam board is between -50/+75°C. There is no capillary absorbency for EPS products. Although being resistant to acid and alkali chemicals, EPS products are sensitive to the methane gases, chimney gases, gasoline, ester, ether, and amine group chemicals. Also it is sensitive to sunlight. EPS products are flammable (according to Turkish standard of TS EN 13501-1, it is certified as "E and F" class) [186]. In addition, during combustion of EPS products toxic gases (carbon monoxide, benzol, monostyrol, and halogen compounds) are emitted. Therefore, EPS products should not be applied in areas unless necessary where there is high risk of fire [196].

Figure 6.47 Photo of EPS foam boards [197]

6.3.6.5 Extruded polystyrene (XPS) foam board

XPS foam board, thermal insulation material with closed porous cell structure, is manufactured from polystyrene raw material by extrusion process. Relying on its usage purpose, it can be manufactured in various densities and sizes, in different edges and surface forms. It has low thermal conductivity value ($\lambda \leq 0.035$ W/mK) and it can maintain this value throughout buildings' service life. The water vapor diffusion resistance factor is m = 90-100. The operating temperature of XPS foamboard is between -50/+75 °C. Due to its completely closed pore cell structure, it does not absorb water [198].

Since XPS material has no nutritional property, insects cannot harm them. It is not resistant to ultraviolet (UV) light, if it is exposed to UV for several months, color change and fading from yellow to brown is observed on its' surface [199]. XPS foam board is resistant against construction materials such as; cement, lime, gypsum, dilute acid, and bitumen etc. whereas it is not resistant to tar products, fuel, varnish, and other solvents based materials. XPS foam board has high strength against short and long-term loads. It is one of the thermal insulation materials with high compressive strength [200].

Since XPS being a petroleum-derived product, it is a flammable material (According to Turkish Standard of TS EN 13501-1, it is certified as "E" class). When it burns, harmful gases are emitted into the environment. It is generally manufactured with a greenhouse gas called HCFC (hydrochlorofluorocarbon) that damages the ozone layer. The use of XPS is either prohibited or restricted in many developed countries [196, 201]. Photo of XPS foam boards is given in Figure 6.48.

Figure 6.48 Photo of XPS foam boards [202]

6.3.6.6 Polyurethane (PU) foam

PU foam is manufactured by blending two chemicals (polyol and isocyanate) thereby foaming and hardening with the help of air [203]. The thermal conductivity coefficient of PU is quite low that varies between 0.016-0.032 W/mK depending on density and temperature. The density of the PU foam is between 30-200 kg/m^3, whereas the PU foam products that are used as building insulation material have 30-40 kg/m^3 density. The operating temperature of PU foam is in the range of -180/+110 °C. Although the PU foam absorbs less water, it is still more than EPS. After 24 hours, PU foam absorbs 0.2-1.0% of water of the sample volume immersed in water [196].

Since PU being a petroleum-derived product, it is a flammable material. However, during the manufacture by the addition of various materials, it may belongs to flame-retardant material class. PU foam is one of the most efficient and high performance thermal insulation materials. Even at modest thicknesses, the insulation performance is remarkably high. It is resistant to mild acids, diesel, gasoline, alkali, and sea water but it is sensitive to ultraviolet rays [201]. Photo of the PU foam sheets is given in Figure 6.49.

Figure 6.49 Photo of the PU foam sheets [204]

6.3.6.7 Insulation cork board (ICB)

Raw material of the cork board is bark of the cork oak tree. Once the raw cork is presented in the production phase, the initial process is the granulation, in which the raw material is grinded with machinery. Thereby, the board is conformed through the combined action of temperature, compression, and polyurethane as a binding agent. Ultimately, boards are split and packed [205]. The granulation industry can be grouped into two kinds: black cork granules and white cork granules. White cork granule by-products are mostly aimed to alimentary usage therefore a preprocessing is needed for cleaning the raw material prior to processing it to satisfy the health necessities of the final product. On the other hand, black cork granule is aimed to non-alimentary usage, particularly for the building market such as floorings and insulators, and for decoration and design purposes [206].

ICB is also of effortless or no maintenance or replacement. It has low ecological effects, it is eco-efficient, obtained from a sustainable resource. It has no toxicity for peoples' well being. ICB implementation are branched in three aspects: acoustical absorption, thermal insulation, and vibration insulation for the construction and industrial sectors [207].

Density of the ICB products varies through 80-500 kg/m^3. As well, thermal conductivity calculation value of the ICB is between 0.045- 0.055 W/mK. The water vapor diffusion resistance coefficient is μ = 5-10. The operating temperature of ICB is in the range -180 / +100°C. It is unaffected by the suns' ultraviolet rays. As well, it has fire-retardant feature (class B2 according to DIN 4102) [208]. Photo of ICB sheets is given in Figure 6.50.

Figure 6.50 Photo of ICB sheets [209]

6.3.6.8 Melamine foam (MF)

MF is manufactured by the synthesis of melamine and formaldehyde resin and various additives and the particular foaming technique, presents the three-dimensional (3D) network structure with high porosity [210]. Due to its properties such as; thermal insulation, sound insulation, light weight, and water absorption, it has been commonly employed in many areas ranging from noise reduction, energy-saving, and building insulation, cleaning goods of catering sector , etc [211]. The MF products are available in several types and sizes in the market. MF has thermal conductivity coefficient of 0.034 W/mK, it has density of 11 kg/m^3. The operating temperature of MF is in the range - 60/ +150°C. Sound absorption coefficient is between 0.30-1.20 and fire rating is Class 0 [186, 203]. Photo of MF samples is presented in Figure 6.51.

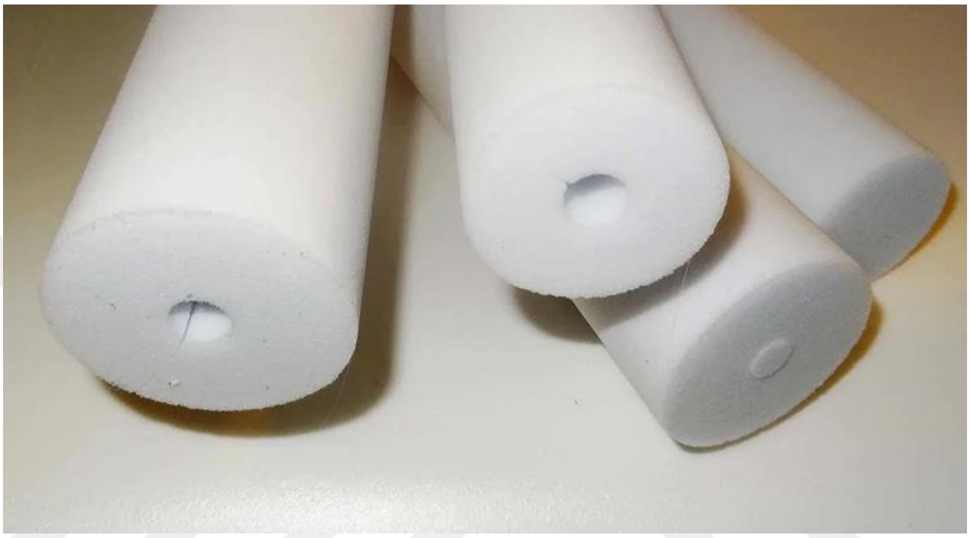


Figure 6.51 Photo of MF samples [212]

6.3.6.9 Phenolic foam (PF)

PF is typically manufactured by mixing, foaming, and curing a phenolic resin together with a blowing agent, a surfactant, a curing catalyst, an inorganic type filler in order to regulate their relatively low pH, and other chemicals, such as flame retardants and colorants [213-216]. Two alternative processes can be utilized in their manufacture, relying on the needed final product; the batch or continuous processes. The preference between the two manufacturing technique affects the arrangement of pores which is a principal parameter can be modified relying on desired performance [215, 217]. To attain specific final properties of the foam, the adjustment of the type and the amount of each components in the formulation is essential [218].

PF is manufactured in two alternative types; low density (30-60 kg/m^3) and high density (80-120 kg/m^3). PF products are available in the form of board, shell, block, plate, or cast-in-place [186]. Low density types have thermal conductivity value of 0.018-0.022 W/mK at 10°C and 0.027-0.031 at 100°C, whereas high density types have thermal conductivity value of 0.024-0.029 W/mK at 20°C, and 0.027-0.032 W/mK at 50°C. Because of their open porous structure, PF products have poor insulation against air, water and steam. Water vapor diffusion resistance coefficient of PF products varies through μ = 6.8-10 [189]. PF has the standard of Class B1 flame-retardant foam devoid of modification [219]. Photo of PF samples is given in Figure 6.52.

Figure 6.52 Photo of PF samples [220]

6.3.6.10 Sheep wool

New and recycled types of wool is utilized for manufacturing insulation materials. The fibers of the wool can be blended with polyester or fastened to grid made of polypropylene. The sheep wool is available market in the form of rolls (see Figure 6.53) and its elasticity enables to be used as a flexible material in floating floors (Dynamic hardness about 5 MN/m^3). Thermal conductivity coefficient of sheep wool is between 0.038 and 0.054 W/mK, its' density varies between 10 and 25 kg/m^3, and its' specific heat varies between 1.3 and 1.7 kJ/kg.K. Sheep wool thermal insulation materials have favorable performance in winter, while their summer performance is quite poor [221].

Figure 6.53 Photo of sheep wool rolls [222]

6.3.6.11 Cotton wool

Cotton fibers are primarily employed in the textile sector; besides, their availableness is very confined in Europe. Thus, 80-90% of cotton-formed sound and thermal insulation materials are manufactured from wastes obtained from the sector. While its' production, cotton fibers are combed and slackened, mechanically stabilized, and processed with a limited percentage of additive material (3-8% boric acid) to enhance its mold-proofing as well resistance against fire. Cotton wool is a renewable material which has good vapor permeability, besides its' production necessitates low energy use [223]. Moreover, It is compostable and recyclable. It has no nutritional property, insects and rodents cannot harm them. Its' primary drawback is high water sorption; thus, it is not appropriate for insulating components that is directly exposed to moisture (e.g. facades). In construction sector cotton based insulating felts, blankets, and strips are available, as well it can also be utilized as blown-in insulator like cellulose. It is mainly employed for insulation of attic floors, attic spaces, and pitched type roofs (between rafters) [224, 225]. Cotton wool products have thermal conductivity value of 0.0585-0.0815 W/mK [226]. Photo of cotton wool samples is given in Figure 6.54.

Figure 6.54 Photo of cotton wool samples [227]

6.3.6.12 Coconut fibers

The fibers are obtained from the middle shell of the coconut which is the by-product available from the coconut industry. It is processed to separate it from decaying constituent organic materials. The fibers of coconut perform high mechanical resistance. Insects and rodents can not harm the fibers, also fibers does not rot. Fire retardants are added to increase fire resistance [221, 228]. Boards and rolls, which are used for thermal and sound insulation, manufactured from coconut fibers are commercially available. Coconut fiber boards and rolls have coefficient of thermal conductivity 0.04-0.05 W/mK, density of 50-160 kg/m^3, and specific heat of 1.3-1.7 kJ/kgK. Dynamic stiffness of some commercial products is about 15 MN/m^3. Coconut fibers can be recycled as waste material, reused and further can be used for fertilizer production [221]. Photo of coconut fiber board is demonstrated in Figure 6.55.

Figure 6.55 Photo of coconut fiber board [229]

6.3.6.13 Cellulose

Cellulose fibre insulation is obtained from fibres of recycled paper and inorganic additives which are used to improve fire resistance and impede mould growth. The cellulose fibre can be employed as insulator in loose fill state or in the form of a fibre board [230]. The usage of cellulose has raised recently because of low value of thermal expansion coefficient, flexibility, high surface area, and biodegradability [231]. Cellulose fibre has low density, high durability, and high strength aside from being a renewable substance [232]. Cellulose has a thermal conductivity coefficient of 0.037-0.042W/m.K, a density of 30-80 kg/m^3, and a specific heat of 1.3-1.6 kJ/kgK [228, 233]. Photo of cellulose fibre insulation batts is given in Figure 6.56.

Figure 6.56 Photo of cellulose fibre insulation batts [234]

6.3.6.14 Calcium silicate board (CSB)

Calcium silicate is a collection of compounds which can be made up of several ratios of calcium oxide (CaO) in addition to silica (SiO_2). CSB is produced by the combinations of natural substances like reactive quartz sand or diatomaceous earth as siliceous material, limestone or typical portland cement as calcium material, and various fiber materials for reinforcement accompanied by blending, molding, and curing at a certain temperatures or sintering at elevated temperature [235, 236]. CSB can withstand high temperatures (some type of CSB can resist up to 1100 ºC) , thus it is used for high temperature insulation. CSB is resistant to severe climatic conditions. Nevertheless, it can be broken easily. Density of CSB products varies through 190–200 kg/m³. Thermal conductivity value at 20 °C is 0.049 W /mK, whereas at 500 °C is 0.100 W / mK. The compressive strength of CSB is very high (approximately 8–10 kg/m²) [208, 237]. Photo of CSB samples is presented in Figure 6.57.

Figure 6.57 Photo of CSB samples [238]

6.3.6.15 Foamed gypsum

Gypsum binders are made by the thermal processing of gypsum stone ($CaSO_4 \cdot 2H_2O$–CsD) at above 105 ◦C temperatures, as it can be modified in anhydrite ($CaSO_4$) or in hemi-hydrate ($CaSO_4 \cdot 0.5H_2O$–CsH) at elevated temperatures [239]. Because of minor thermal processing temperatures and the potential to recycle it in closed-loop systems, the gypsum binder is deemed to be ecological when compared with other sorts of inorganic cements. Currently, one of the primary usage of gypsum binder is the manufacture of gypsum plasterboards [239]; another usage of gypsum binder is to manufacture of sound and thermal insulation materials [239-245].

Gypsum based thermal insulation components can be acquired either by blending it with lightweight type aggregates, comprising several waste such as polyurethane foam, rubber, expanded polystyrene [244], and shredded electric cables waste [243, 246], or direct foaming utilizing several sorts of gas generators (calcium carbonate, aluminum sulphate together with citric acid or sodium bicarbonate [240-242]). The thermal conductivity value of this sort of materials can modify from 0.085 up to 0.416 W/mK relying on the property and quantity of the additions and the assessment technique [240, 242, 243, 245, 247].

Efforts to generate lightweight gypsum together with foaming agents have resulted in a material with a density varying through 300 to 600 kg/m^3[248]. Such material has superior thermal and sound insulation, low density and can be regarded as a sustainable material with improved performance [249]. In compliance with European standard of EN 13279-1 [250], gypsum binders or gypsum plasters are categorized as Class A1 regarding reaction to fire as they include less than 1% by volume or weight of organic substances, devoid of supplementary testing. Photo of foamed gypsum insulation material is given in Figure 6.58.

Figure 6.58 Photo of foamed gypsum insulation material [251]

6.3.6.16 Wood chipped board

It is manufactured in board form by compressing wood shavings with magnesite binder. Wood chipped board also provide sound insulation. It is resistant to suns' ultraviolet rays. Since it is an organic material, it may be harmed by various organisms and insects [186].

Maximum operating temperature of wood chipped board is about +110 °C. Heat conductivity calculation value is 0.09–0.15 W/mK, water vapor diffusion resistance factor (μ) is 2-5. With regard to fire resistance, wood chipped board belongs to "Class 1" considering the BS476 standard. Density of wood chipped board is in the range of 360–570 kg/m^3, the water absorption rate is approximately 10% by volume and the compressive strength is 200 kPa (20 tons/m^2) [186]. Photo of wood chipped boards is presented in Figure 6.59.

Figure 6.59 Photo of wood chipped boards [252]

6.3.6.17 Vacuum insulation panel (VIP)

VIP is made up of bearing and porous core materials, barrier packaging substance (having superior quality) and degasser that has significantly small value of thermal conductivity (5-10 times lesser than that of ordinary insulation materials like polystyrene and polyurethane foams) [253-255]. The main function of core material is to ensure the mechanical and insulating properties for VIP [256]. Therefore core materials within VIP should have features such as much porosity together with small interconnecting open cell build. Various materials are employed for core materials, for instance; inorganic fibers, polymer foams with opencell structure, and powders. The early thermal conductivity value of VIP can be as low as 5.2 mW/(m K) for organic foam, 3.6 mW/(m K) for nanoporous silica, and 2.2 mW/(m K) for glass fiber type core material [257-259]. Although VIP shows significant potential as a thermal insulator of future, there are various obstacles which have to be solved. VIP necessitates a low value of pressure inside. If the panel is damaged in any way, the vacuum will also be damaged so that the thermal conductivity will enhance. As well, splitting and adapting the VIP at field of implementation is not performable. Insulating a structure with VIP thus necessitates comprehensive planning from a initial step and a layout design of how and where the VIP shall be inserted into place. Further precautions should be taken while mounting VIP since they are a brittle. Also, damaged VIP also may cause of condensation and mould spread [260]. VIP can be used as an insulation material at facade, glazing, door, roof, and floor [256]. Photo of VIP insulation is demonstrated in Figure 6.60.

Figure 6.60 Photo of VIP insulation [261]

6.3.6.18 Aerogels

Aerogel is a foam in solid state that has rich open porosity (diameters of pores ranging from 2 to 50 nm). They are generally manufactured by drying a silica-included gel at certain temperature value [262]. Silica aerogel has porosity rate of 85-99.8% [263]. Rich porosity rate of silica aerogel leads to acquire low density (about 3 kg/m^3). Density of aerogel products used as building insulation material varies through 70-150 kg/m^3[221]. At ambient pressure, aerogel has 2– 3 times lower thermal conductivity value with regard to ordinary insulation materials. Apart from VIPs, aerogels can be modified at the implementation field. Because of its low tensile strength, the aerogel material is very fragile [256].

