Sustainable Refurbishment of Existing K-12 School Buildings and the Impacts of Sustainable Schools on Environmental Literacy of Students

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This thesis is submitted to Kingston University, London in partial fulfilment of the requirements for the award of Master of Philosophy.

May 2022

Abstract

Currently, due to limited energy resources and the corresponding energy problems, designing energy-efficient buildings has increasingly gained importance. In recent years, limited numbers of school buildings have been designed on the basis of sustainability principles. This research emphasises two fields – sustainable architecture and environmental education, and indicates how they are interconnected in the sustainable school building. A literature review has been conducted on sustainable architecture as the first stage of the research, focussed on the refurbishment of existing school buildings, and environmental education. The focus was mostly on environmental awareness of students through the school buildings as the third teacher and a 3D textbook. In this regard, this thesis aims to investigate the refurbishment possibilities of existing K-12 schools in accordance with the criteria of sustainable architecture and the effects of sustainable schools on students' environmental literacy. With this aim, an analysis of sustainable school building examples from around the world, in terms of various sustainability certification systems, was conducted, and refurbished schools were assessed.

However, K-12 public schools in Turkey are constructed with 5 standard school types in Turkey, regardless of climate conditions. In this context, these school buildings were examined. Then, daylight-shadow modelling was generated with the "DesignBuilder" energy performance simulation software. After establishing the design interventions for K-12 school buildings, values for the heating energy gain of the sample school building were compared using "DesignBuilder" building energy performance software and the effect of intervention on the heating energy gain was examined. As a result of this comparison, sustainable refurbishment suggestions were presented. This research will reveal the role of sustainable K-12 school buildings in passing on children's sustainability awareness to individuals of the community and families.

Key Words: Sustainable certification systems, Sustainable school design, Refurbishment of existing school buildings, Environmental literacy

Acknowledgements

A lot of valuable people have provided assistance with this research. First and foremost, to my supervisors Assoc. Prof. Eleanor Suess (Director of Studies) and Prof. Stephen Pretlove, thank you for the wonderful journey you have leaded me. I am deeply indebted to them since they supported me at every stage of preparing the thesis. I am grateful to them for their creative suggestion, endurable patience, guidance and expertise which strengthened my motivation and provided great inspiration during my studies. I owe my sincere thanks and gratitude to them for the completion of my endeavour. I also would like to thank my co-supervisor from Turkey, Dr Duygu Erten for reviewing and giving final comments.

Secondly, to the academics and staff of the Department of Architecture and Landscape Architecture, Kingston School of Art, I owe a debt of gratitude for the intellectual challenges, your informative conversations and support. I am especially thankful to Dr. Paul Micklethwaite who took part in the sustainable education research. The study could not have taken place without your collaboration and participation.

To all those who participated in the research through school visits, conversations and consultations also a big thank you. I would particularly like to thank the staff and students of Tekeli Secondary School, OIB Technical and Vocational High School, TED Renaissance College and Serik Anatolian High School for their enthusiasm, time, contributions and the collaborative work undertaken.

I would particularly like to acknowledge Aslihan Cetinkaya for the role she played in developing my confidence and competence to engage with the thesis, for believing in my study, and for the support she gave to me. To achieve this target, she motivated and encouraged me. I would not be standing in my current position without her help.

Then, I would like to express my biggest gratitude to my family, mom, dad and brother for enduring the four years of discussions about sustainability, the changes in lifestyles they have made without complaint, and most importantly the support they have given. Finally, I would like to dedicate this work to my younger sister who passed away 12 years ago. I acknowledge whom I have not mentioned, but that there always been for me.

The Author

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Silay has inspired by the MA course and examined how school buildings might be improved sustainably and what the effects of sustainable education are on this. She started her PhD degree in 2015. She has also investigated sustainable K-12 schools supporting environmental literacy.

She has undertaken and published a range of research studies in evaluating the thermal comfort on schools, improving the sustainability of K-12 school buildings, assessing perceptions of students about learning environments, and supporting environmental literacy of students.

Her research interests are in the contribution of school buildings to students' environmental literacy, sustainable education and architecture.

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List of Abbreviations

3D textbook Three-Dimensional Textbook
AIA American Institute of Architects
ASHRAE The American Society of Heating, Refrigerating and Air-Conditioning Engineers
BREEAM Building Research Establishment Environmental Assessment Method
CAD Computer-Aided Design

CASBEE	Comprehensive Assessment System for Built Environment Efficiency in Japan
CCCLab	Climate Culture Communication Lab
CEDBIK	Turkish Green Building Council
DfES	Department for Education and Skills
DGNB	The German Sustainable Building Council
DOE	The Department of Energy in the United States of America
DXF	Drawing Exchange Format
EPA	United States Environmental Protection Agency
ESD	Education for Sustainable Development
GHG	Greenhouse Gas
HVAC	Heating, Ventilating and Air Conditioning
IAQ	Indoor Air Quality
IEA	International Energy Agency
IPCC	Intergovernmental Panel on Climate Change
K-12	Education from Kindergarten (K) through the 12th grade
kWh	KiloWatt-hour
LED	Light-Emitting Diode
LEED	Leadership in Energy and Environmental Design
MEB	Republic of Turkey Ministry of National Education
NAAEE	North American Association for Environmental Education
NABERS	The National Australian Built Environment Rating System
OECD	Organisation for Economic Co-operation and Development
OIB	The Uludag Automotive Industry Exporters' Association
PNNL	Pacific Northwest National Laboratory
PV	Photovoltaic
PVC	Polivinyl Chloride
SEED	Sustainability Education and Economic Development
SURYAD	Sustainable Buildings and Materials Council
TED	Turkish Education Association
TMMOB	Union of Chambers of Turkish Engineers and Architects
TS-825	Turkish Standards about Thermal Insulation in Buildings
TUIK	Turkish Statistical Institute
UHI	Urban Heat Island
UIA	The Union of International Architects
UNEP	United Nations Environment Program
UNESCO	Educational, Scientific and Cultural Organisation
UNFCCC	The United Nations Framework Convention on Climate Change
USGBC	United States Green Building Council
USGCRP	The United States Global Change Research Program
WCED	World Commission on Environment and Development
WWAP	United Nations World Water Assessment Programme
YEGM	Republic of Turkey Ministry of Energy and Natural Resources, General Directorate of Renewable Energy