The optical features of aerogel are fairly notable. It is practicable to manufacture aerogel in transparent, translucent, or opaque form so that employing it for a broad category of implementations is possible, such as facades, windows, and roofs that will enable daylight and solar radiation to move through [264]. Aerogel is non-reactive and non-flammable material [256]. Aerogels have low value of thermal conductivity that varies through 14 and 19 mW/(m·K), strong hydrophobicity, low water vapour diffusion resistance, and favorable fire resistance. As compared to ordinary insulation materials, just about one-half of the thickness is required for aerogels in order to attain a specified insulation performance. Thus, aerogels are remarkably appropriate for the retrofit of historic structures in which limited space is available or in which a thick insulation would modify the aspect of the building significantly. A handicap of some aerogel materials for instance granules, boards, and blankets is that they generate dust while handling [265]. Photo of aerogel thermal insulation batt is given in Figure 6.61.

Figure 6.61 Photo of aerogel thermal insulation batt [266]

6.3.6.19 Phase change materials (PCM)s

PCMs capture and spread out heat to alleviate the heating and cooling energy consumption of a building. PCMs fundamentally serve as a thermal mass by way of liquefying as they gains heat, hindering the heat from spreading the conditioned volume and emitting the heat as the outdoor temperature alleviates (particularly at night) [283].

PCMs can be categorized into three groups relied on their chemical constitution these are; (i) organic type PCMs, (ii) inorganic type PCMs, and (iii) eutectic type PCMs. The category of organic PCMs can be subgrouped in paraffins and non-paraffins [267].

Paraffin type PCMs have a low thermal conductivity value (around 0.2W/mK) that limits their implementation [268] and have substantial change in their volume while the phase conversion [269]. The non-paraffins incorporates a broad category of materials for instance fatty esters, acids, glycols, and alcohols have usually perfect freezing and melting properties, however these are three times more costly when compared to paraffins. Organic PCMs are mostly chemically steady, they are not affected by supercooling, moreover they are non-toxic and non-corrosive. Organic PCMs have a great latent heat of fusion [267]. Inorganic PCMs mostly have good thermal conductivity, a quite high heat of fusion. They are economical as well non-flammable. Nevertheless, most of them are corrodent to majority of metals, suffer from phase decomposition and supercooling. Hydrated salts are the most ordinary inorganic PCMs that cannot be straightly integrated into a building material. Eutectics or eutectic mixtures are a blend of numerous solid materials in such ratios that the temperature of melting is as low as possible. For eutectics, limited data is available related with their physical and thermal properties [267]. Various applications with PCMs is available for energy efficient building design considerations such as; PCM application in construction materials (see Figure 6.62); PCM in HVAC systems/heat exchangers; PCM in glazing, blinds and shading [284].

Figure 6.62 Photo of PCM (left image) and its' implementation (right image) [270]

6.3.6.20 Ceramic wool

Ceramic wool is a fibrous insulation material that is used at very high temperatures. It can be used for operating temperatures of 1200–1400 °C in which rock wool cannot be used. It can be manufactured in the pattern of board, blanket (see Figure 6.63) and loose. It is white in color, density of material varies through 100–150 kg/m^3 according to its shape. Due to being a soft material, even the plate types have very low compressive strength. The variation in thermal conductivity value versus temperature for blanket type ceramic wool (having 160 kg/m^3 density) is given Table 3. Ceramic wool belongs to non-combustible material group. It is not affected by acids except for phosphoric acid and hydrofluoric acid [237].

Table 6.3 The variation in thermal conductivity value versus temperature for blanket type ceramic wool, having 160 kg/m^3 density [237]

°C	400	600	800	1000	1200
λ (W / mK)	0.0688	0.0946	0.1376	0.1806	0.2752

Figure 6.63 Photo of ceramic wool blanket [271]

6.3.6.21 Polyisocyanurate (PIR) foam

PIR foams have closed pore cell structures, they are manufactured by insertion of gas as forming PIR polymer, that is the identical step utilized for the manufacture of PUR foams [272, 273]. Among the foamed plastics, PIR materials have the best fire resistance (class "B" fire resistance category with regard to EN 13501-1). Coefficient of thermal conductivity for PIR is 0.027 W/m.K, density of PIR ranges through 15-45 kg/m^3, and specific heat is about 1.4 kJ/kgK [221, 228, 274, 275]. Photo of PIR foam boards is presented in Figure 6.64.

Figure 6.64 Photo of PIR foam boards [276]

6.3.6.22 PVC foam

PVC foam is a polyvinyl chloride based thermoplastic substance, it can be manufactured soft, semi-rigid, and rigid forms. Its' poreous structure modifies with regard to the manufacturing technique. Manufacturing with high pressure system generates closed-pore material, with low-pressure system generates mixed pore or open pore material, with non-pressurized system generates open pore material [203]. Thermal conductivity value of PVC foam is 0,042 W/mK at 20 °C [208]. Density of PVC foam products varies through 30-300 kg/m^3. Generally, density of the products used in construction sector varies through 30-40 kg/m^3. Hard PVC boards are brittle, while soft ones are elastic. Water vapor diffusion resistance factor for PVC foam varies through 40-80 (materials with closed pore do not absorb water, while other types absorb water). PVC foam is resistant to corrosion and decay, it can not be destroyed by insects [203]. Photo of PVC foam board is presented in Figure 6.65.

Figure 6.65 Photo of PVC foam board [277]

6.3.6.23 Vermiculate (VMT)

VMT is a layered silicate type mineral with the primary features of non-toxic, natural, negative charging , and superior expansion rate that is the main product of phlogopite and biotite modified by low-grade metamorphism [278, 279]. VMT has the peculiar feature of volume expansion thereafter heating in elevated temperature [280]. The product thereafter expansion is known as expanded VMT, that is curved in the form of a leech and has porous and loose structure and soft texture [281]. Subsequent to heating, the volume enhances and the density diminishes. Expanded VMT has perfect features of light weight, thermal insulation, low thermal conductivity, sound insulation, and adsorption that result expanded VMT implement to a broad sector; such as construction, thermal insulation, agriculture, acoustics, environment protection , etc. [282].

Also, VMT has the features of low cost, good chemical stability, high utilization rate, high thermal stability, etc., and can be utilized as a component of flame retardant thermal insulation materials. Thus, VMT is generally employed as an additive material for flame retardant coatings, flame retardant and thermal insulation polymer composite substances where VMT reside in a state of exfoliation [283, 284]. Vermiculite has a thermal conductivity value of 0.044–0.047 W/mK, a density of 50–130 kg/m³ [208]. Photo of VMT board is given in Figure 6.66.

Figure 6.66 Photo of VMT board [285]

6.3.6.24 Lightweight expanded clay aggregate (LECA)

LECA is a cellular substance manufactured by expanding clay minerals at high temperatures [286]. Granular form of LECA can be implemented independently or blended with plaster. It is also employed for lightweight concrete production [287]. These materials have fairly high thermal conductivity coefficient (0.08-0.20 W/m.K). The specific heat of LECA varies through 0.9 to 1.0 kJ/kgK [228]. LECA can be utilized efficaciously as a sound absorber over a wide frequency interval [288]. Photos demonstrating structure of LECA and its implementation as an insulator is presented in Figure 6.67.

Figure 6.67 Photos demonstrating structure of LECA (top image) and its implementation (down image) as an insulator [289]

6.3.6.25 Expanded Perlite (EP)

It is obtained by heating perlite, that is a sulfated sedimentary rock, at 900-1100 °C. It has a mixed (open and closed) cell structure. Perlite comprises 2% – 6% water; generally gray or dark gray in color. As well nearly, 75% of perlite is made up of silica (SiO_2) and 15% is aluminum oxide (Al_2O_3). As the perlite is heated volume of which enhances up to 5 and 25 times with the effect of embodied water and temperature. The density of EP is between 80 and 150 kg/m^3, thermal conductivity value is between 0.040-0.052 W/mK. As a good sound absorber, its sound absorption coefficient is comparable to other materials in granular form such as slightly expanded clay aggregate and expanded vermiculite [221, 290, 291].

Perlite is incombustible, non-flammable, and non-toxic material. It can be used up to 1000°C devoid of any loss in its properties. Its vapor vapor diffusion resistance coefficient is 1.8. Since it is chemically neutral material, it is not affected by acids and bases. Also, it is not affected by sun rays. It is resistant to biological effects and does not rot. Perlite can be utilized as a loose-fill thermal insulation material or it can be blended with a free binder into several materials such as composite panel, plaster, brick, and concrete [221, 292]. Photo of various grades of EP is demonstrated in Figure 6.68.

Figure 6.68 Photo of various grades of EP [293]

CHAPTER 7
CASE STUDY BUILDING

7.1 General features of the Gaziantep city

Located in one of the ancient settlement sites of Anatolia, where intersection region of Mediterranean and Mesopotamia zone, Gaziantep has been frontier settlement in every period of history. The city has experienced the Paleolithic, Neolithic, Chalcolithic, Hittite, Mitanni, Assyrian, Persian, Alexandrian, Seleucid, Roman, Byzantine, Islamic, Seljuk, Turkish-Islamic, and Ottoman ages, also conserves traces and artefacts of these periods. Gaziantep has been the shelter a lot of civilizations within the history by virtue of its geographic site. It has been settled since the pre-historic periods, the ancient silk road crosses through the city, it is located at the junction of the roads. Such reasons have made the city popular in terms of cultural, commercial, and artistic aspects so far [294].

Gaziantep is located at the juncture of the Mediterranean and Southeast Anatolian regions of Turkey, between longitude 36˚ 28’ and 38˚ 01’ East, and latitude 36˚ 38’ and 37˚ 32’ North. The city is neighbored by Kilis and Syria to the south, Osmaniye to the west, Kahramanmaraş to the northwest, Şanlıurfa to the east, Adıyaman to the northeast, Hatay to the southwest . The city has nine district; these are Araban, İslahiye, Karkamış, Nizip, Nurdağı, Oğuzeli, Şahinbey, Şehitkamil and Yavuzeli (Oğuzeli, Şahinbey and Şehitkamil are central districts). Figure 7.1 demonstrates location of Gaziantep in Turkey [294].

Gaziantep covers 6,222 km^2, that forms about 1% of Turkeys’ total surface. The land in the city is generally rugged and undulated. The city lies between the Arabian Peninsula flatlands to the southward and the curved Taurus Mountains to the northward and westward, and does not have much wide plains. Land of the city is geologically diversified, basalt masses are existent in some fields, as well plateaus of limestone and argillaceous limestone are encountered in other fields. Generally, the northern portion of the city is higher compared to the southern. Mean altitude of the city center is about 850 meter above sea level. Approximately, 52% of the city surface is covered by mountains, as well 27 % by plains [294].

Center of the city is located in field called the Gaziantep plateau (Gaziantep yaylası), that has higher altitude with regard to the surrounding field. The plains of Pazarcık, Narlı, and Araban lie northward of the Gaziantep plateau. The plains of Barak and Doğanpınar exist southward along the Syrian border whereas eastward is the lower altitude valley flowing Euphrates River. Other large plains are the İslahiye, Fevzipaşa Sakçagözü, Oğuzeli, and Yavuzeli [294].

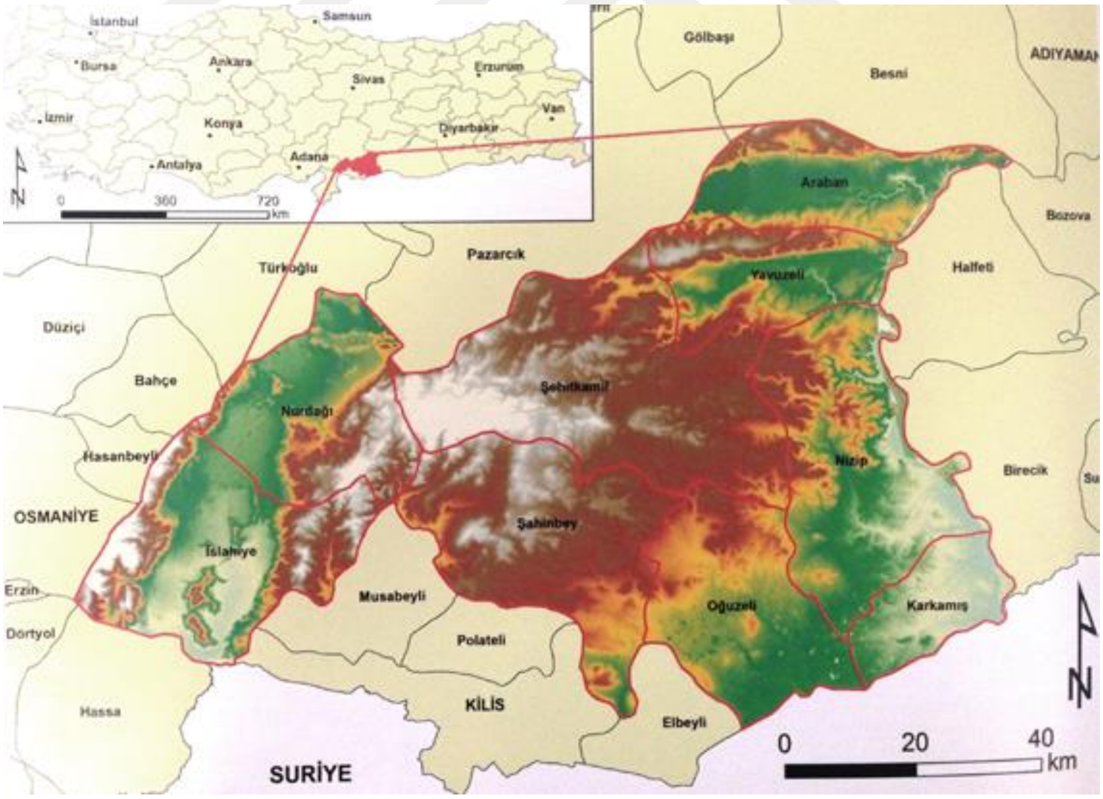


Figure 7.1 Location of Gaziantep in Turkey [295]

Gaziantep plateu has a few streams. Geological form of the land is not convenient for lake formation and most of the precipitation infiltrates to underground. Most of the streams in the city discharge to the Euphrates. Karasu (64 km in length) flowing from west to east in Araban plain, Merziman stream flowing in Yavuzeli plain, Nizip stream (longer than 100 km) and Sacır stream (about 80 km) are the principal streams which flow in to the Euphrates. Streams in Burç district, that is located 8 km westward to the city center, streams in Islahiye district discharge into the Amik Lake in Hatay. These streams are Sabun, Afrin, and Karasu [294].

Gaziantep is at the transition zone of from Mediterranean climate to continental climate. Because of the Amanos Mountains between the city and the Mediterranean region, continental climate is prevailing in inlands. Summer seasons are typically hot and dry, whereas winter seasons are warm and wet. In the city, prevailing winds are the poyraz (northeast) in winter season and the karayel (northwest) in summer season. The climate is more severe in the higher fields of the Gaziantep plateau and the Sof Mountains [294].

The annual mean temperature in Gaziantep is about 15.2 ºC. June, July, August, and September are the hottest months, as well the coldest are December, January, and February. The highest temperature ever recorded in Gaziantep is 44°C, while the lowest is -13°C. The highest precipitation amount is observed through December-February, whereas the lowest precipitation amount is observed through June-September. The annual mean precipitation is about 551.6 mm, and the seasonal precipitation regime from the highest to lowest is given as winter, spring, autumn, and summer [296].

Olive trees are abundant in the southward of the city (this property shows the impacts of Mediterrenean Climate). Pistachio trees, peculiar to the region, are abundant in Nizip, Oğuzeli, Araban, and Yavuzeli. The cumulative forest and heath field in the city is 92.419 ha, this value corresponds to 15 % of total area of the city. The westward and eastward of Gaziantep plateu is mountainous. The mountains that extent from southward to the northward in the west of the plateu; Hazil, Karuca, Kartal, Big Arap-Dede and Sof (West) Mountains. In the West Mountains, Kepekçi hill that has altitude of 1496 m, is the highest hill of the plateu. In the city, aside from West and Amanos mountains, the other considerable mountain is Karadağ [294].

7.2 Şahinbey district and Kolejtepe neighborhood

Şahinbey district has population of 936,351 the property of which makes 4th biggest district in Turkey. The district was established on July 4, 1987 (with the law having number of 3398) and started to work on September 19, 1988. The district has 181 neighborhoods with total surface area of 960 km^2 .

Kolejtepe neighborhood located in northeast part of the Şahinbey district (see Figure 7.2). The neighborhood has approximate surface area of 381,463 m^2, with 1 boulevard, 5 avenue and 18 street. The neighborhood consist of 296 buildings together with 4,094 detached units. It has total population of 8,056.

Figure 7.2 Kolejtepe neighborhood within the Şahinbey district (source: Şahinbey Municipality)

7.3 Building models

Gaziantep was strategically located close to old commercial paths was a crucial citadel that secures the Syrian corridor and was acquired in 1183 by Turks. Aging from the 11th and 19th centuries, numerous mansions, churches, castles, and mosques, which were inherited from Byzantine and Ottoman civilization, are existing in the city. Generally, these inherited buildings had been built with identical building materials obtained from the region with comparable processes [297]. In this study, an ancient building, that is legally under conservation, was surveyed to represent the most of the historical stuctures built in Gaziantep city.