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CHAPTER 1

INTRODUCTION

1.1 Introduction

This research addresses issues of sustainability in Turkish educational buildings – using case study research and analysis, the thesis proposes how existing school buildings may be sustainably redeveloped, rather than expending additional energy and material resources constructing new sustainable school buildings. For the individual learner, an education building is the context which frames and shapes their educational experience (Gokmen, 2010 p. 352). Through the manifestation of sustainable principles in redeveloped school buildings, this thesis also indicates how such buildings can contribute to the environmental literacy of students who are educated within them, who can subsequently transfer that literacy to their families and future generations.

This introductory chapter outlines the structure of the thesis and the context for the research. The main objective of this research study is to promote sustainability through the refurbishment of standard existing K-12[1] school buildings in Turkey, with an emphasis on combining opportunities for improving environmental performance and enhancing the environmental literacy of the student body. In this context, this research contributes to knowledge at the interface of two disciplines: sustainable architecture and environmental education.

The study draws together research in the fields of environmental education and sustainable architectural design, to propose strategies for the future of school buildings in Turkey to best enable them to contribute to combatting the climate emergency. To begin with, the literature review focuses on environmental education and environmental literacy as effective tools to reduce the negative impacts of environmental problems, and goes on to give an overview of the role of the sustainable school buildings themselves in potentially supporting their students' environmental literacy. Then, the literature review focuses on environmental problems and the impact of buildings upon them. Sustainable architectural principles,

[1] The term "K-12" was first used in the United States and Canada in the field of in education and educational technology. Other countries such as Australia, Ecuador, Egypt and India subsequently adopted this term. The term refers to all publicly-supported primary and secondary schools before college. K-12 covers kindergarten (K) and the 1st through the 12th grade (1-12) (Corsi-Bunker, 2010).
In Turkey, formal education is comprised of pre-school education (3-5 years), primary (6-10), secondary (10-14), high school (14-18) and HE institutions.

sustainable building certification systems, and examples of sustainable school buildings from around the world are investigated in order to determine how best to sustainably refurbish existing K-12 school buildings. Also, the literature review provides the necessary foundation upon which two strands of the research were carried out with an analysis of precedent schools and a simulation analysis of the case study building (Tekeli Secondary School). This study examines how the energy consumption of existing school buildings might be reduced while the building is in operation. Then, adaption of energy efficiency features to the existing school buildings was investigated. One of the existing school buildings is then analysed in more detail, to provide tangible proposals for how such a typical existing 'standard' school might be refurbished to bring it up to a good level of sustainability, and to use these improvements as active teaching tools to support the environmental education of its students. By providing a clear example of how the proposed combination of sustainable refurbishment and environmental education could be combined in practice, the thesis aims to offer a model for how this might be applicable for other, similar schools in Turkey. The thesis proposes that government policy and strategy could be developed to link the sustainable refurbishment of existing schools with the pedagogic opportunities associated with sustainable refurbishment of school buildings.

As the global population increases, non-renewable resources are being rapidly exhausted and the uncontrolled use of these resources is a significant problem. Increasing ecological awareness and the development of the concept of sustainability has led to more effective management of the environment and natural resources.

In terms of environmental, economic and social aspects, the concept of sustainability addresses the detrimental impact of the built environment on the natural environment in a practical way. Buildings consume a great amount of energy. In this context, sustainability deals with environmentally friendly practices in the design, construction and management processes by placing emphasis on the relationship between buildings, their environments and their users. Commercial and residential consumers in buildings utilise one-fifth of the total energy consumed in the world (IEA, 2008). On the other hand, energy-efficient design methods and techniques in sustainable buildings might be a guideline in order to minimise energy consumption. The USA and European countries have numerous practices in relation with sustainable architecture. Today, despite the fact that limited number of examples of sustainable buildings are available in Turkey, the popularity for the concept of sustainability has grown in the field of architecture and incentives for making structures more sustainable have been increasing during recent years.

Research has been conducted about increasing building energy performance, the comfort, well-being, health and productivity of users and conserving natural resources. Although the reflections of sustainable architecture studies about K-12 educational buildings have also been effective on educational buildings, Turkey has a lack of actual sustainable school buildings: only six of the K-12 educational buildings in Turkey have sustainable building certificate (BREEAM, 2019; LEED for Schools, 2020). In developed countries, there are many academic studies in the discipline of architecture focussed on improving energy performance regarding the sustainable refurbishment of existing school buildings. Furthermore, several research studies in the discipline of environmental education have been published on raising students' environmental literacy, which can be developed through experience from a very early age – between 6 and 18 years old (including K-12 education period). However, only a limited number of research studies link these two fields to investigate the teaching potential of the sustainable refurbishment of school buildings. The research conducted in this thesis combines these two separate fields, and aims to fill the gap in the existing knowledge by integrating these two disciplines.