In this thesis, three building models (BT1, BT2, and BT3) have been surveyed. BT1 is the historic-listed building, BT2 is the novel building scenario and BT3 is the restoration and structural retrofit of the BT1. The only assumptions made for this study is façade wall insulation for BT3. Except for this, whole the data pertinent to buildings have been obtained from a real restoration and structural retrofit project in Gaziantep, Turkey.

Comprehensive functional and architectural data pertinent to historic-listed building has been received from Şahinbey Municipality. Floor plans pertinent to BT2 have been arranged by conserving the architectural form and structure of the BT1.

7.3.1 Central Turkey College (BT1)

The schools opened by foreign states in the Ottoman lands were actually came out as a result of missionary actions. Before the Tanzimat reforms, missionary actions, that is part of the capitulations granted to foreign states, showed a rapid increase in the 19th century and accepted by many people so that influenced Ottoman education policy [298].

Foreign educational institutions within the Ottoman lands was established especially France, thereby England, America, Italy, Austria, and Russia. Schools pertaining to Germany, Austria, and Italy were established in the late 19th century, however, their numbers have enhanced rapidly [299]. United States of America, which acts as a protector of Protestants, performed more detailed and comprehensive studies, so that about 400 educational institutions opened until the end of the 19th century [300]. The American Board of Commissioners for Foreign Missions has contributed substantially to the rapid increase in American educational institutions. The board, founded in Boston in 1810, sent its first missionary to Ottoman lands in 1820, executed exhaustive and planned workout at three principal regions, namely Western Turkey Mission, Eastern Turkey Mission and Central Turkey Mission [298, 301]. Central Turkey Mission, had the largest number of Protestant congregations in these regions, achieved a prominent status for American missionaries. Central Turkey Mission comprised important settlements like; Antep, Adana, Tarsus, Maraş, Haçin, Antakya, Halep, and Urfa. Among these settlements, the capital city of the mission was Antep [302-304]. American Board Missionaries established many schools for education of girls and men in Antep. One of the most leading among these schools is Central Turkey College, that was the first college opened by the missionaries in Anatolia [305].

7.3.1.1 History of the Central Turkey College (BT1)

The building of Central Turkey College (in Ottoman archive documents called as Antep Ottoman Central School or Maarif America School) was thought to be built in 1875 [306]. Besides, It was officially established with the authority of Massachusetts state council on March 27, 1874 and it was licensed by the Ottoman Empire on January 15, 1878 [307]. Education in the college was initiated on September 11, 1876, and the first graduation eventuated in 1880 [307]. The land, on which the building is located, was donated by Kethüdazade Hacı Taha Efendi and some of prominent families of the Antep ensured support during the establishment of the college [308]. Moreover, Catholics, Antep Muslims, Protestants, Jews and Gregorians made support to the founding [308]. The college consisted of preparatory department, medicine department and science departments that provided 4-year education to male students. Students from outside of Antep town could also attend this college, from 1878 the college also accepted boarding students [305]. One of the most significant feature of the college was the establishment of hospital, that was a practical training oppurtunity for the students of the Department of Medicine. Headmaster of College, Dr. Tillman C. Trowbridge, has an important act in establishment of the hospital and the hospital was built on the honor of the first American missionary in Antep, Dr. Azariah Smith in 1880. The hospital, established with the grant of Azariah Smith's friends, was named as Azariah Smith Memorial Hospital [309]. The students that were trained in the school of medicine, also supplied the staffing needs of the hospital.

7.3.1.2 Location and architectural properties of the Central Turkey College

The Central Turkey College was a campus which comprised various structures. The college, that is ascertained to have been situated outside the Antep settlement in the 19th century, was constructed on a land with surrounding walls. In a document, obtained from the Ottoman archives (dates back 1914), the layout of the college and can be seen in Figure 7.3.

Considering this document, the main building (Trowbridge hall) located in the center. To the northwest of the main building Dickinson dining hall is located, and to the southwest is Andrews hall. To the northward of the Dining hall, a small bath is located. To northeast side of main building the teachers' house is situated , to the southward the house of college president and Dr. Spheards' exists. The college campus entrance is located on the east side [304]. As a result of harmful fire occured on December 22, 1890 about 70% of the buildings within the campus was destroyed [310]. An ancient photo of the buildings in this field is presented in Figure 7.4.

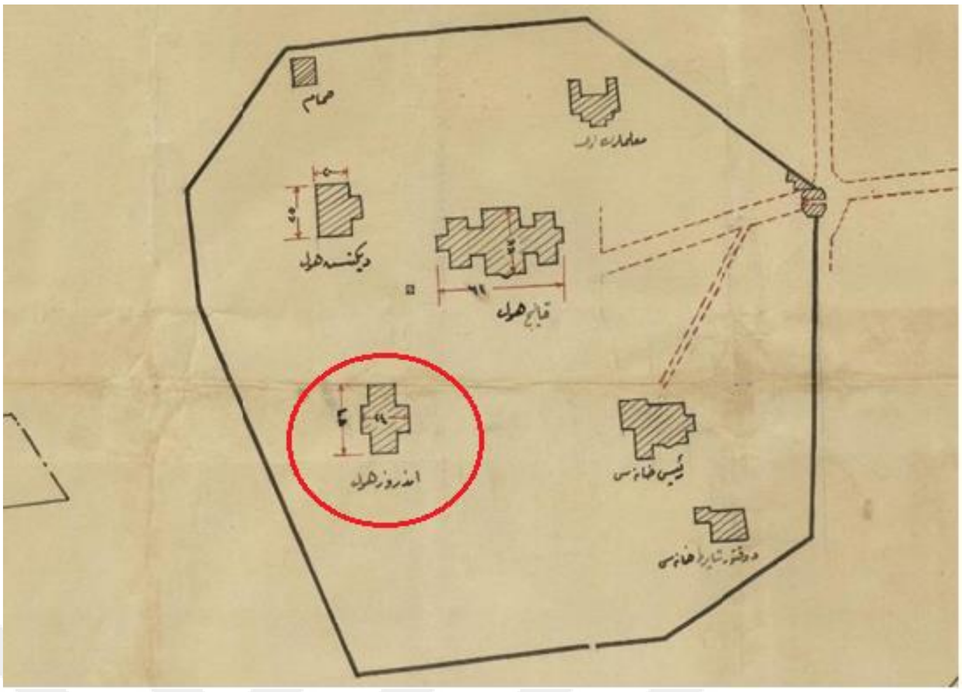


Figure 7.3 Layout of the college building [304, 311]

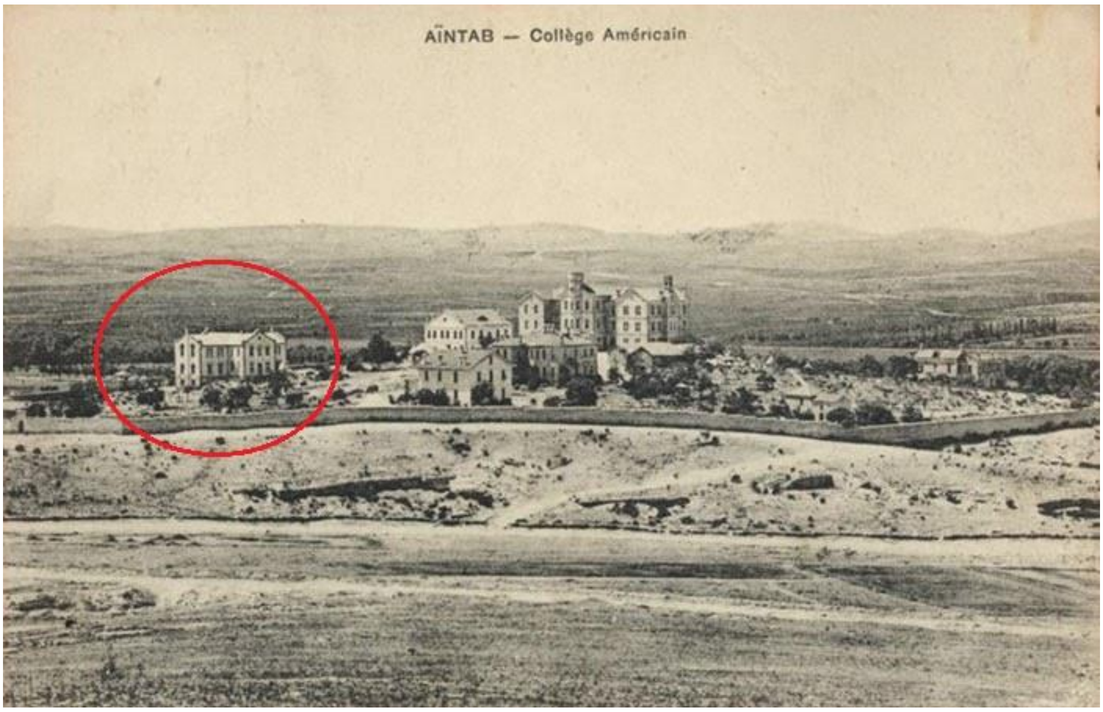


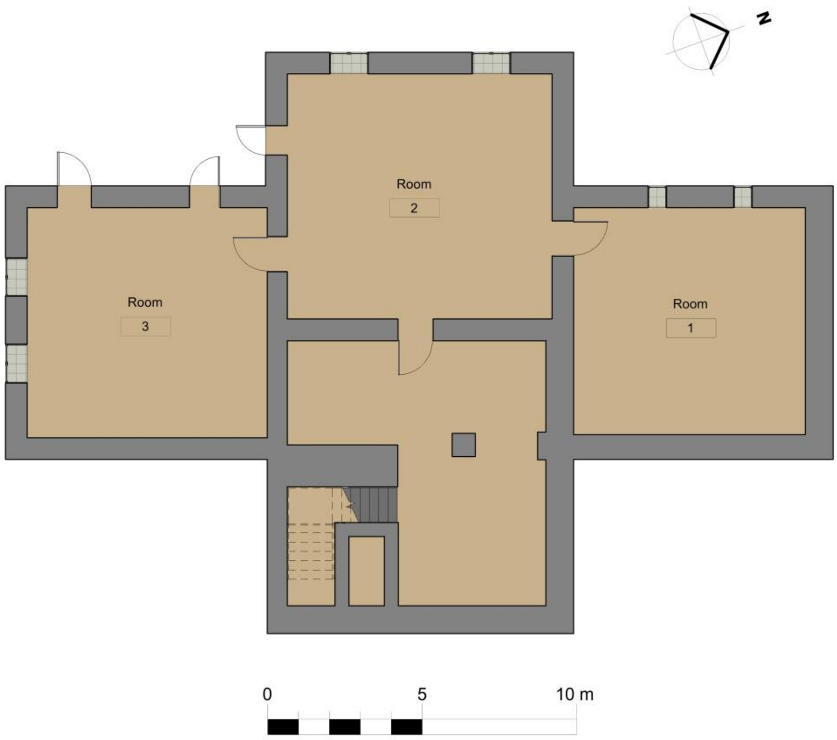
Figure 7.4 Photo of the Central Turkey College [312]

Regarding Central Turkey College, the only building that has remained standing up to now is Andrews hall, located in the southwest of the main building. This building, which was built by Miss Lucy Andrews in 1913, was utilized as the library of the college [313]. Currently, the building located in Gaziantep Şahinbey district, Kolejtepe neighborhood, Yeşil Cami Street, 2093 numbered city blok, 1 numbered parcel (the cumulative area of the parcel is 29,415.323 m^2) in the area where Gaziantep Şahinbey Municipality is located. Figure 7.5 presents current cadastral map of the college building. The studied building is currently used as the History of Islamic Science Museum. The building, has a cruciform plan shape, was constructed on a basement floor with 2 floors. The entrance to the ground floor of the building is provided through the flat door in the middle of the east facade. The entrance hall, that comprise a small area, is reached immediately after the door. To the southward of the entrance hall is staircase and to the westward there are two round arch openings leading to the middle hall. The third arch opening in the south direction reaches to the stair hall. In the north, south, and west side of the middle hall, there are three rooms having a square form. The rooms in the southward and northward are accessed through a round arched opening, whereas to westward room access is provided through a round arched door. The basement floor of the construction have a similar layout to the ground floor plan. Nevertheless, the middle hall has no connection with the spaces to the northward and southward. The middle hall serves as the transition to the western space that is utilized as a multipurpose hall today. There is a door on the north and south walls of this hall so that adjacent spaces are reached. Additionally, there is a computer hall, library, and restroom on this floor [304].

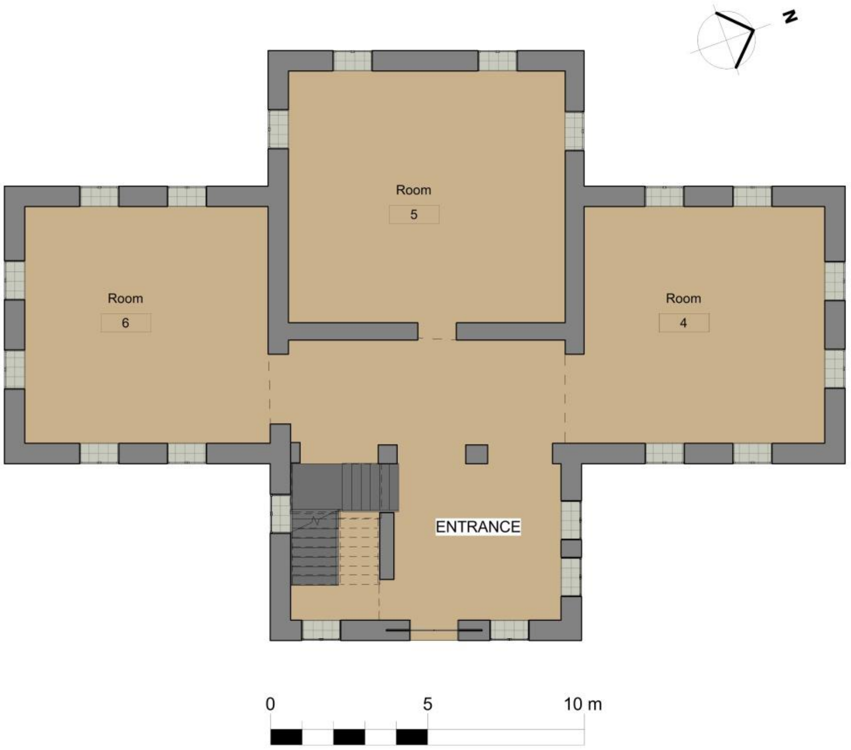
The first storey of the building has a different plan form from the other floors. On this storey, a small square planned room is located to the northward of the staircase. The other space is a single and large hall without any partition wall within the volume. Although the façade design of the building is in a symmetrical form, the size and shape of windows vary among the floors. Door and window openings are flat on the basement floor, there are round arched windows on the ground floor. On the first floor, both flat and round arched windows are existent. Nevertheless, the flat windows in this floor are in the form of two successive rectangular windows, connected by a single lintel from above and enclosed in a frame. The northern, southern, eastern, and western façades, forming cross plan form of the building, end with a triangular pediment. In the middle of the south and north façades, the protrusions of the chimneys exist. On the westward, there is also a chimney on the façade, however there is no protrusion of it. On the façade, where the entrance exist, the pediment rises from the roof with rounded lines and a small round window exist in the middle of the pediment. At the corners of the building, staggered rows of stones are placed. The façade of the college, that was constructed with the local limestone (keymık). Black basalt stones were used on the façade corners pediments and window arches [304].

The college building has been selected as a case study due to the fact that a well-detailed constructional data is available about the building as well as it is open to visit for fieldwork of this study.

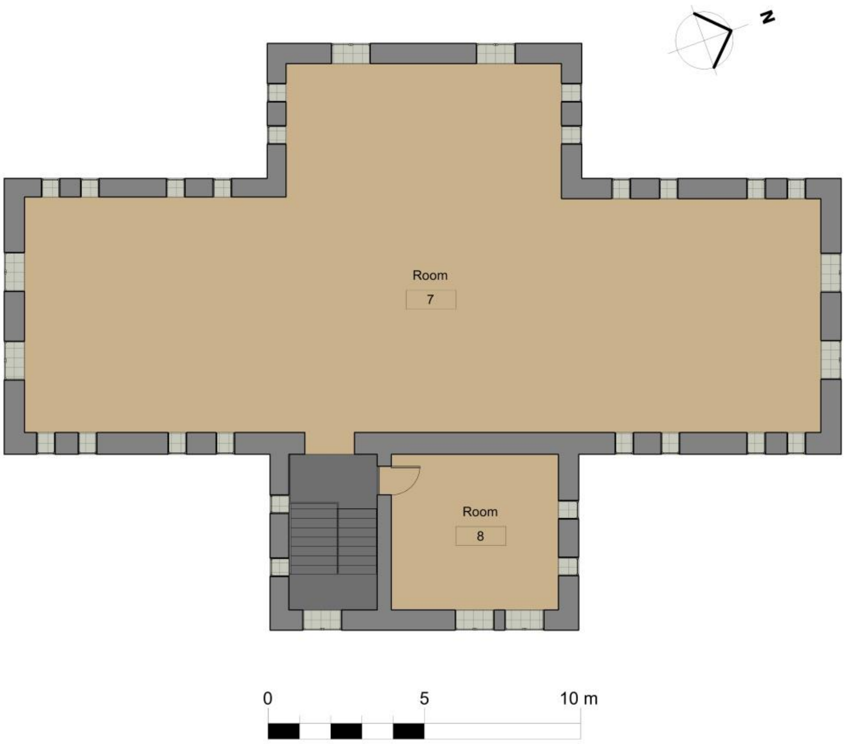
Figure 7.5 Current cadastral map of the college building (source: Şahinbey Municipality)



Basement floor plan



Ground floor plan



1 st floor plan

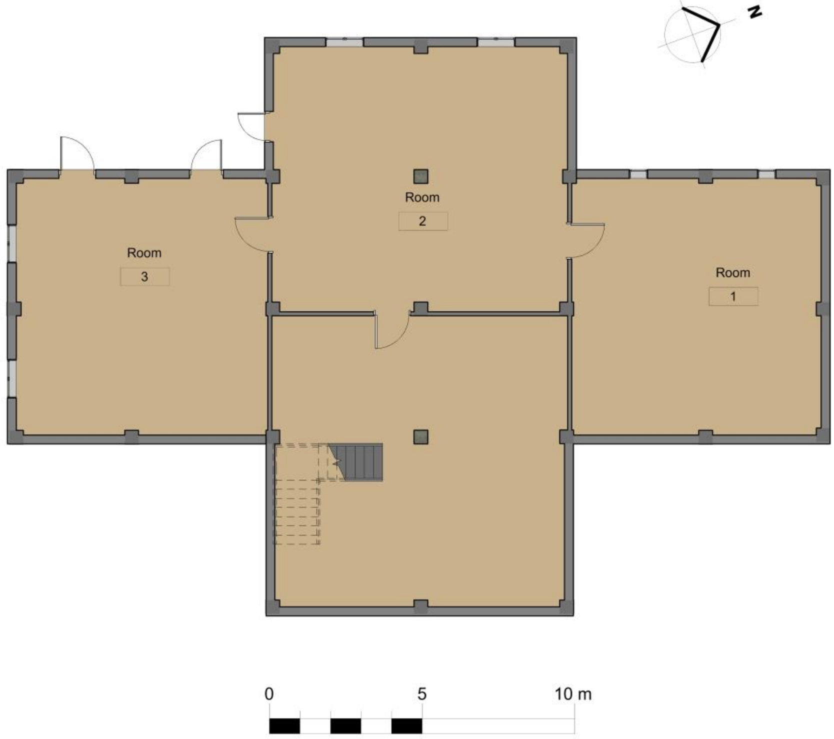
Figure 7.6 Floor plans of the BT1

7.3.2 Re-built scenario (BT2)

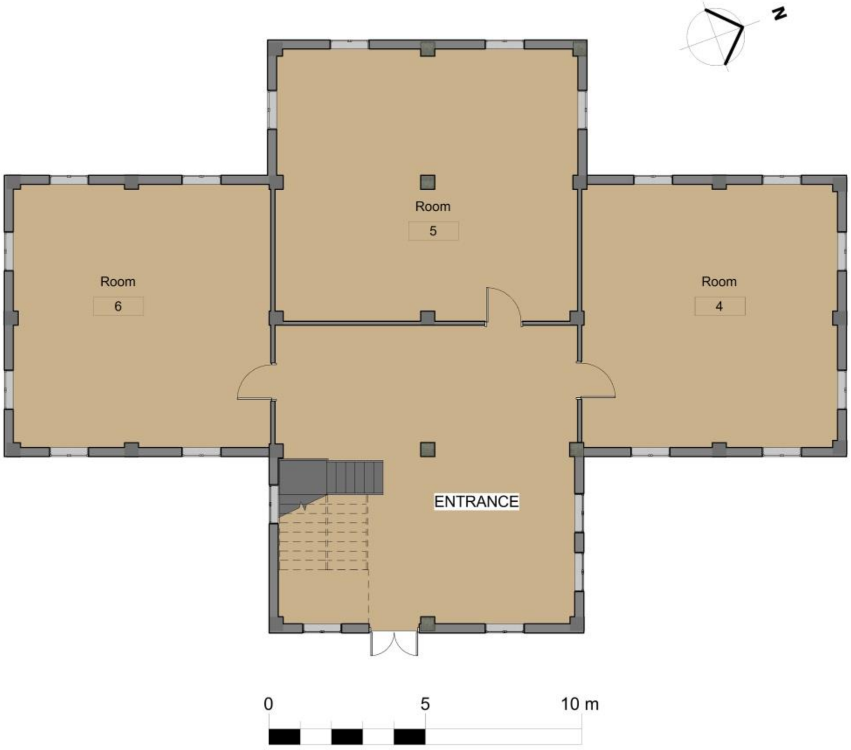
The second building model is BT2 in which the re-built scenario has been surveyed via using state of art construction elements and corresponding materials. The building is evaluated to be reconstructed by RC framed structure which has arranged with High-Strength Concrete (HSC) of 35 MPa and steel rebar having grade of S420.

Interior and exterior wall constructions of BT2 have been formed with AAC blocks rather than limestone blocks. The buildings' facade has been designated in accordance with the mandatory standard of "TS825 – Thermal Insulation Requirements for Buildings" via utilizing commonly used construction materials in existing projects in Gaziantep.

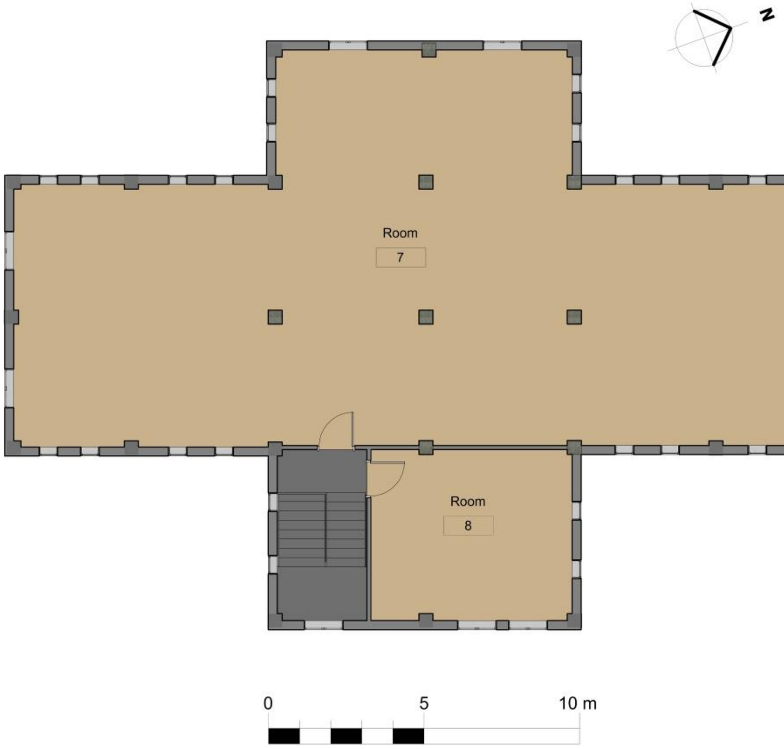
Bitumen have been implemented to the foundation of the structure in order for preventing the harmfull effect of moisture as well ingress of water,. Exact details pertinent to buildings physical features are given in Table 7.1. Also, floor plans pertinent to BT2 are given in Figure 7.7.



Basement floor plan



Ground floor plan



1 st floor plan

Figure 7.7 Floor plans of BT2

7.3.3 Restoration and Retrofit case (BT3)

Within the years 2008-2013, in order to enhance overall integrity of the structure, BT1 was seismically strengthened with steel framing system. Moreover, old single glazed windows were renewed by timber double glazed windows that have glazing thickness of 6 mm. Destroyed roof of the BT1 was renewed with a roof structure that has a layer of bitumen and glass wool insulation with 8 cm thickness.

It has been stated by the authority that before the restoration of the BT1 two different restoration project had been prepared; the first option is façade walls having 3 cm thick rock wool insulation (internally implemented) , the second option is devoid of façade walls insulation. According to local conservation policies, it was not allowed to implement thermal insulation for the façade walls of the historic building. Hence, in order for investigating effect of insulation on energy consumption, it has been assumed that façade walls of the building had been insulated with 3 cm thick rock wool (internally implemented) overlayed by 1.5 cm thick plaster layer.

The bill of quantities pertinent to restoration and structural retrofit was acquired from Şahinbey Municipality. Exact details of the buildings physical features are given in Table 7.1. Figure 7.8 demonstrates photos of BT3 during restoration and structural retrofit. As well Figure 7.9 presents photos of BT3 thereafter restoration and structural retrofit.

Roof aspect of BT3

Interior aspect of BT3

Interior aspect of BT3

Interior aspect of BT3

Figure 7.8 Photos of BT3 during restoration and structural retrofit (source: Şahinbey Municipality)

Front aspect of BT3

Side aspect of BT3

Interior aspect of BT3

Interior aspect of BT3

Figure 7.9 Photos of BT3 thereafter restoration and structural retrofit (source: Şahinbey Municipality)

Table 7.1 Specifications of BT1, BT2, and BT3

Specifications	BT1	BT2	BT3
Number of storey	3	3	3
Gross building area (m^2)	1008.16	1008.16	1008.16
Base area (m^2)	340.33	340.33	340.33
Storey height (m)	2.93 for basement storey 3.70 for ground storey 3.70 for 1 st storey	2.93 for basement storey 3.70 for ground storey 3.70 for 1 st storey	2.93 for basement storey 3.70 for ground storey 3.70 for 1 st storey
Cumulative height (m)	10.33	10.33	10.33
Foundation	20 cm compacted gravel	50 cm mat foundation Bitumen 10 cm lean concrete	20 cm compacted gravel
Interior wall	Limestone block wall (45-60 cm thickness) (U-value is 1.2-1.5 W/m^2 K)	10 cm AAC block (U- value is 0.45 W/m^2 K)	Limestone block wall (45-60 cm thickness) (U-value is 1.2-1.5 W/m^2 K)
Exterior wall	Limestone block wall (60-90 cm thickness) (U- value is 0.5-1.2 W/m^2 K)	20 cm AAC block (U- value is 0.22 W/m^2 K)	Limestone block wall (60-90 cm thickness), 3 cm rockwool insulation (U- value is 0.25-0.85 W/m^2 K)

Roof	Roof tile Wooden frame (Overall U-value is 0.788 W/m^2 K)	Roof Shingle, Wooden frame (Overall U-value is 0.705 W/m^2 K)	Roof tile, Wooden frame, 8 cm thick glass wool (Overall U-value is 0.415 W/m^2 K)
Floor	25 cm wooden framed slab (Overall U-value is 1.22 W/m^2 K)	15 cm reinforced concrete slab 2 cm marble tile (Overall U-value is 2.85 W/m^2 K)	25 cm wooden framed slab (Overall U-value is 1.22 W/m^2 K)
Windows	Cumulative area of windows 109.28 m^2, 3 mm glass, single glazed, wooden frame (overall U-factor is 5.57 W/m^2 K)	Total area of windows 109.28 m^2, 3 mm glass, double glazed, 12.7 mm air space, aluminum frame (U- value is 4.18 W/m^2 K)	Total area of windows 109.28 m^2, 3 mm glass, double glazed, 12.7 mm air space, wooden frame (U- value is 2.86 W/m^2 K)
Doors	Wooden framed (U- value is 1.2 W/m^2 K)	Wooden framed (U- value is 1.2 W/m^2 K)	Wooden framed (U- value is 1.2 W/m^2 K)
HVAC system	Central VAV, HW heat, chiller 5.96 COP, boilers 84.5 eff.	Central VAV, HW heat, chiller 5.96 COP, boilers 84.5 eff.	Central VAV, HW heat, chiller 5.96 COP, boilers 84.5 eff.

CHAPTER 8
METHODOLOGY

8.1 LCA methodology

Environmental issues such as climate change, tropospheric ozone formation, stratospheric ozone reduction, depletion of natural resources, acidification, eutrophication, human-toxicological and eco-toxicological contaminants, land use, water use, and noise has created major concern on people. The enhanced ecological awareness and the potential impacts affiliated with products or service has raised interest in the evolution of methodologies to better perceive and handle these impacts [314]. Assessment of environmental loads of a product or goods within several life cycle stages constitutes principal concept underlaying the LCA. LCA approach rates entire the supply as inputs, embracing water, energy and materials, and ecological loads encompassing greenhouse outputs as well refuses of a building throughout separate phases of the life cycle [10, 315-319]. LCA can be stated by the subsequent algebraic formula:

$$I = I_{Extraction} + I_{Manufacture} + I_{Onsite} + I_{Operation} + I_{Demolition} + I_{Recycling} + I_{Disposal} \tag{8.1}$$

where I denotes to life cycle environmental loads, and I_j denotes to environmental loads of jth building phase.

There are several defined practices to specify scope and perform a LCA. These are classified as [320]:

- Cradle-to-grave: This procedure is the most inclusive and detailed phase. A product or system are inspected from acquisition of raw materials to disposition in cradle-to-grave practice. Accordingly; all manufacturing, shipment, and end of life phases are considered.
- Cradle-to-gate: This procedure does not comprise use and disposal stages; thus, it is a limited LCA from cradle (raw material obtainment) to gate. The gate can be specified in two modes. It could be a plant in which goods are produced. Moreover, it could be a site in which ultimate product is expended. The distinction between two modes is shipment/distribution stage. If the gate is described as a site in which ultimate product is expended, distribution likewise have to be included to the system boundaries.
- Cradle-to-cradle: It is a closed-loop procedure that involves analysis devoid of disposal and landfill stages. Hence, it is primarily a recycling procedure.
- Gate-to-gate: It is a partial LCA procedure in which cradle phase of products (such as raw material extraction, etc.) is not considered. It merely deals with manufacture phases for instance shipping of material from one gate to another or ultimate product life period between the manufacturing plant and final users.
- Gate-to-grave: This procedure is utilized to survey end of life phases. It does not include manufacturing phase. The system boundaries initiate with final consumer and terminate with end of life phase.

8.2 Standards related with LCA

Evaluation of energy flow and environmental impacts of a process, product, or a building is complicated and complex task during its life time. The initial modern LCA approach was conducted in 1969 by Coca Cola in order to survey environmental impacts of packaging [321]. Thereafter, various institutions attempted to standardize a framework for LCA. International Standards Organization (ISO) has presented a series of standards for LCA these being; ISO 14040 that relates with principles and framework [322], ISO 14044 that relates with requirements and guidelines [323]. Considering these standards, LCA approach has four principal steps: goal and scope definition, Life Cycle Inventory (LCI) analysis , Life Cycle Impact Assessment (LCIA), and interpretation as can be seen Figure 8.1. However, LCA approach for buildings has various distinctions from a routine product manufacturing. For that reason , a new approach has presented for buildings. This approach is called as EN 15978 that relates with calculation method. It is a European standard and it was published by British Standards Institution (BSI) [324]. The standard branches the building life time into several phases. Figure 8.2 demonstrates building elements life cycle.

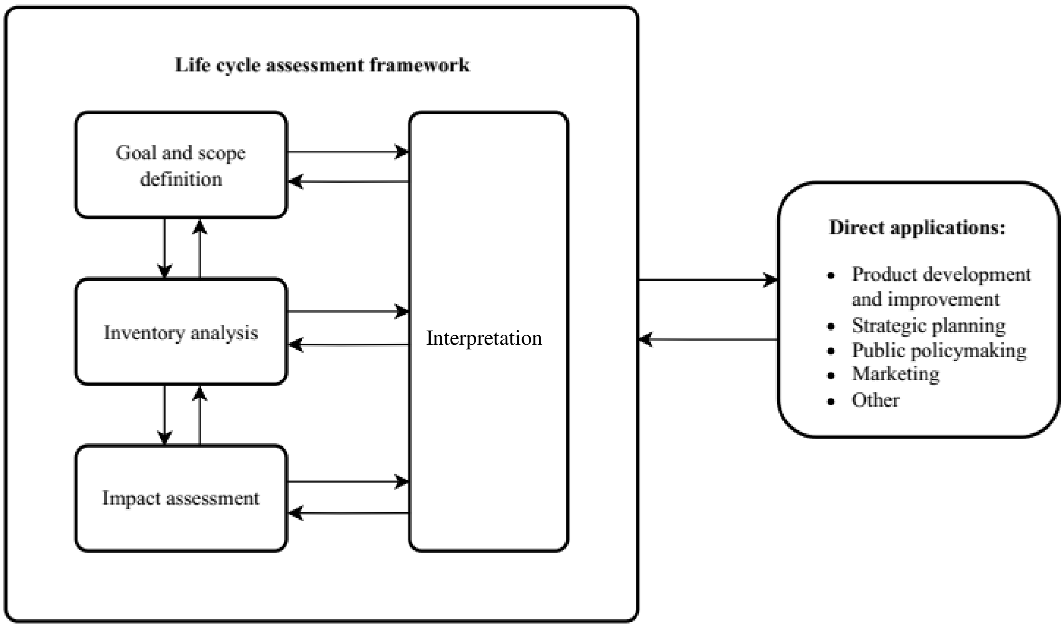


Figure 8.1 Steps of LCA [322]

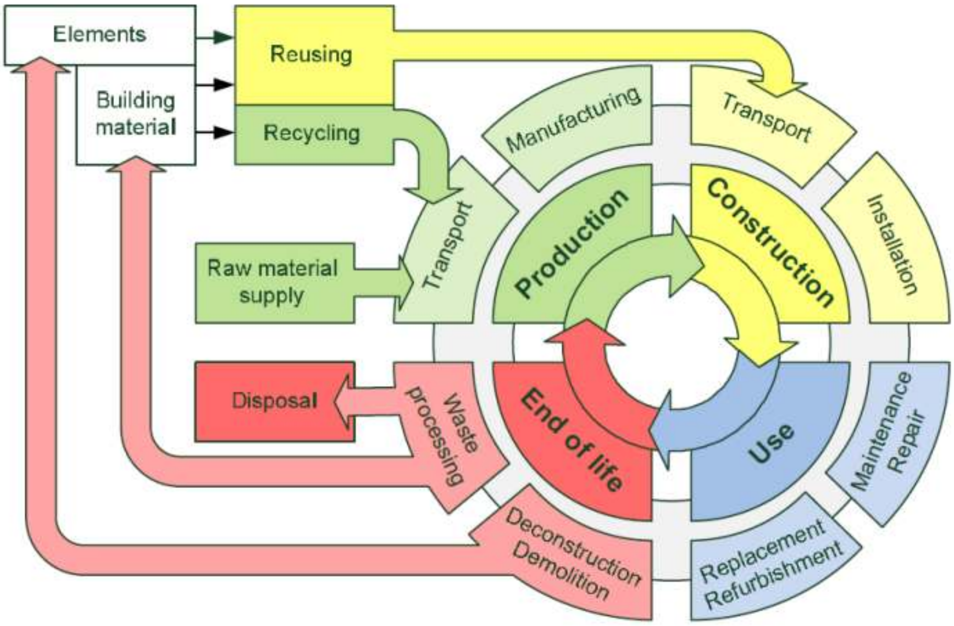


Figure 8.2 Building elements life cycle [325]

Goal and scope definition

This phase of a LCA ensures a explanation of the manufacturing system with regard to the functional unit and boundaries of the system. The functional unit is the crucial support which facilitates alternative services, or products to be compared and examined. The functional unit is not invariably only an amount of goods. Practiser might want make a comparison, for instance, several kinds of enwrapping relied on 1 m^3 of enwrapped and shipped goods - the service that the goods ensures. The quantity of enwrapping equipment needed, entitled the reference flow, can differ relying on the enwrapping equipment chosen (plastic, metal, kraft, composite, etc.) [326].