The principal outcomes of the conducted research are the development of some robust proposals which will support sustainable school buildings and education, and a discussion of sustainable refurbishment methods for the architecture of existing learning environments.

1.2 Research Background

Environmental issues have started to be globally noticed in recent years. Specifically, the term 'climate emergency' has been on the agenda in the last couple of years to reach net zero carbon emissions. In this regard, the United Kingdom first declared a 'climate emergency' on the 1st of May 2019 to tackle climate change (Tutton, 2019). According to the IPCC (2018) report, annual global carbon emissions have to be halved by 2030, and carbon zero target must be achieved by 2050 (IPCC, 2018; Zhenmin and Espinosa, 2019). So, as well as reducing carbon emissions caused by buildings being crucial to tackle environmental issues on an international scale, it is also vital to raise environmentally conscious individuals who will play a role in limiting continued global warming caused by human activities.

Economic development and industrialization has led to a significant increase in the global construction rate (Erman, 2001 p. 985; TMMOB, 2004; Dixon, 2010). Contemporary human civilisation depends on buildings for its continued existence; humans spend the majority of their lives in and on constructions such as living in houses, travelling on roads, studying in schools, working in offices, and socializing in buildings. According to the IEA[2], 36% of global energy is consumed and approximately 40% of total carbon emissions are released by buildings globally (IEA, 2019). Buildings in member states of the OECD[3] account for around 30% of total energy use; this includes both construction and use of buildings (OECD, 2019). The building sector is one of the most energy intensive sectors, and the sector should seek to contribute to decreasing energy consumption and tackling climate change (Buildings and Initiative, 2009). Industry and transportation are two other energy consuming sectors (IEA, 2013). According to TUIK (2019) data, there are currently more than 9.2 million buildings in Turkey[4]. A significant amount of them cannot meet the levels required to achieve sustainable building ratings and certifications. Just 379 buildings have LEED certification, while 61 buildings have achieved BREEAM certification (LEED, 2019b; BREEAM, 2019). Unsustainable buildings unnecessarily consume energy and natural resources, and so they cause the deterioration of the ecological balance, whereas a rated building has better performance in energy use and can also be more economically attractive. Sustainable building assessment systems enable the design team to follow established strategies for sustainable design so that certified buildings would have less negative impact on the environment, from design to demolition. Therefore, the existing building stock needs to be refurbished to be sustainable, and national building regulations should limit the number of new unsustainable buildings.

However, new buildings are not always constructed in a sustainable way or may not have sustainable building certificates. One of the most important reasons is that sustainable buildings have higher initial costs than conventional buildings (Ozkan and Gurbuz, 2019). The lack of experience of companies in the building sector causes an increase in initial costs and extension of project duration. Inadequacy of government incentives and lack of customer demand are also factors which affect the number of sustainable buildings. From an environmental point of view, demolishing buildings leads to heavy environmental pollution (Power, 2008; Ding and Ying, 2019). First and foremost, construction waste and

[2] IEA (International Energy Agency) established in 1974 consists of the OECD countries and supports energy policies.

[3] The OECD (Organisation for Economic Co-operation and Development) is a global platform of nearly thirty countries to deal with the economic, social and environmental difficulties. The OECD member countries are: Austria, Australia, Belgium, Czech Republic, Canada, Denmark, France, Finland, Greece, Germany, Hungary, Ireland, Iceland, Italy, Japan, Luxembourg, Mexico, Norway, Netherlands, New Zealand, Portugal, Poland, Republic of Korea, Spain, Slovak Republic, Switzerland, Sweden, Turkey, United States and United Kingdom (Chiu and Chang, 2009).

[4] In calculation of TUIK data, building census statistics and annual building license statistics were utilised.

need for material resources should be reduced by way of reusing and refurbishing existing buildings (Edward and Turret, 2000).

Architects, engineers, landscape architects and anyone taking an active role in building design should seek to design their projects with eco-friendly approaches in mind, whilst also creating an environment for the users' psychological, socio-cultural, and economic needs. They should design projects to minimise the negative effects of the built environment on the natural environment and on people. Therefore, a critical task regarding the efficient use of natural resources falls to architects, engineers, designers, clients, developers, surveyors, contractors and regulatory bodies. It is crucial therefore that the next generation of construction professionals has a strong awareness of sustainable practices. This can be achieved through university courses in the educational curriculum. These courses will definitely have sustainability as a key part of the curriculum already. However, it is useful if these professionals received their start in understanding sustainable principles when they were at school. Moreover, designing educational buildings to act as environment and sustainability 'laboratories' as 'learning environments that teach sustainability' will undoubtedly be effective learning tools to support the curriculum.

> "We teach how to build, but what we build teaches us how to live" Richard Register, Founder of the global Eco-City Movement (Graham, 2003, p. 11).

> "We shape our buildings and afterwards our buildings shape us" Winston Churchill (Liang and Wang, 2019, p. 3).

The quotes above suggest that architecture could influence the life and behaviours of humankind. There are great opportunities for learning environments to be tools for education. For example, educational buildings could teach rainwater harvesting and growing vegetables in a school garden rather than learning from the curriculum (Innovative Design Inc., 2009). Additionally, the school environment serving as a 3D textbook can assist students to understand school subjects in the curriculum (Taylor, 2009).