Life Cycle Inventory (LCI) analysis

LCI is a technique in order to assess the depletion of natural resources and the amounts of waste streams and released greenhouse outputs or else imputable to life cycle of a goods. Depletion of natural resources and production of waste/greenhouse outputs are possibly to arise;

- At numerous regions and places of the world,

- As separate portions of the cumulative greenhouse outputs at any one place (the portion needed to ensure the determined functional unit; share within relevant and irrelevant coproducts in a plant for instance, a refinery, etc.),
- At distinct times (e.g. use stage of an automobile in comparison with its disposal), and
- Throughout distinct time intervals (multiple generations in some instances, e.g. for landfilling) [326].

Life Cycle Impact Assessment (LCIA)

LCIA ensures indicators and the framework in order to identify and quantify impacts of extraction resources and refuses/greenhouse outputs in an inventory to a broad category of possible impacts. The outcome of the LCIA is an asssesment of a goods life cycle, relied on a functional unit framework, with respect to various impacts classifications (for instance land use, toxicological stress, climate change, noise, etc.) and in some situations, in a accumulated manner for instance years of man life deceased because of carcinogenic effects, climate change, etc [326].

Interpretation

The interpretation takes place at every phase in an LCA. If a comparison between two options of two goods are made and one option exhibits greater depletion of each resource and each material, an interpretation absolutely relied on the interpretation can be decisive. A practiser, nevertheless, might likewise wish to make a comparison throughout impact groups, specifically as there exists trade-offs within goods options, or if it is desirable to make priority to fields of interest through a particular life cycle survey. For instance, CO_2 outputs in a particular life cycle might lead to a greater climate change index with regard to other one, however the option requires more pesticides as well has a greater potential of toxicant effects. Accordingly, a participant might wish more data to choose which distinction is a greater precedency [326].

In available studies, three main branch of studies are present concerning with the ecological burdens of structures. The initial branch of studies is LCA, which evaluates the cumulative ecological burdens of structures within their entire life cycle. Life

Cycle Energy Assessment (LCEA), that constitutes the second branch, is an inspection of the energy use within several phases of life cycle of structures, designated as primary energy use up from nature furthermore secondary energy as tangibly consumed energy [327, 328]. Life Cycle Carbon Emissions Assessments ($LCCO_2A$) is the latest nomenclature , the target of which is to estimate the CO_2 loads within the complete life cycle of a structure [328]. Basically, LCEA appraises energy imported to a structure and $LCCO_2A$ estimates CO_2 related emissions exposed from the structure.

8.3 LCEA and $LCCO_2A$ methodology

LCEA is a methodology which handles energy intakes to a structure throughout its life cycle. The system limits encompass the energy depleted during manufacture phase (embodied energy), use (operational energy), and demolition phases. Manufacturing phase incorporates production and carriage of constructional materials and maintenance efforts of the structures. Use phase comprises entire practices (lighting, heating, cooling, cooking, electricity devices, and hot water) concerning the operation of the structures, within its life time. After all, demolition stage encompasses destruction of the structure and carriage of disintegrated residue to landfill spaces else recycling mill. LCEA can be carried out utilizing either primary or secondary energy. Energy sourced from nature (natural gas and coal) is termed as primary energy, whereas actually depleted energy (e.g. electricity) is termed as secondary energy [319].

LCEA should be expressed in mathematical form by exchanging the expressions I's in Eqn. (8.1) by E's to obtain Eq. (8.2) as illustrated in the formula given below:

$$E = E_{Extraction} + E_{Manufacture} + E_{Onsite} + E_{Operation} + E_{Demolition} + E_{Recycling} + E_{Disposal} \tag{8.2}$$

in which E denotes to the overall energy depleted within the complete life cycle of a building, as well E_j denotes to the energy depleted within j^{th} building phase.

All carbon relevant greenhouse gas outputs released at distinct phases of the life cycle of a building form the LCCO_2A's system boundary. By exchanging the expressions I's in Eqn. (8.1) with 'CO_2', we can estimate life cycle carbon emissions value and numerically it can be found out from the Eqn. (8.3) :

$$\begin{aligned} CO_2 &= CO_{2Extraction} + CO_{2Manufacture} + CO_{2Onsite} + CO_{2Operation} \\ &+ CO_{2Demolition} + CO_{2Recycling} + CO_{2Disposal} \end{aligned} \tag{8.3}$$

in which CO_2 denotes to the CO_2 outputs of a building within the complete life cycle, CO_{2j} denotes the CO_2 outputs within the j[th] building stage.

8.3.1 Construction phase analysis

Preference of the primary analysis technique, controls the precision of a LCA . There are three techniques employed in LCA ; process analysis, input-output (I - O) analysis, and hybrid analysis. Process Analysis is a bottom-up technique that solely involves processes within the boundaries of the product system under investigation. Nevertheless, environmental loads, associated with inputs and outputs, that are situated beyond the system boundaries are apart from context of this technique. This practice is often entitled by the 'truncation error', which is affiliated with the elimination of processes left outside of the system boundaries [329].

Embodied energy is made up of two primary elements [330]:

- Initial embodied energy: is the cumulative energy arised in extraction and fabrication of material, subsequently energy required to carriage of the material to building site.
- Recurring embodied energy: is the cumulative energy involved for replacement, repairing, or renovation of building.

In this survey, in order to compute primary energy demands and related greenhouse emissions, Inventory of Carbon and Energy (ICE) Version 3.0 [331] is employed .

The ICE comprises estimates of EE, carbon and GHG (computed in grams of CO_2 equivalent, g CO_2eq.) for a diverse category of materials. Recurring embodied energy have been utilized to compute life cycle EE value of the buildings. $LCCO_2A$ evaluates all the carbon equivalent emission released by a building throughout various phases of its life cycle. The “Embodied GHG” (EGHG) emissions encompass the GHG emissions caused by procuring of resource materials to the building site. The “embodied carbon” expression is employed for both GHG and carbon outputs in the ICE. Throughout this study, the data extracted from ICE database has been employed. Concerning the energy and emissions intensity values for construction materials, there are currently no list in Turkey. Considering this study, the ICE database may result in imprecise outputs because of the diversity in fabrication processes of construction materials of each country.

8.3.2 Operation phase analysis

Use (operational) energy can be described as the energy required for providing comfortable living conditions in the buildings. Use energy encompasses lighting, energy for electricity appliances, hot water, and HVAC equipment. It is largely in interaction with climatic conditions, the limits of comfort circumstance demanded and operating schedules [6].

In order to estimate use energy demand of buildings, three procedures have been utilized:

- Via utilizing the actual energy use records acquired from utility bills, or energy auditing.
- Via benchmarking several energy consumption databases. For instance, databases from Energy Information Administration (EIA) in the United States.
- Via using energy simulation techniques. Building Information and Modelling (BIM).

In this survey, in order to create architectural model of the case study buildings regarding inventory database of building materials, Autodesk Revit BIM software tool is employed. GBS energy simulations service, that is incorporated to BIM software, is utilized to compute OE use of case study buildings. GBS automatically discovers the closest air station for receiving weather facts, that is sought out during the simulation of project.

8.3.3 Demolition phase analysis

Energy needed to destruct the building, subsequent to the buildings' operation lifetime, and to transfer the debris material to landfill fields or recycling facility is termed as demolition energy [332]. It is the cumulative energy depleted by the actual destruction works and energy needed to transport debris material.

It is important to decide the appropriate waste processing procedure that bring about fewer greenhouse emissions. The environmental effects of recycling structures' destruction remainings range through each structural materials [333]. Masonry debris recycling process has much fewer ecological impacts with regard to metal waste. Within various lifecycle stages, the insitu stockpile and sorting have the highest share to the overall ecological impacts.

8.4 Presumptions and uncertainties

LCEC and LCCE of buildings comprises a lot of presumptions and simplifications pertinent to the sorts of used building materials and energy demands of buildings during construction, use, and demolishment stages. Crucial uncertainties are present affiliated with energy depletion and CO_2 outputs owing to the location and the place of the constructions, material production phases, and the building materials used. The outcome of this survey might be affected by disparities and deviations in any of such determinants. The subsequent presumptions were developed when performing the computations:

- The lifecycle periods of the building models for this survey was assumed to be 50 years in order for being able to make comparison for the outcomes.
- The floor plans pertinent to BT1 and BT3 type buildings were received from the Şahinbey Municipality. The BT2 type building (new construction

scenario) has been designed in the most identical model to the historic listed building.

- Energy intensities, conventional construction techniques of building, and construction materials were supposed to be uniform throughout the subsequent fifty years.

- Production of all end products was considered to be take place in the town of Gaziantep, supposing that shipment of materials is carried out through a 40 km radius.

- The usage periods were supposed to be identical for both the buildings and materials of construction.

- The amount of timber required for roof construction was identified by the norms of the “Turkish Ministry of Enviroment and Urbanisation” bidding rules.

- BT1, BT2, and BT3 buildings have usable floor spaces of 555 m^2, 666 m^2, and 501 m^2 respectively, with regard to area preference limitations of Revit software.

- The building materials and technique employed for the BT2 case has been supposed by inspecting the latest implementations of standard building firms in the district.

- For the studied buildings identical HVAC equipment is operated throughout the service life of the buildings.

- Estimations concerned with energy use that is intensely interrelated with the forthcoming changes in costs, legislation, user behaviour, environmental concerns, and corresponding greenhouse outputs during use stage are immensely uncertain. It was supposed for this study that a constant energy use rate relied on data from the years of 2015 to 2020.

- In order for reaching the intended thermal comfort, energy needs was assessed on an annual basis for cooling and heating periods and supposed to remain constant throughout the buildings' service life.

- An average inhabitants of 10–15 people has been presumed.

- The destruction of the buildings will rely on heavy machinery for instance lorries, excavators, and loaders thereafter the service life, the energy required for destruction is presumed to be diesel.

- The recycling plant range, shipping limits of the lorries, the carbon emission factor of the lorries, and the fuel economy are presumed to be 200 km, 20 tons, 0.005 kg CO_2/L, 15 L per 100 km respectively.

- EE related with destruction and disposal of construction materials was presumed to be negligible as well discarded from the survey.

- Some ecosystem properties for instance quality of indoor air are discarded, ecosystem effects are presumed to be unchanged throughout the service life.

- Because of the unforeseeable service life of the heritage buildings, the energy use and greenhouse outputs due to the destruction phase has been discarded.

- For LCEC and LCCE calculations GJ/m^2/year and tCO_2/m^2/year units are respectively considered .

- The EE (MJ/kg) and CO_2 outputs (kgCO_2/kg) have been amended in terms of extraction, processing, and manufacturing phases so as to reveal the actual circumstances in our country. Sensitivity analysis has been conducted taking into account the distinction in EE values and the deviations pertinent to outcomes have been given in Figures 9.14 and 9.15.

8.5 Tools and method

The floor plans pertinent to case study buildings were modelled by Autodesk Revit software. By this way, calculations related to quantities of materials and life cycle OE for studied buildings were procured by Autodesk Revit tool. The quantities of rebar and concrete for BT2 have been identified via using a structural analysis software tool (ideCAD Structural Analysis v 10.17) by fulfilling the requirements of Turkish Building Earthquake Code of 2018. Lastly, ICE Version 3.0 [275] has been employed to compute primary energy demands and related CO_2 outputs.

Autodesk Revit is BIM software tool which is practiced by architects, civil engineers, mechanical, electrical, as well plumbing engineers, building designers and contractors to create projects [334]. Autodesk Revit employs building components for instance walls, roof, doors, windows, columns, girders, and floor as building element rather than lines, squares, and circles. Moreover, it has a comprehensive object library. By using this software tool, 3D models can be formed and floor plans, aspects and sections can be received straightly [335].

The objects in the design have dimensional features for instance lengths, planes, as well volumes. Objects are incorporated mutually and if any modification is generated at plan; elevations, sections, and aspects are automatically reformed. Also, as new building elements are attached to model, it spontaneously modifies all of the design since it has capability to organize every building component in a single database so any modifications generated in the model, related revision can be obtained in the other views [334, 336].

Autodesk Revit can present quantity takeoffs of building materials in its' BIM database to facilitate construction procurement and quantification [337]. Thus, stakeholders can extract material quantities from the models directly.

Autodesk GBS is a flexible cloud-supported service which enables to perform energy performance simulations for buildings to optimize energy efficiency and to labor on 'net zero' at the beginning of design phase. GBS will contribute to broaden designers capability for designing high performance structures in a short haul and cost of ordinary techniques [338].

The GBS cloud service is a forceful building performance survey platform which is planned to considerably simplify the labor of performing whole building performance survey in currently available BIM design tools. The GBS employs DOE-2, a validated and proven simulation tool, to deliver energy consumption, carbon outputs, and water use results. Autodesk GBS can be utilized as a standalone web application.It moreover powers Autodesk Revits' whole-building energy modelling tools (open to Autodesk subscription users) [338].

CHAPTER 9
RESULT AND DISCUSSION

9.1 Construction phase

Data in relation to EE and equivalent CO_2 intensities of various construction materials obtained from ICE database are given in Table 9.1. Table 9.2, 9.3 and 9.4 presents the EE, CO_2 values and the amounts of building materials pertinent to BT1, BT2, and BT3, respectively.

Table 9.1 Embodied energy and CO_2 intensity ranges for several construction materials.

Type of construction material	Embodied energy intensity (MJ/kg)[a]	CO_2 Intensity (kg CO_2/kg)[a]
Aluminum	155–227	8.24–11.4
Asphalt and bitumen	2.6–51	0.045–0.48
Blocks and bricks	0.9–6.9	0.2–0.6
Concrete	0.7-1	0.05-0.14
Glass	15–18	0.85
Limestone	0.64-2.15	0.08-0.12
Gravel, stone and aggregate	0.075-0.095	0.0035–0.0052
Paint	10.0–81.5	0.9–3.56
Plywood	8.5-15	0.75-1.35
Plaster, screed and render	1.4–1.8	0.12–0.16
Structural steel and steel rebar	9.9–35	1.72–2.82
Acoustic and thermal insulation	3–45	0.15–1.86
Timber	7.4-11	0.23-0.63

[a] Intensity values are obtained from ICE database

Table 9.2 EE, CO_2 and construction material quantities of each section of BT1

Sections	**Materials (kg)**	**Amount (kg)**	**EE (MJ/kg)**	**CO_2 (kgCO_2/kg)**	**Total EE (MJ)**	**Total CO_2 (kg CO_2)**
Foundation	Gravel	184,951	0.083	0.0048	15,351	887.7
Wall	Limestone block	1,828,612	1.5	0.09	2,742,918	164,575
Floors	Timber	82,376	10	0.31	823,760	25,536
	Limestone tile for basement	92,475	1.5	0.09	138,713	8,322
	Limestone block for stairs	30,607	1.5	0.09	45,911	2,754
Roof	Roof tile	15,132	6.5	0.48	98,361	7,263
Others	Timber	13,480	10	0.31	134,800	4,178
	Wood doors	872	11	0.7	9592	610
	Iron railing	326.2	25	1.91	8155	623
Windows	Wood window unit (with single glazed glass)	75	286	14.60	21,450	1,095
				TOTAL	4,039,013	215,847

Table 9.3 EE, CO_2 and construction material quantities of each section of BT2

Sections	Materials (kg)	Amount (kg)	EE (MJ/kg)	CO_2 (kgCO_2/kg)	Total EE (MJ)	Total CO_2 (kg CO_2)
Foundation	Concrete	491,408.6	0.88	0.13	432,439.57	64,865.94
	Steel	14,822	21.6	1.9	320,155.2	28,161.8
	Bitumen	1,234	50	0.43	61,700	530.62
Wall	Aerated concrete	83,438.8	0.83	0.1	69,254.2	8,343.88
	Painting	478.9	70	2.91	33,523	1,393.6
	Plaster	47,938.5	1.8	0.13	86,289.3	6,232.01
Floors	Concrete	599,334.3	0.88	0.13	527,414.18	79,112.13
	Steel	24,325.7	21.60	1.9	525,435.12	46,218.83
Flooring	Marble tiles	51,161.1	3.33	0.21	170,366.46	10,743.83
	Plaster	21,813.1	1.8	0.13	39,263.58	2,835.7
	Painting	335.5	70	2.91	23,485	976.31
Roof	Roof tiles	15,132.6	6.5	0.48	98,361.9	7,263.65
	Timber	13,480	10	0.31	134,800	4,178.8
	Bitumen	1,175.3	51	0.43	59,940.3	505.38
Others	Wood doors	992	11	0.7	10,912	694.4
	PVC doors	180.6	77.2	2.61	13,942.32	471.37
	Aluminium railing	113.3	214	12.5	24,246.2	1416.25
Windows	Aluminium window unit (with double glazed glass)	75	4,500	229	337,500	17,175
				TOTAL	2,969,028	281,119

Table 9.4 EE, CO_2 and construction material quantities of each section of BT3

Section	Material	Amount (kg)	EE (MJ/kg)	CO_2 ($kgCO_2/kg$)	Total EE (MJ)	Total CO_2 (kg CO_2)
Foundation	Gravel	184,951.9	0.083	0.0048	15,351	887.7
Wall	Limestone block	1,828,612.5	1.5	0.09	2,742,918.75	164,575.13
	Rockwool	2,666.4	16.8	1.05	44,795.52	2,799.72
	Plaster	28,070.7	1.8	0.13	50,527.26	3,649.19
Floors	Timber	82,376	10	0.31	823,760	25,536.56
	Limestone tile for basement	92,475.9	1.5	0.09	138,713.85	8,322.83
	Limestone block for stairs	30,607.5	1.5	0.09	45,911.25	2,754.68
	Steel	63,280	21.6	1.9	1,366,848	120,232
Roof	Roof Tile	15,132.6	6.5	0.48	98,361.9	7,263.65
	Timber	13,480.6	10	0.31	134,800	4,178.8
	Bitumen	1,175.3	50	0.43	58,765	505.38
	Glass wool	534.9	28	1.35	14,977.2	722.12
Others	Timber	13,480	10	0.31	134,800	4,178.8
	Wood doors	872	11	0.7	9,592	610.4
	Iron railing	326.2	25	1.91	8,155	623.04
Windows	Wood window unit (with double glazed glass)	75	286	14.6	21,450	1,095
					5,709,726	347,935

The findings demonstrated that overall EE value of BT1 is 4039.01 GJ which equates to 7.28 GJ/m^2. The overall embodied CO_2 pertinent to construction of the BT1 is 0.389 tCO_2/m^2. In relation with EE requirements of BT1, limestone block elements (72% of EE) and timber (24% of EE) are the principal materials. It is estimated that limestone block elements (81%) and timber (14%) generate the highest contribution regarding CO_2 outputs.

Overall EE value of BT2 is 2969 GJ (4.46 GJ/m^2). The cumulative embodied CO_2 pertinent to construction of the BT2 is 0.422 tCO_2/m^2. In relation with EE requirements of BT2, concrete (29% of EE) and reinforcing steel (26% of EE) are the principal materials. Concrete and reinforcing steel generate the highest contribution regarding the CO_2 outputs with a equivalent share of 48%, and 25%, respectively.

Overall EE value of BT3 is 5709 GJ (11.4 GJ/m^2). The cumulative embodied CO_2 pertinent to the construction of the BT3 is 0.694 tCO_2/m^2. It is estimated that limestone block elements and steel generate the highest contribution regarding CO_2 outputs with a equivalent share of 48% and 35%, respectively. It is crucial to state that restoration and structural retrofit of BT1 has enhanced about 57% of EE and 79% of embodied carbon outputs of the building.

The EE shares of the construction materials pertinent to BT1, BT2, and BT3 are presented in Figures 9.1, 9.2, and 9.3 respectively. The life cycle EE and related carbon outputs of each component of the surveyed buildings are presented in Figure 9.4 and Figure 9.5, respectively. The wall components have the highest contribution to EE for BT1 and BT3, whereas floor sections have the greatest contribution to EE with a corresponding rate of 40% for BT2.

Energy demand of structures can be mitigated around 20-40% by the implementation of appropriate heat insulation [133]. For BT2, the efficacy of insulation on energy use and related emissions is surveyed. Accordingly rockwool insulation, having a thickness of 5 cm, is implemented to both exterior walls and floors. In that case, the overall EE values and related carbon outputs have the value of 4.46 GJ/m^2 and 0.422 tCO_2/m^2, respectively.

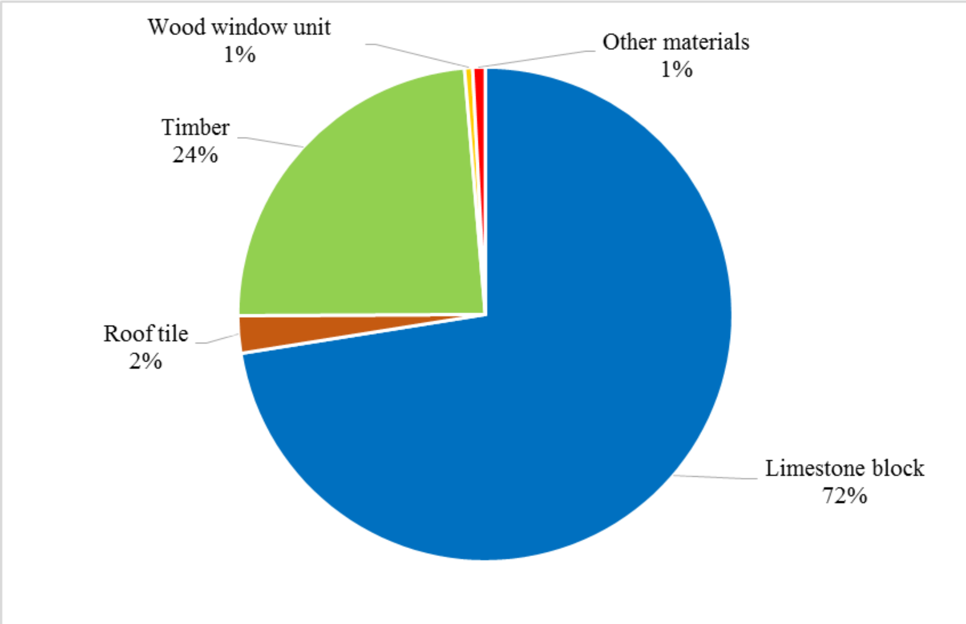


Figure 9.1 EE shares of construction materials for BT1

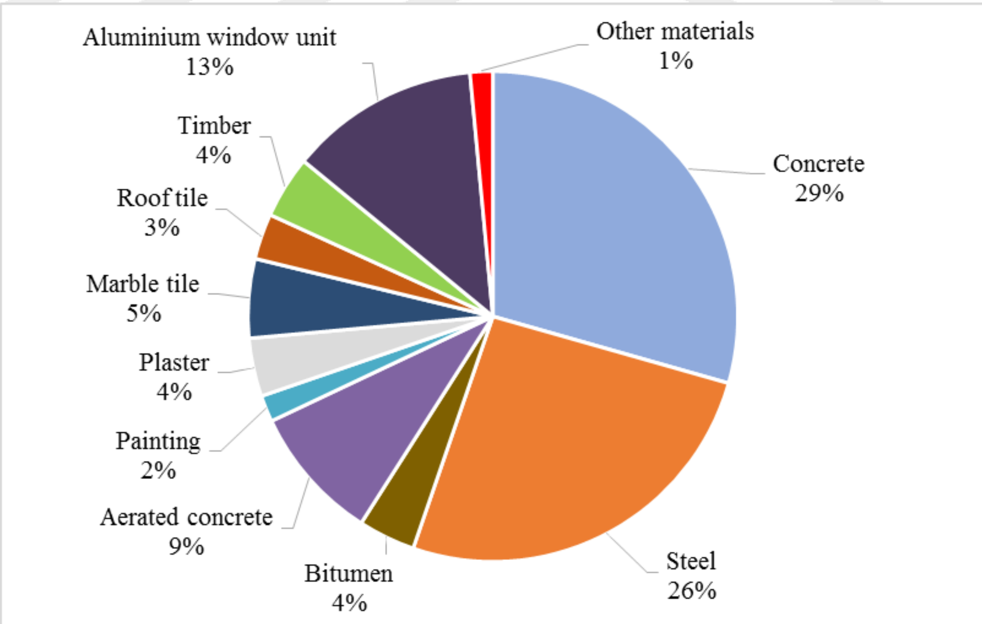


Figure 9.2 EE shares of construction materials for BT2

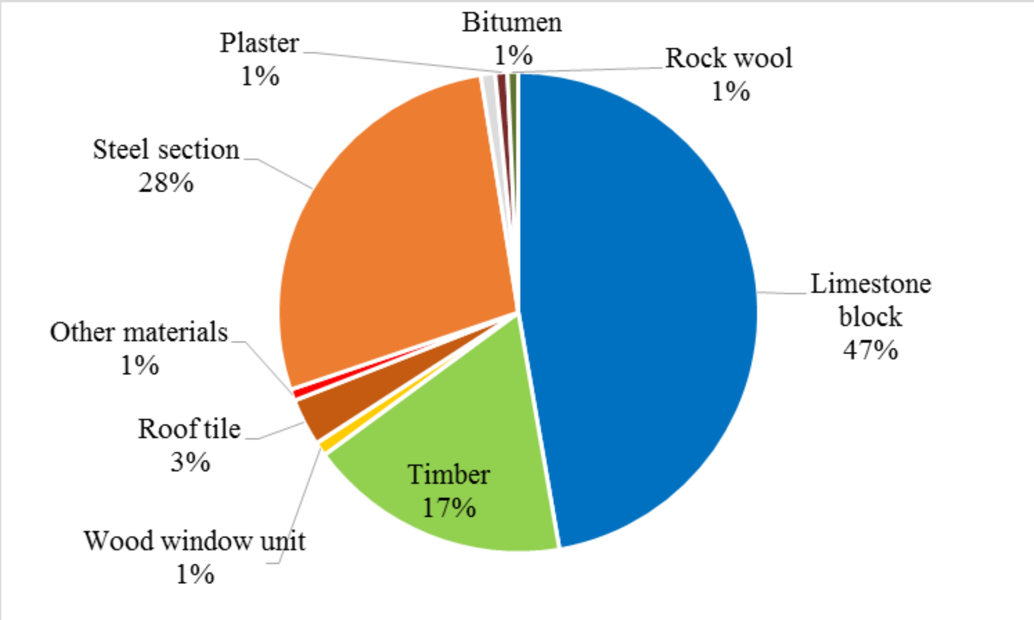


Figure 9.3 EE shares of construction materials for BT3

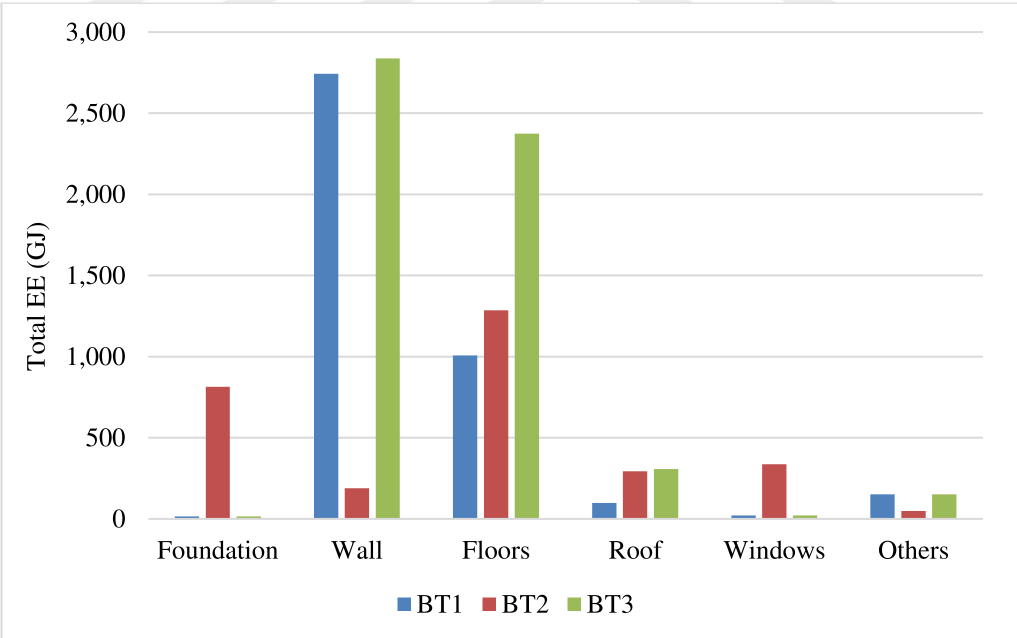


Figure 9.4 Life cycle EE of each component of studied buildings

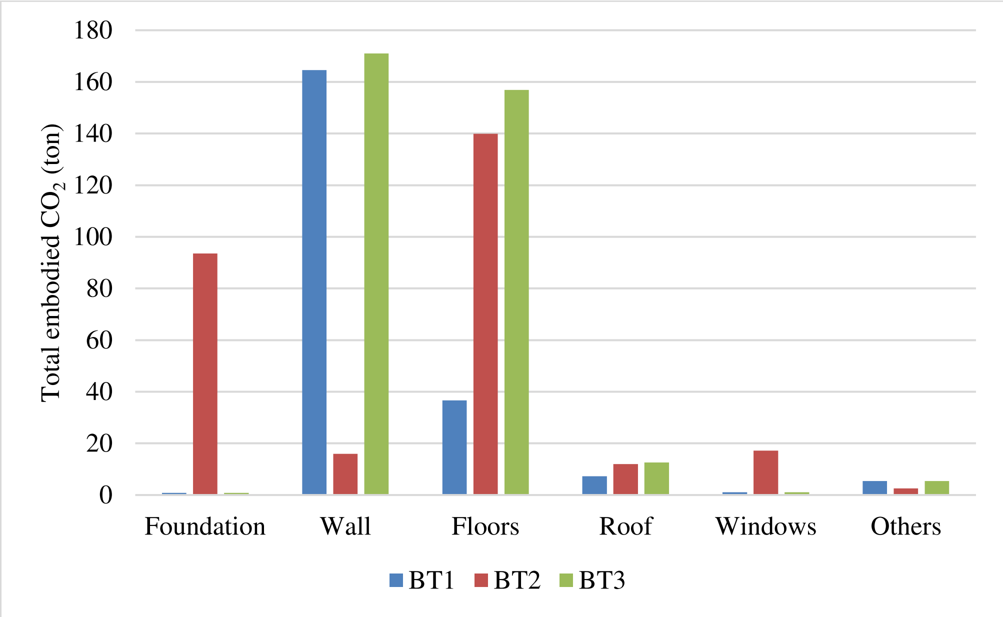


Figure 9.5 Life cycle embodied carbon of each component of studied buildings

9.2 Operational phase

BT1 has life cycle electrical energy demand of 22,875.5 GJ (20.5% of lightening, 35.2% of equipments and external loads, and 44.3% of HVAC system). Also BT1 has life cycle fuel energy demand of 30,040.98 GJ, 86.9% of which is expended for space heating moreover 13.1% for producing hot water. Yearly electrical energy end use chart for BT1 is presented in Figure 9.11.

The life cycle carbon outputs associated with the operational energy demand of BT1, BT2, and BT3 have the value of 7652.92, 6215.4, and 4694.98 tCO_2, respectively. Considering the BT1, approximately 61% of carbon outputs are generated via natural gas depletion and 39% by electrical energy use. For BT2 case, the life cycle operating energy use has a value of 54.74 GJ/m^2. Life cycle electrical energy use equates to 22,988.16 GJ which originates from 25.1% of lightening, 37.2% of equipments and external loads, and 37.7% of HVAC devices. Life cycle fuel energy demand has a value of 20,319.8 GJ, 77.4% of which is expended for space heating and 22.6% for hot water production. Yearly electrical energy end use chart for BT2 is presented in Figure 9.12.

Life cycle electrical energy use of insulated case of BT2 (i.e. rockwool insulation, 5 cm in thickness, is implemented to both exterior walls and floors) equates to 22,988.16 GJ (25.1% of lightening, 37.2% of equipments and external loads, and 37.7% of HVAC system). Life cycle fuel energy use of insulated case of BT2 has a value of 13,468.68 GJ, 65.8% of which is expended for space heating and 34.2% for hot water production. The life cycle operational carbon outputs have a value of 5111.31 tCO_2, 59% of which is generated by electrical energy use and 41% by natural gas depletion. Insulated case of BT2 has 20% lower operating energy use and 22% lower carbon outputs as compared to BT2.