Teaching and learning are expected to happen within the four walls of classrooms (Ford, 2007). Despite the fact that the curriculum emphasises the efficient use of water, school toilets are flushed with drinking water. In addition to this contradiction, schools use non-renewable energy sources even though students are informed about climate change and renewable energy. In this regard, it is not expected that the students could cognise the real function of sustainability in the built environment. Schools consuming fewer natural resources and producing less waste could strengthen students' attitudes, behaviours and awareness.

Correspondingly, integrating Environmental Education to the curriculum is not enough to develop environmental behaviour and attitudes in the population. However, the physical environment of educational buildings can have a significant effect on supporting Environmental Education. The physical environment of school buildings should be taken into consideration as much as the curriculum (Sanoff, 2009), since the physical features of sustainable educational buildings aim to promote the adoption of environmental behaviour among children. Therefore, refurbishment of existing schools has many positive consequences in terms of environmental, economic and social aspects.

There is no doubt that raising sustainability awareness across the society is necessary. Attempts to transform educational buildings into 'sustainable educational buildings' primarily concentrated on the curriculum (Henderson and Tilbury, 2004; UNESCO, 2005). Some lessons in the educational curriculum encourage students to develop environmental attitudes and behaviours but also a school building itself as a teaching tool serves as a complementary to the curriculum in the name of learning sustainability and creating its consciousness (Nair et al., 2009; Nair, 2014; Kong et al., 2015).

According to Professor A. Taylor an expert in the field of child-focussed environmental design, the physical environment of sustainable schools could undertake the task of the "silent curriculum" (Taylor, 2009, p. 25). In this way, sustainable school architecture improves the awareness of occupants about sustainability issues. However, the majority of existing and new buildings are unsustainable (Orr, 2004). If schools are designed with sustainability criteria in mind, both their impact on the environment will be reduced and sustainability awareness of the building's users will be raised.

In addition, refurbishing school structures compared to other public buildings could be an efficient example in terms of expanding awareness for energy efficiency. Sustainable design interventions for existing educational buildings aim to both make learning environments more sustainable and reduce energy and resource consumption. Refurbished schools promote the protection of natural resources by supporting environmental education with sustainable architecture. When analysing existing educational buildings in Turkey, it was seen that K-12 school buildings are the most numerous, therefore they have significantly negative impacts on the environment. Additionally, most of such existing educational buildings are referred to as “standard projects” since they have not been constructed with sustainable design principles in mind. As more and more standard school buildings are constructed due to the need of increasing youth population and lack of capacity in existing building stock, the amount of greenhouse gases produced will increase rapidly because of the construction density. Thus, the negative effect on the environment of newly constructed school buildings will be decreased if they are designed sustainably instead of standard projects.

For this reason, there is a need to re-evaluate existing school buildings that have “standard project” designs, in order to raise sustainability awareness among children at early ages and to reduce energy consumption of these buildings. The sustainable refurbishment of standard educational buildings could be an opportunity to reduce their energy consumption and environmental impact. Accordingly, Brunoro (2008) suggested that the sustainable refurbishment of an existing building shell can have a huge impact in terms of reducing energy consumption (Brunoro, 2008). According to Bachman, refurbishing building envelope systems could be a fundamental intervention to improve the performance of school buildings (Bachman, 2003). Thus, retrofitting the building shell could provide economic and environmental benefits (Digravina, 2015). Le states that the principal purposes of retrofitting the building envelope (wall and roof) are window improvements, natural ventilation, and renewable resources (Le et al., 2018). According to Ucar, replacing fossil fuels with renewable energy resources such as photovoltaic panels could be a beneficial intervention for sustainable refurbishment of buildings (Ucar, 2018). Furthermore, rainwater collection systems have been evaluated as economic and ecological systems to be adapted to existing buildings (Jaber et al., 2012; Muftuoglu and Percin, 2015). In this vein, refurbishing existing K-12 school buildings with these sustainable systems is essential. However, this refurbishment is not on the agenda in Turkey due to the limited budget of the government (YEGM, 2018). Although most of the new K-12 school buildings in Turkey have been built as standard and unsustainable projects, there is a potential opportunity to apply sustainable design interventions to many schools.

1.3 Research Questions

The following research questions are addressed in this thesis:

* Which features of sustainable schools from around the world could be adapted to the existing school buildings in Turkey in order to improve their energy performance?

* How can existing K-12 school buildings in Turkey be refurbished sustainably considering the criteria of sustainable building certification systems?

* How can the sustainable refurbishment of school buildings in Turkey contribute to their students' environmental literacy?

1.4 Purpose of Research

In this study, a holistic approach between two different disciplines is taken. In this respect, I aim to suggest some energy and cost-efficient refurbishment opportunities for existing K-12 school buildings in Turkey in the light of sustainable architecture principles, sustainable certification standards, and examples of sustainable schools from around the world. Moreover, this thesis considers the effects of the sustainable school building on the environmental education of its users, potentially acting as a third teacher and/or a 3D textbook.

1.5 Research Objectives

The following objectives support the development of responses to the research questions:

* To identify and evaluate the characteristics of sustainable schools which may be applied to existing school buildings in Turkey.

* To establish how the sustainable systems used in a school building can be "read" by students such that they understand "green" principles of building design and use.

* To propose how sustainably designed education buildings may increase the environmental awareness and literacy of the users of those buildings.

1.6 Constraints and Limitations

In terms of convenience and cost, this study has concentrated on sustainable interventions to apply in Turkey. So, this research mainly focuses on energy-efficient interventions but in general, suggestions have been offered about other intervention titles such as material, water and landscape. With reference to "Energy and Atmosphere" and "Water Efficiency" titles in LEED certification system, sustainable interventions in this research are limited to building envelope, LED lighting, window glazing, solar panels, HVAC[5] systems, and rainwater harvesting unit interventions to implement refurbishment projects of K-12 school buildings.

The refurbishments suggested in this study are limited to a single school, Tekeli Secondary School, as a representative standard school building in Turkey. The sustainable refurbishment proposals could be considered as 3D teaching tools. The existing secondary school building itself does not teach students, but the refurbishments that I suggest have the potential to be an educational tool for sustainability.

Another limitation is the use of DesignBuilder as a building energy simulation software tool to analyse the building energy performance. There are several alternative software packages that could have been used. According to the Building Energy Software Tools Directory, established by the U.S. Department of Energy, more than 350 building energy software tools are available for sustainable and energy-efficient design processes. Of these software tools, TRANSYS and Energy Plus-based DesignBuilder are used most commonly. So, "DesignBuilder" was chosen for the building simulations. DesignBuilder was preferred due to its user-interface that reduces potentially incorrect inputs and the convenience it provided in the modelling process.

1.7 Research Methodology

This research utilises a number of strategies to investigate the current energy performance and potential energy performance after refurbishing of existing buildings, and to make suggestions in light of the analysed precedent schools from around the world for improving the environmental literacy of their end users. First of all, the existing research is presented in the comprehensive literature review, covering the topics of environmental problems, sustainability issues, environmental education, sustainable architecture, sustainable building certification systems, sustainable school building architecture and lastly successful examples from around the world. Environmental education and environmental literacy was investigated and the relationship between these concepts used to identify existing gaps in the literature. To effectively promote sustainability in school design, technical principles and environmental targets were reviewed in the light of previous successful applications. Then, this study separately examined the best examples of sustainably built and sustainably refurbished educational buildings from around the world in terms of sustainability criteria and certifications in order to determine sustainable systems in the selected schools. Also, the

[5] HVAC (Heating, Ventilation, and Air Conditioning) is a system to provide thermal comfort and acceptable IAQ.

adaptable aspects of these buildings were analysed to inform the refurbishment of the existing ones in Turkey. Thus, the review of the literature has provided the foundation for the thesis and a grounding for the field work, which encompasses case study analyses. Field work was undertaken to evaluate the existing context of the buildings themselves and their users. In this field work, there were two different methodologies. One of them was the documentation and measurement of the case study building, the other was the detailed analysis of the precedent schools that contributes to refurbishing the building.

Simulation tools were used to further evaluate the building's existing performance, and then to test proposals for improvement to the building's performance. By examining adaptation possibilities of sustainable systems in precedent school buildings from around the world, most applicable sustainable systems to existing unsustainable school buildings in Turkey was determined. DesignBuilder (building energy performance software program) was used for simulations in order to improve the building performance, and detect how much energy the existing building needs. As a result of surveys, researches and simulations (DesignBuilder), three proposals (scenarios) were put together for the refurbishment of existing school buildings in accordance with sustainable criteria and the payback periods were calculated. The first scenario (S1) includes improving the performance of the window glazing and building envelope and integrating LED lighting. Among five different kinds of window glazing and insulation models for the building envelope, an appropriate intervention type was selected as an energy-efficient renovation strategy. In the second scenario (S1 + S2), the installation cost and energy savings of using photovoltaic panels are determined after the total surface area of the case study building's roof was calculated. Then, the final scenario (S1 + S2 + S3) demonstrates the simulations of HVAC systems intervention on energy consumption.

Interventions to improve IAQ, thermal comfort, water and energy efficiency, materials to integrate to standard school buildings were examined. Most school buildings built in Turkey have a similar design and appearance. They are usually built by using similar kind of materials without considering climate conditions, vernacular materials, and a sustainable approach. With the aim of reducing water consumption, replacing armatures with water efficient ones, as well as rainwater harvesting is suggested. It is calculated that the volume of collectable rainwater in a year meets how much of the water requirement of the case study school. Since this study focuses on the refurbishment by reducing the negative impacts on the environment, it contributes to environmental sustainability.

1.8 Structure of the Thesis

This study comprises of five chapters. The first chapter presents general arguments such as the thesis introduction, the definition of the problem, the purpose and objectives of the research, the research questions, methodology, limitations and structure of the research.

Chapter 2 reviews the relevant literature in the field, especially by emphasising the previous research studies. Moreover, this chapter of the thesis introduces the background required to close gaps in the field itself. Many published resources and websites were reviewed in order to provide a background in the research field. This section covers the topics of environmental problems, sustainability, environmental education, environmental and ecological literacy, sustainable architecture, sustainable building certification systems, sustainable school architecture, sustainable school building examples from around the world awarded with LEED or BREEAM certification, and lastly standard K-12 school projects in Turkey. Precedent study building analyses contribute to the sustainable refurbishment of existing school buildings and their students' environmental literacy. In particular, the literature review emphasises two fields – sustainable architecture and environmental education, and indicates how they are interconnected in the sustainable school building.

The first section of Chapter 3 includes the identification of the school' problems. In the second section of Chapter 3, the existing building analysis is conducted. It sets out the investigations of the school where the field work is done. This section includes the collection of actual data in the case study school such as the observations and then it continues with the examination of the sustainability of one of the standard K-12 school buildings according to sustainable rating systems. Finally, the existing energy and heat performance measurements of the case study building are presented with the DesignBuilder simulation program. The simulation analyses assess the current state of the environmental performance of the school building.