Life cycle electrical energy use of BT3 equates to 20,386.26 GJ (22.6% of lightening, 36.8% of equipments and external loads, and 40.6% of HVAC system). BT3 has life cycle fuel energy demand of 13,012.91 GJ, 74.8% of which is expended for space heating, moreover 25.2 % for producing hot water. Yearly electrical energy end use chart for BT3 is presented in Figure 9.13.

The life cycle operating energy consumption of the BT1, BT2, and BT3 are estimated to be 95.35, 65.67 and 66.67 GJ/m^2, respectively. Figure 9.6 demonstrates operating energy demands of the buildings. Operating carbon outputs of the buildings have been demonstrated in Figure 9.7. Figure 9.8, 9.9 and 9.10 demonstrate yearly electrical energy use and fuel depletion in BT1, BT2, and BT3 respectively. Tangible energy use records obtained via questionnaires and utility bills were employed to collect whole the data for the electricity-expending appliances.

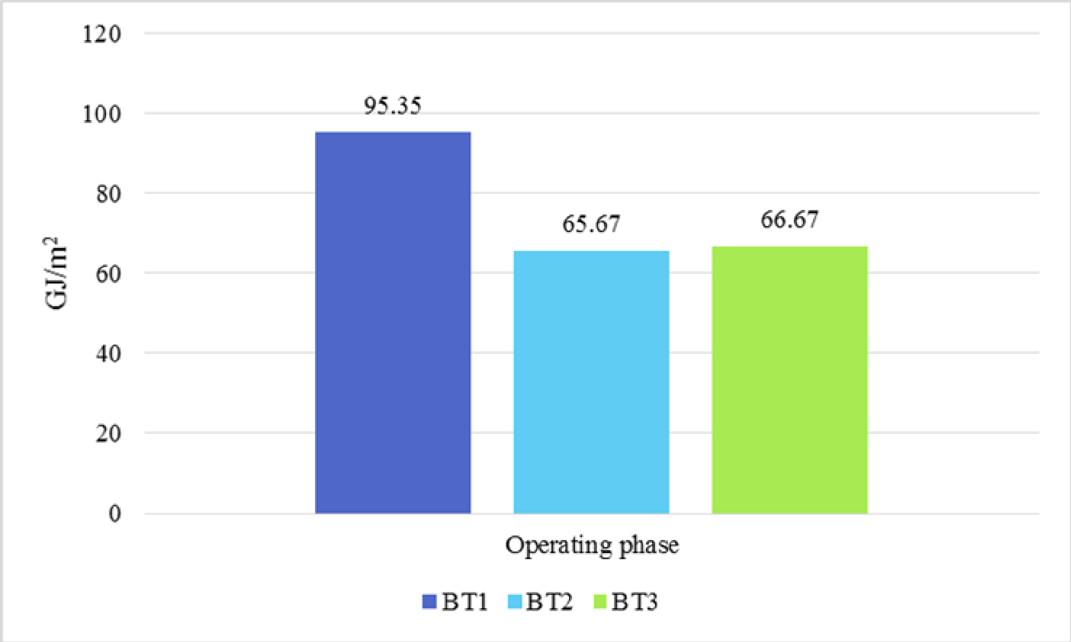


Figure 9.6 Operating energy demands of the studied buildings

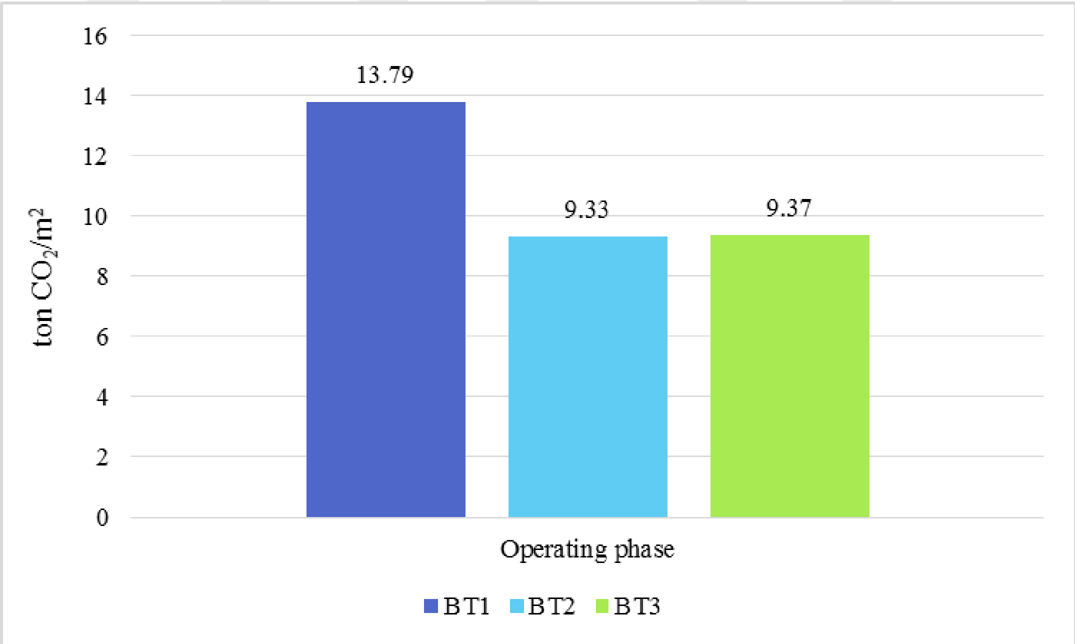
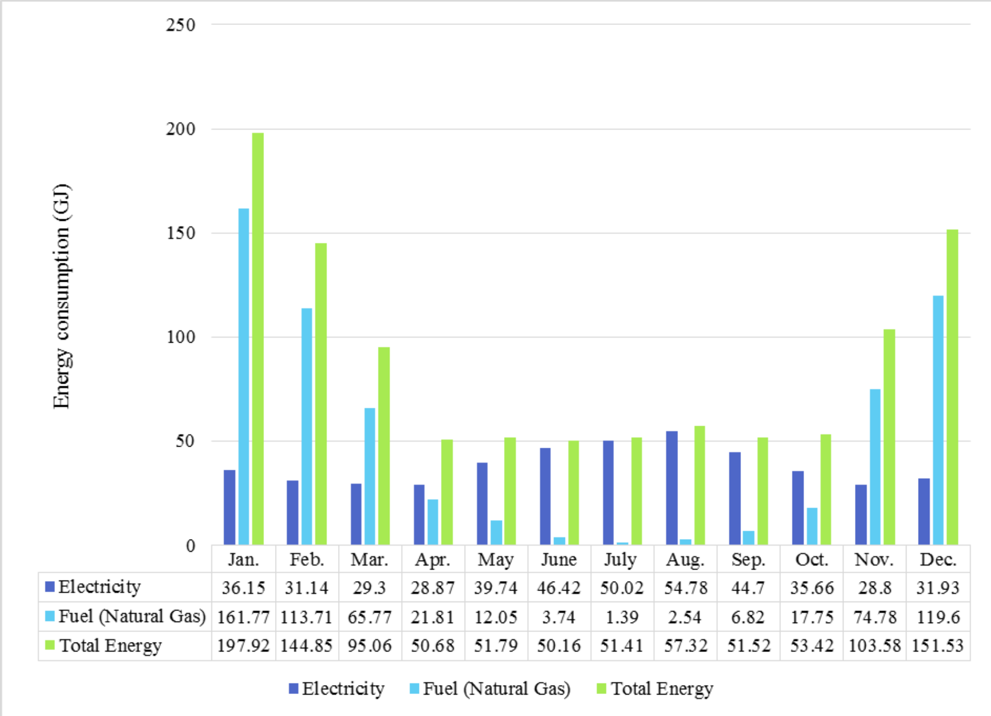
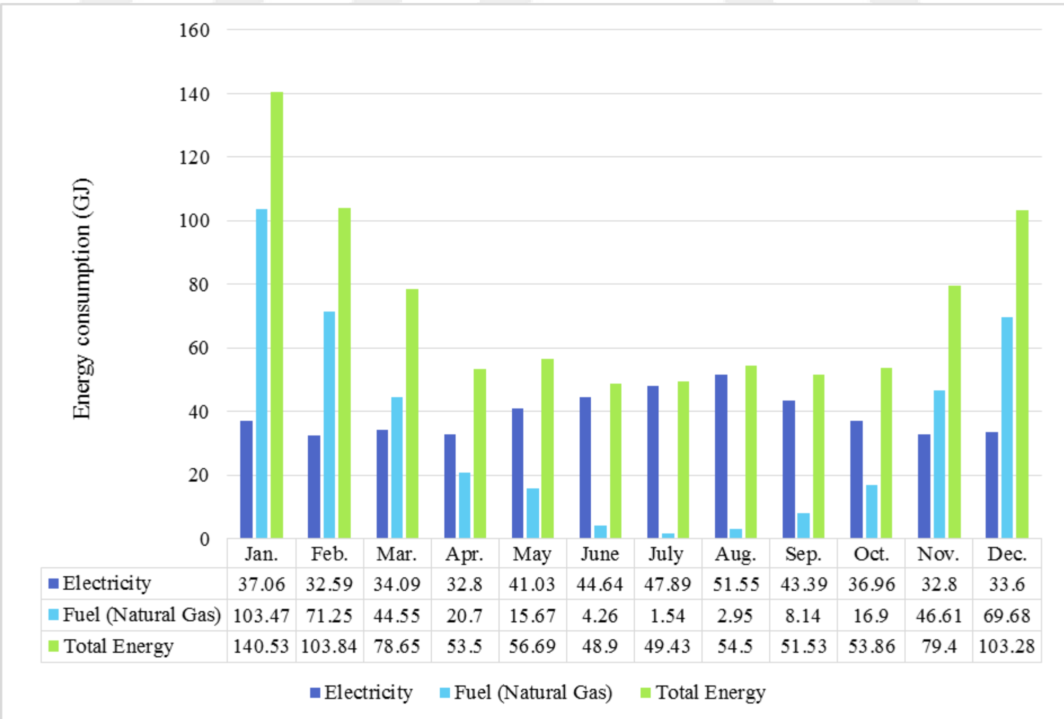


Figure 9.7 Operating CO_2 outputs of the studied buildings



	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.
Electricity	36.15	31.14	29.3	28.87	39.74	46.42	50.02	54.78	44.7	35.66	28.8	31.93
Fuel (Natural Gas)	161.77	113.71	65.77	21.81	12.05	3.74	1.39	2.54	6.82	17.75	74.78	119.6
Total Energy	197.92	144.85	95.06	50.68	51.79	50.16	51.41	57.32	51.52	53.42	103.58	151.53

Figure 9.8 Yearly electrical energy use and fuel depletion in BT1
1 kWh is equal to 3.6 MJ, 1 m^3 of natural gas = 39 MJ (GCV) = 10.83 kWh



	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.
Electricity	37.06	32.59	34.09	32.8	41.03	44.64	47.89	51.55	43.39	36.96	32.8	33.6
Fuel (Natural Gas)	103.47	71.25	44.55	20.7	15.67	4.26	1.54	2.95	8.14	16.9	46.61	69.68
Total Energy	140.53	103.84	78.65	53.5	56.69	48.9	49.43	54.5	51.53	53.86	79.4	103.28

Figure 9.9 Yearly electrical energy use and fuel depletion in BT2

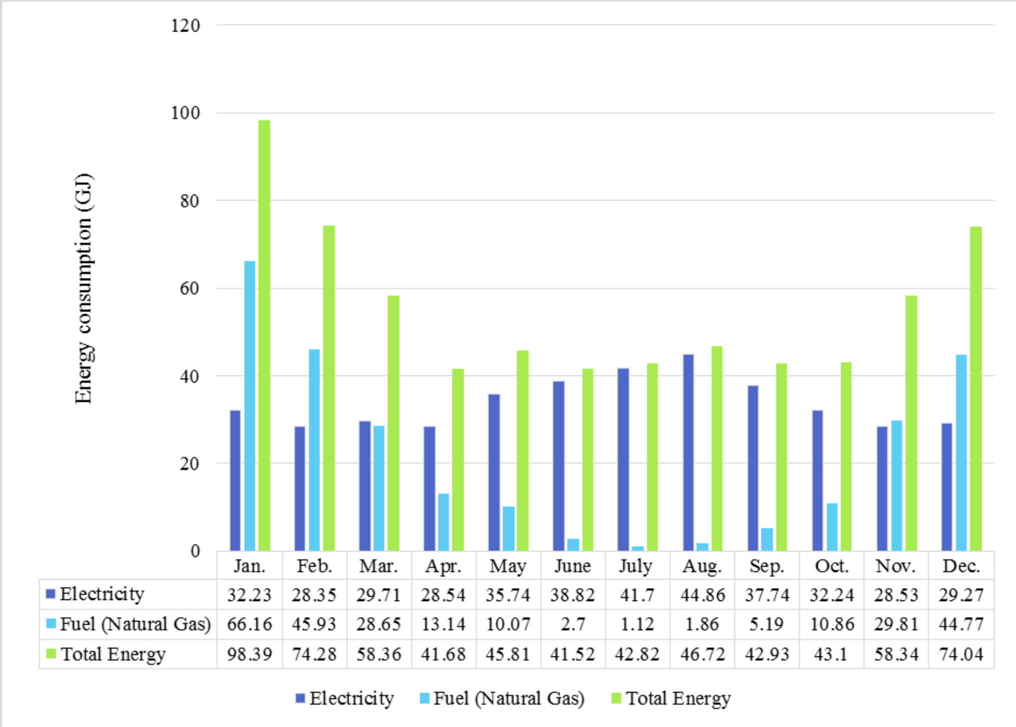


Figure 9.10 Yearly electrical energy use and fuel depletion in BT3

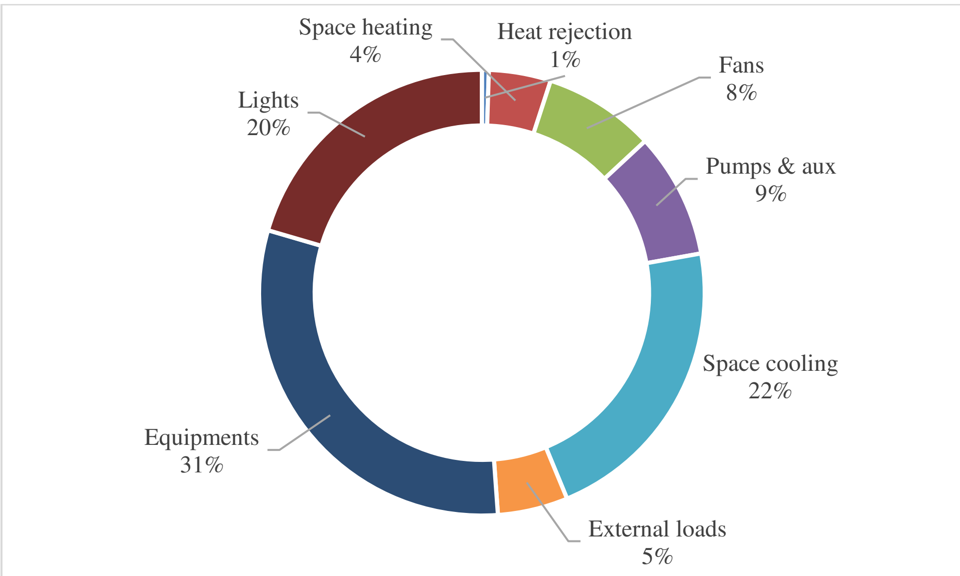


Figure 9.11 Yearly electrical energy end use chart for BT1

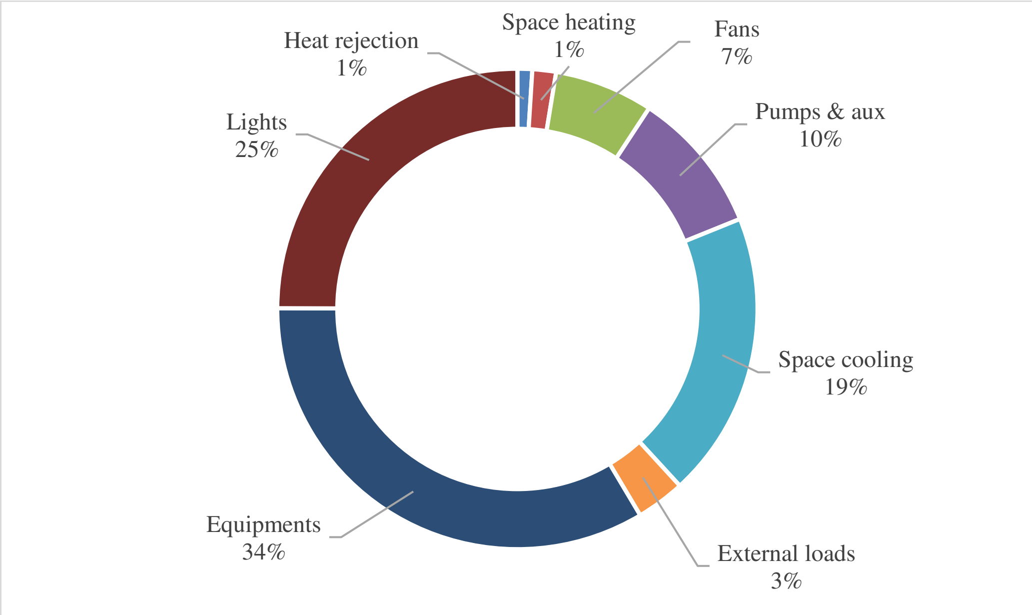


Figure 9.12 Yearly electrical energy end use chart for BT2

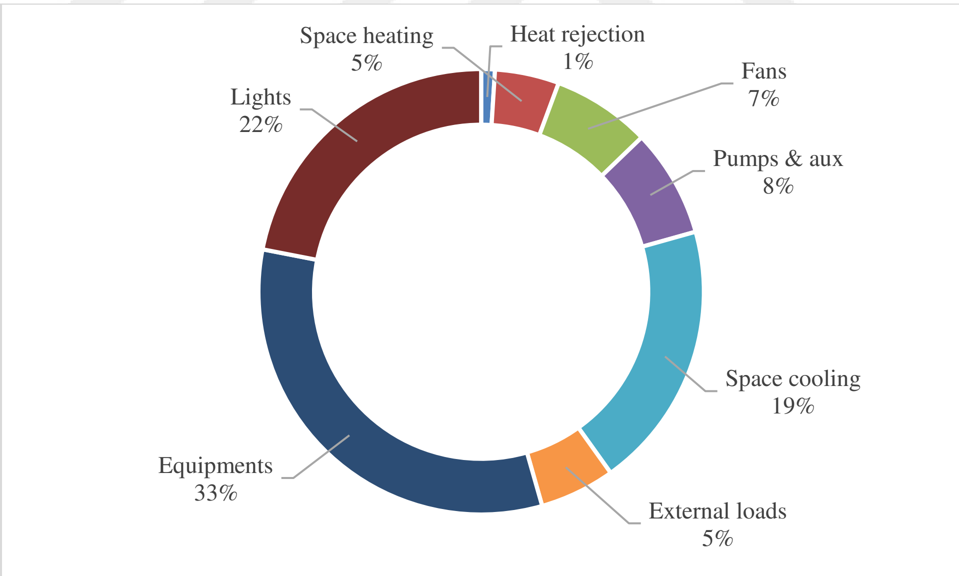


Figure 9.13 Yearly electrical energy end use chart for BT3

9.3 Demolition phase

As building LCA studies are investigated, it can be inferred that OE has the greatest contribution, and after that EE, while destruction process has omissible or minor share.