Chapter 4 takes forward the knowledge gained in the case study work, proposing energy-efficient interventions and water, material and landscape efficient suggestions for Tekeli secondary school. The building energy performance was again calculated following the proposed interventions in Scenario 1, 2 and 3. The initial results were evaluated and compared with the proposed results. Also, the initial costs and the payback period were calculated. The simulation models could then test the effectiveness of different potential interventions. Suggestions for the application of key principles to the existing school buildings in similar climate conditions to the case study school in Turkey are presented.

Finally, Chapter 5 draws together the principal findings of this study, discusses specific results obtained from the analyses described in the preceding chapters, and offers theoretical and practical recommendations for multi-disciplinary future studies on refurbishing school buildings sustainably.

1.9 Chapter Summary

The first chapter provided an introduction to this thesis. This chapter presents the outline of the study by explaining the research background, the importance and the purpose of this research, and the research method. The chapter concludes with the thesis structure.

This study focuses on the relationship between sustainable architecture and education. To make schools environmentally friendly and following the needs of this century, this thesis will also contribute to the works of the Ministry of National Education in Turkey on refurbishing school buildings sustainably. The following chapter reviews the relevant literature on this research.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

The aim of this thesis is to develop proposals for the refurbishment of school buildings in Turkey to increase their energy performance, and in so doing, to nurture the environmental literacy of students. A review of relevant aspects of the literature spanning the respective fields of environmental education and sustainable building design has been undertaken to provide a synthesised foundation for this research project. This chapter will provide the definition of terms in relation to environmental literacy and environmental education, a brief overview of the history of environmental education, and will focus specifically on how the school building itself might relate to and potentially support environmental education. The next section will address sustainable building design, specifically in relation to strategies that are appropriate for schools, along with criteria for refurbishment based on sustainable certification systems. The subsequent chapter will continue with this theme and present a number of case study precedent school buildings selected from around the world, identifying where these can be used as a model for sustainable refurbishment of existing school buildings in Turkey.

2.2 Environmental Literacy and Education, and the Role of the Sustainable School Building

In this research study, environmental literacy as one aspect of environmental education, and school buildings as a part of the physical built environment, are considered. This section firstly explains environmental literacy and then provides an overview in the field of environmental education. It will then present ideas around the description of the sustainable school building as a '3D textbook' and 'third teacher' in raising more environmentally literate individuals.

2.2.1 Environmental Literacy

Many concerns about the environmental problems caused by human actions have led to the development of concepts such as ecological literacy, ecoliteracy and environmental literacy. Although the meaning of these concepts is similar, they are different. The term 'ecological literacy' was first publicly used by Risser in 1986 (Risser, 1986; McBride et al., 2013, p. 10). Then, physicist Fritjof Capra and environmental educator David W. Orr used it in the 1990s (Orr, 1992a, as cited in Steele, 2010, p. 4; Capra, 1999, p. 2). Ecological literacy is defined as an understanding of the systems in nature and an understanding of the relationship between people and the natural environment (Jordan et al., 2009, p. 495; Powers, 2010; McBride et al., 2013, p. 11; Orr, 1992a, as cited in Steele, 2010, p. 4). Although the terms 'ecological literacy' and 'ecoliteracy' are sometimes conflated (the latter being used as a shorthand for the former), ecoliteracy, which was first introduced by Capra in 1997, moves beyond ecology and has a focus on creating societies that have sustainable environmental consciousness (Centre for Ecoliteracy, 2013). However, the term environmental literacy could be seen to cover the other two terms when examined in a broad sense. Thus, in this thesis, due to being more comprehensive and including the other two terms, the term 'environmental literacy' is used.

The term 'environmental literacy' was coined by Charles E. Roth in 1968, who described environmental literacy as the level of an individual's awareness of environmental information (Roth, 1992). From that time, the definition of the term has changed and been comprehensively revised (Roth, 1992; Simmons, 1995; Weiser, 2001; Morrone et al., 2001; North American Association for Environmental Education (NAAEE), 2004; O'Brien, 2007; McBride et al., 2013). In the general sense, environmental literacy is the ability of individuals to have the knowledge necessary to support the healthy functioning of the interconnected environmental systems and to transform this knowledge and skill into action—in other words, behaviour (Disinger and Roth, 1992). The most common definition of environmental literacy is concern about and awareness of the environment and its problems, as well as the skills, knowledge and motivations to mitigate them (NAAEE, 2004; McBride et al., 2013). An environmentally literate person has the ability to make sustainable choices, is aware of his/her negative impact on the environment, and knows about how to reduce it. Contreras (2014) considers that environmental knowledge, attitudes, uses and concerns form environmental literacy.

Environmental literacy is a broad concept encompassing not only an individual's environmental knowledge or environmental attitude but also their environmental behaviour and problem-solving skills (Roth, 1992; Hsu, 1997; McBeth et al., 2008). In recent years, McBride et al. narrated the development of the term environmental literacy in the context of environmental education (McBride et al., 2013). In accordance with the literature review conducted by McBride et al., there is no one definition of an environmentally literate person, or what defines environmental literacy. However, researchers mostly agree on several characteristics that describe an environmentally literate person. Roth (1968) defined the key features of an environmentally literate person as 'somebody who possesses the basic skills, understandings and feelings for the relationship between people and the environment'. Researchers who agree with Roth's thought stated that an environmentally literate individual can establish connections between society and the environment (Orr, 1992b; Bybee and DeBoer, 1994; Palmer, 2003; Ozsoy et al., 2012). According to Disinger and Roth (1992), an environmentally literate person should be able to use environmental behaviour, beliefs, opinions and attitudes to identify and limit environmental problems, in addition to having a broad knowledge of the environment. The authors also state that the person should be able to show what s/he has learned and which skills s/he has acquired. Observable behaviour can determine the person’s level of environmental literacy (Disinger and Roth, 1992).

Using the terms 'behaviour' and 'attitude' interchangeably can be a problem because they are very different. Behaviour refers to a person’s actions, whereas attitude influences his/her opinions, feelings, and thoughts. Environmental attitudes do not necessarily lead into environmental behaviours. Having a positive attitude does not mean having pro-environmental behaviour such as recycling, using less water and energy, polluting, making less impact. According to Eilam and Trop (2012), attitude and behaviour are different. Their study indicates that the factors influencing attitudes and behaviours are not the same thing and observable effects on behaviours are apparent (Eilam and Trop, 2012). Developing an active participation in environmental activities and promoting environmental behaviour are significant—changes in behaviours can reduce the impact of human actions on the environment.

Based on descriptions derived from different definitions, it can be summarised that the term 'environmental literacy' is related to environmental knowledge, awareness, attitude, and behaviour. There are studies that show that even though attitude and behaviour are different, they often correlate, so someone with an environmentally conscientious attitude is much more likely to manifest environmentally conscientious behaviour than someone without. In one of these, Maurer and Bogner (2020) suggested that there is a difference between environmental attitude and behaviour, but attitude is linked to behaviour (Maurer and Bogner, 2020). An environmentally literate person can reflect their attitude in their behaviour, and ultimately behaviour is essential in terms of their actions in reducing negative impacts on the environment. Therefore, the following section will discuss one of the ways of raising environmentally literate individuals. That way called 'Environmental Education' aims to educate young people, improve their environmental literacy, and shape their behaviour and action. The details are presented in the section below.

2.2.2 Environmental Education

The field of what is now known as environmental education grew out of the foundation of the National Association for Environmental Education (NAAEE) in 1971 and its aim is to improve the environment and change people’s behaviour towards the environment by increasing the level of environmental knowledge (Pooley and O’Connor, 2000, as cited in

Cabuk et al., 2019). This section presents an overview of the field of environmental education. Then, the section discusses its historical development, definition, relationship with environmental literacy and its ambition to give people the understanding and skills needed to tackle many of the most complex 21 st century problems, and raising awareness in order to change environmental habits and minimise environmental problems. It also presents several key areas of research in environmental education and its potential for enabling a greater level of positive environmental behaviour.

In the late 1960s and early 1970s, the global population increased and this brought environmental problems. Humans believed that nature automatically renews itself and ignored the preservation of the environment (Abdiraimov, 2016, pp. 30-31). With the increase in environmental problems, Onen (1994, as cited in Erol 2005, p. 25) state that the studies in environmental education and awareness have been carried out since the 1960s (Onen, 1994, as cited in Erol, 2005). Thanks to these studies, people were starting to become aware of humans causing damage to the environment. *Silent Spring* (1962) written by Rachel Carson is one of the first books raising awareness about environmental issues. It highlights the negative environmental impacts caused by the use of pesticides. With the increase in reports and research on the environment, the level of environmental awareness of people has increased throughout the world (Kaya, Cobanoglu and Artvinli, 2011).

Examining the situation with the environment takes place at a global level, with environmental problems discussed by academics, researchers, politicians, the United Nations, and other international organisations (Onen, 1994, as cited in Erol, 2005). The transformation towards sustainability has been promoted by many international forums. They comprise the United Nations (U.N.) Conference in 1972 (the first global evaluation about the environmental awareness and international environmental issues), Tbilisi Declaration in 1977, I. World Climate Conference in 1979, II. World Climate Conference in 1990, Rio Summit in 1992 (Henderson and Tilbury, 2004). This study emphasises on three of the general principles of environmental education determined in the Tbilisi Declaration: firstly 'having an interdisciplinary approach', secondly, 'highlighting the importance of problem-solving and critical thinking skills due to the complicated environmental problems' and lastly but potentially most importantly for this thesis, 'benefitting from various learning environments and educational approach about the environment' (Keles, 2007; UNESCO, 2015).

Over the period 1970 to 1992, several significant conferences highlighted the importance of education as an essential tool in combating climate change, reducing the negative impact of humans on the natural environment, limiting global warming and pollution, and raising environmental awareness (Scoullas and Malotidi, 2004, as cited in Ozsoy, 2010). At these conferences, the aims, goals and principles of environmental education were identified. This included the notion that improving the sensitivity to recognise, protect and use the natural environment is the basis of environmental education. Regarding the issues that environmental education is mainly concerned with, sustainability educator Stephen Sterling stated that environmental education initially deals with the history and study of nature and conservation education in terms of mitigating environmental problems caused by human actions (Sterling, 2004).

David W. Orr, an American professor and a pioneering researcher working in the field of sustainability and environmental education from the 1970s, posited that environmental education, which takes a participatory, multidisciplinary, and experiential approach and concentrates on the learning process, is an education science that provides useful knowledge about sustainability (Orr, 1997). UNESCO[6] defines environmental education as ' educating environmental literate citizens who are aware of the environmental problems the world facing and know how to solve them' (UNESCO, 1980). UNESCO’s definition was replicated by the researchers as the main purpose of environmental education is to create environmentally literate society (Roth, 1996; Rothkrug and Olson, 1991; Wilke, 1995).