Raising the usage period of the building will correspondingly diminish the impact of destruction phase. Hence, in this survey the impacts of destruction phase are not estimated annual rationale. Building demolition and thereafter shipping of demolition waste are liable for only 0.2% of cumulative life cycle PE demand of the buildings [339, 340]. Eqn. (9.1) is used to estimate total emissions arised over the destruction stage of BT1, BT2, and BT3. Table 9.5 presents cumulative energy demand and CO_2 outputs pertinent to studied buildings in demolition stage.

$$\sum CO_2 = \sum \left(\frac{WD}{LC}\right) \times DT \times FE \times EF \tag{9.1}$$

Table 9.5 The cumulative energy demand and CO_2 outputs per building type in demolition stage

Cumulative energy and CO_2 outputs	BT1	BT2	BT3
Cumulative energy consumption (MJ)	205.26	141.14	158.06
Cumulative CO_2 outputs released (kg CO_2)	**18.55**	**11.27**	**19.58**

in which WD corresponds to disposal weight (t), LC denotes to the load carrying capacity (t), DT denotes to the travelled range (km), FE denotes to the fuel consumption (L/100 km), and EF denotes to the carbon emission factor (kg CO_2/L).

The emissions emitted during destruction process have proportionality with mass of the destructed structure. Besides, on a floor area rationale the destruction of bigger structures involves more energy in respect of smaller structures owing to the disparity in mass of the structures. When the studied buildings are considered, BT1 have the upmost destruction energy because of the most leading PE demand. In contrast, BT3 the upmost emissions value is caused by BT3 that is attributable to heavy mass of the structure.

9.4 Overall results

Over the buildings fifty-year usage period, the operation phase has the most significant impact, responsible for 84-93% of the total energy use as well the 93-97% of carbon outputs respectively. PE demand and carbon outputs of the BT1, BT2, and BT3 are given in Figures 9.14 and 9.15. In order to evaluate the impacts of changing EE and CO_2 intensity ranges, a sensitivity analysis is performed for several construction materials regarding LCEC and LCCE of the structures (see Figures 9.15 and 9.16).

BT1 has PE demand and carbon emissions value of 102.63 GJ/m^2 and 14.17 tCO_2/m^2, respectively. The EE equates to 7% of the cumulative energy demand of BT1, operating energy has a share of 93%, whereas energy required for destruction is omissible. In terms of embodied carbon emissions, BT1 has the least value (0.389 tCO_2/m^2) that are 7.8% and 8.5% fewer than BT2 and BT3, respectively. It is obvious that the cumulative energy required for manufacturing the main building materials of BT1, comprising its production is remarkably less than the modern construction materials.

BT2 has the least life cycle overall energy use and carbon outputs. The carbon emissions and PE demand have corresponding value of 9.75 tCO_2/m^2 and 70.13 GJ/m^2 respectively. It is crucial to state that, subsequent to implementation of appropriate thermal insulation the total energy needs and CO_2 emissions of the BT2 diminish 17% and 15%, respectively.

Owing to the immoderate usage of structural steel in the course of the restoration and structural retrofit (BT3), heritage listed buildings' (BT1) EE value enhance by 56.6 % whereas the cumulative LCEC of the building diminishes by 23.9 % subsequent to the restoration and structural retrofit of the building.

Furthermore in this study, energy derived from renewable systems has been surveyed. Various HVAC systems with heat pump equipments have been simulated via Autodesk Revit tool considering BT3. It is recognized that, if the BT3 was equipped with a high efficient HVAC system (Central VAV, HW heat, chiller 5.96 COP, boilers 84.5 eff.) 40% and 34% reduction in life cycle CO_2 outputs and primary energy demand would be achieved, respectively. The life cycle CO_2 emissions and primary energy demand would be 6.06 tCO_2/m^2 and 51.81 GJ/m^2 respectively.

Over the roof of the historic listed building (BT1) , the implementation of solar Photovoltaic (PV) systems has been surveyed. Using the BIM software tool, roof mounted PV systems (single crystalline category having 13.8% efficiency) are simulated. Usable roof surface is 141 m^2 for the establishment of PV panels. The systems' establishment price is about 0.85 USD per watt as well the electrical energy price is about 0.09 USD/kWh. The outcomes of simulation demonstrate that PV roof systems would deliver 106.62 GJ/year energy need of BT1 for payback period of 6 years.

Overall LCEC and LCCE values pertinent to some referenced studies are listed and checked against the findings of this survey and submitted in Figure 9.16. The findings of the survey mostly comply with the results of earlier studies. Nevertheless, it is observed that a small group of LCEC and LCCE values are less with regard to the present survey [341, 342]. The discrepancies in LCEC and LCCE values are mainly caused because of the differences in material selections, scenarios, and construction methods. In a study presented in Ref. [5], the system boundaries of the case study buildings have been indicated for eight alternative sites by application of distinct construction materials as well methods. Moreover, the buildings that are given in the Figure 9.16 have been constructed within a broad interval of time (from 1880 to 2010).

The implemented LCA procedure and presumptions have remarkable impacts on the computations. The preliminary investigations regarding the energy refurbishment expediency have been deemed in 4 distinct stages in the study given in Ref. [342] with distinct LCA procedures and presumptions. In reference [343] owing to the variations in the data utilized for twelve distinct studied structures, it has been detected that there is a considerable deviation in yearly PE demand (from 6.7 to 105.7 kWh/m^2) as well carbon output values (from 0.5 to 69.4 $kgCO_2/m^2$). The employed database to estimate intensity and emission values have remarkable impact on the outcomes of LCEC and LCCE values.

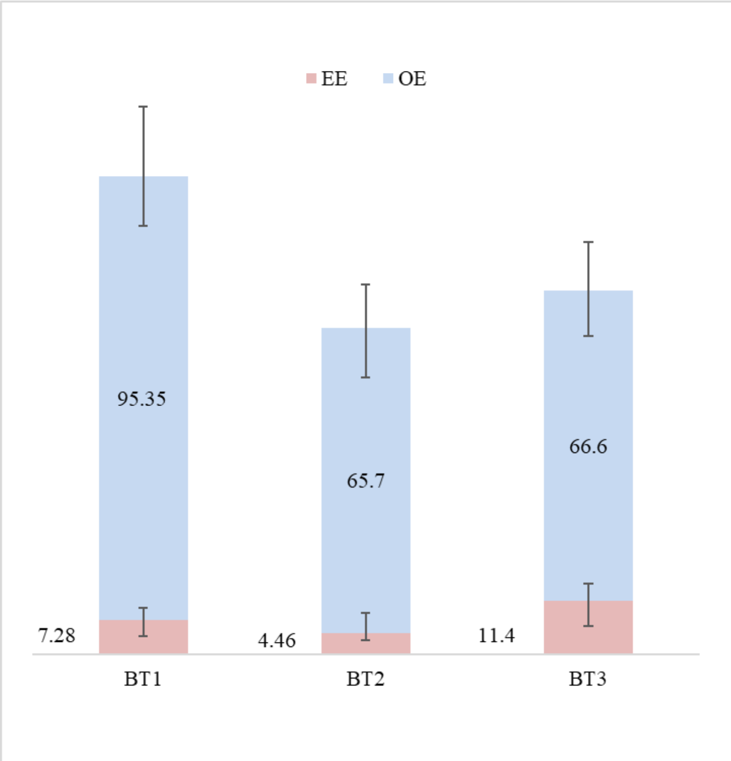


Figure 9.14 LCEC of the studied buildings (GJ/m^2)

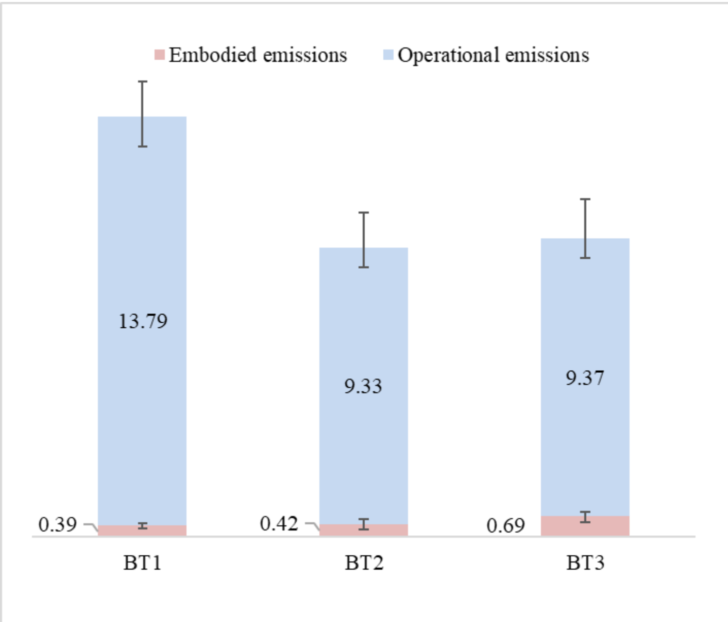


Figure 9.15 LCCE of the studied buildings (tCO_2/m^2)

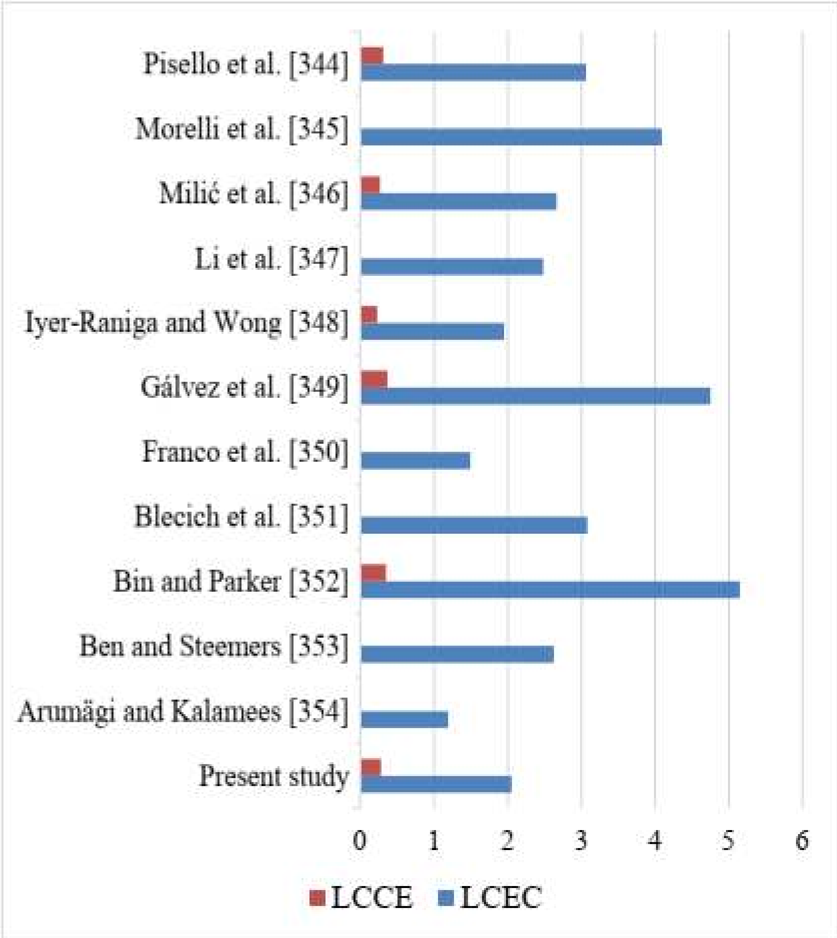


Figure 9.16 LCEC (GJ/m^2) and LCCE (tCO_2/m^2) calculated by various studies

CHAPTER 10
CONCLUSIONS

In this study, LCEC and LCCE of a listed heritage building (BT1), re-built scenario of a modern building (BT2), and structurally retrofitted and restored heritage building (BT3) in Gaziantep, Turkey are surveyed comprehensively.

Energy demands and carbon outputs within construction (EE) period are estimated to have corresponding share of 7%, 6.3%, 14.6% and 2.74%, 4.33%, 6.9% overall energy demands for BT1, BT2, and BT3 respectively.

It is understood that the use stage was governing, responsible for 85.4–93.6% of the overall energy demands and 93.1–97.2% of carbon outputs throughout the fifty-year service life.

BT2 case is responsible for the least LCEC (70.13 GJ/m^2) and LCCE (9.75 tCO_2/m^2) demands. Modern (BT2) and retrofitted and restored (BT3) buildings account for 31.2% and 31.8% fewer cumulative impacts respectively in respect of energy and environmental requirements.

When compared to historic listed building (BT1), the novel building (BT2) is responsible for less embodied (32%) and use (31%) energy consumption. However BT1 case accounts for less life cycle embodied carbon footprints.

Immense amount of building materials that have remarkable embodied carbon footprint for instance steel rebar, cement, insulation materials, and paint are used by construction firms in newly built structures. EE and corresponding carbon footprints are greatly affected by the choice of building materials . The EE of a wood window with double glazings is 0.49 GJ/kg whereas corresponding equates to 5.47 GJ/kg for a aluminium window with double glazings (See Table 9.2 and 9.3). Energy simulation findings for BT3 indicate that installment of a high efficiency HVAC equipments would enable 41% decrement in life cycle operating energy use (from 33,399.17 GJ to 19,762.03 GJ) and 43% decrement in life cycle carbon outputs (from 4694.98 tCO_2 to 2672.61 tCO_2).

It is ascertained that despite active and passive energy solutions lead to a slight raise in EE, they have a great potency to diminish operating energy accordingly the life cycle energy use and carbon footprints of the buildings.

Sustainable energy options should be incorporated into energy renovation efforts of heritage structures devoid of any damage to the historic fabric of the structure so as to alleviate the contribution of fossil energy in overall energy demand.

For future implementations, during the reconstruction of a heritage building, that is made up of more than one wall layer, thermal insulation can be embedded within wall layers devoid without any impact to the buildings' authenticity.

The results of the study demonstrated that the life cycle energy use and corresponding carbon footprints of the historic building could be diminished by 22.9% and 28.7% respectively, thereafter the structural retrofit and restoration implementation by respecting and preserving its' historic value and structural reliability.

Sustainable restoration and retrofit practices for various grades of historic structures are a substantial method to alleviate the LCEC as well LCCE values. It can be inferred that conservation, energy retrofit, and reconstruction implementations for historic buildings have a major significance regarding energy use and carbon footprints. With the aim of saving energy and mitigating heat dissipation, it is crucial to implement suitable heat insulation in the structures' envelope (walls, ceilings, and roofs) and highly efficacious HVAC equipments.

Due to the national legislation limitations, limited choices are available for changing the type of construction and material selection in construction phase. The energy and corresponding carbon outputs are firmly rely on types of building, methods of construction, materials, national legislational limitations, the system boundaries, the database employed in computations, LCA procedures, and presumptions. With the purpose of reducing LCEC and LCCE values of heritage structures, innovative design methods built on the concept of diminishing overall energy uses, utilizing resources efficaciously, and usage of renewable sources should be comprised in national legislations.

The findings obtained from this survey are a breakthrough for the historic building inventory of our country in order for realizing the life cycle response. Future surveys should concentrate on the investigation of proper multi-objective refurbishment procedures and techniques for historic buildings. The findings of this study may accelerate to policy revisions regarding the restoration projects of historic buildings to evolve progressive energy and carbon legislations in the future.

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