In this context, researchers have carried out studies on the environmental literacy of individuals that build society. For example, Boca and Saracli (2019) investigated the environmental literacy of 358 Romanian university students studying in different fields (engineering electrical, mechanical, and economic). As a result of the survey analysis, it was observed that the individuals’ environmental perceptions showed an improvement, while there was not an improvement in their environmental attitudes and behaviours (Boca and Saracli, 2019). According to the authors, this is because environmental issues in the mass media (TV, radio, newspaper, internet, etc.) were exaggerated and participants were not interested in information about environmental problems, and did not behave pro-environmentally (Boca and Saracli, 2019). As seen in research similar to Boca and Saracli

[6] UNESCO (The United Nations Educational, Scientific and Cultural Organisation) was founded in 1945, in the United Kingdom. Its aim is to achieve international cooperation between nations in the fields of education, science, and culture.

(2019), Timur, et al. (2013) undertook an empirical study which identified that student teachers' environmental literacy increased and their environmental behaviours were orientated in a positive direction if they had undertaken environmental education and science classes as part of their training (Timur et al., 2013). It is significant for teachers to be environmentally literate and well educated in this essential subject because they educate the next generation.

This study about environmental education in the university led to a similar conclusion about the importance of environmental education in schools. In concordance with this study, Collado et al. (2020) presented evidence that nature-based environmental education activities such as scouts or summer camp had a greater positive effect on Spanish primary school students' environmental attitude than traditional curriculum. Collado et al. (2020) promote supporting the curriculum with a nature-based pedagogy. In this respect, the authors such as Boca and Saracli (2019), Timur et al. (2013), and Collado et al. (2020) provided substantial evidence; assertions based on them support that schools should integrate environmental education with the curriculum. Although Azizi and Wilkinson (2015) argued that green buildings do not influence occupants' environmental awareness and energy saving behaviour, Clarke (2013) investigates in his doctoral thesis whether buildings have pedagogical roles and sustainable buildings shape environmental behaviour. According to the assumptions from his survey analysis, sustainable buildings support sustainable behaviours (Clarke, 2013). Another doctoral study by Rokosni (2019) aims to understand how the architecture of sustainable buildings may shape sustainable occupant behaviours. The author uses mixed method, both interviews with the architects of BREEAM-certified accommodations in order to explore designed affordance, and surveys with students in order to explore perceived affordance. The thesis has contributed to the statement 'sustainable architecture supports sustainable occupant behaviours when occupants perceive their needs are well supported by the building and its features' (Rokosni, 2019).

Moreover, Izadpanahi and Elkadi (2014) investigated the impacts of school design on students' environmental attitudes. In order to understand the differences in environmental attitude, they surveyed 597 students, aged 10-12 years old, studying in three sustainably and three conventionally designed schools in Australia (Izadpanahi and Elkadi, 2014). Sustainable schools were selected randomly from those primary schools awarded a five-star certificate of sustainability from ResourceSmart Australian Sustainable Schools Initiative Victoria, which helps schools to benefit from embedding sustainability in everything they do. As a result of their analysis, this research indicates that there is a significant difference in environmental attitudes of students studying in these two different types of schools. The authors reported that there is an impact of sustainable school design on students and so suggested that features of school design such as recycling water from the school roof, solar panels, outdoor space as a classroom should be more invested for more pro-environmental students (Izadpanahi and Elkadi, 2014). The reviewed literature shows that the effects of sustainable school buildings on the environmental literacy of students are still debated. This issue can be related to the effective use of architectural elements. More empirical studies are needed in this field.

In addition, the space in which the learning and teaching occurs has an impact on learning. Gokmen asserted that schools that have sustainable design offer a higher success rate, increased student participation and performance and satisfaction, positive changes in student behaviour (Gokmen, 2012). In this context, Reynolds and Scott suggested that sustainable schools encourage students in learning by enhancing attitude, behaviour and motivation; they also support healthy lifestyles and school environments (Reynolds and Scott, 2011). Reynolds and Scott defended the 'eight sustainable schools doorways' concept mentioned in Gayford’s research to provide sustainability through curriculum, campus, and community (Gayford, 2009, p. 2; Reynolds and Scott, 2011). Barrett et al. (2019) reported that being a sustainable school raises standards and enhances young people’s well-being (Barrett et al., 2019, pp. 36-38). The research evidence supports the idea that this is because sustainable schools engage young people in their learning, so improving motivation and behaviour, and also promote healthy school environments and lifestyles. In addition, evidence shows that sustainable schools advance community cohesion by making valuable connections between the school and its parents and carers and the wider community.

The physical context in which students undertake pedagogic activities covers the natural or built environment. This means that some classes can take place in buildings or outside. There is a real potential teaching value in each of these settings. Louv (2008) mentions that education might work really well in the natural environment (Louv, 2008). According to Louv (2008), having classes in the natural environment and using natural habitats for learning and teaching can be really positive. Louv (2008) also suggests that nature could be a laboratory for teaching about the environment and developing children’s creativity, development and learning skills. According to Louv (2008), a connection with the natural environment can be a really enriching and important experience for children. The natural environment in which students can learn might contribute to their learning (Louv, 2008). There are other researchers who talk about the importance of learning in a natural environment. Kavak and Coskun (2017) supported Louv's view with a study about the use of materials in nature for early childhood education. In this journal article, the authors investigated the difference between pre-school teachers in Turkey and Germany in terms of developing informative material. The research method is based on experiences and observations in two kindergartens of two different countries. The authors also noted that teachers in Germany benefitted more from materials in nature. These materials had a positive impact on children's learning because the activities designed with natural materials encouraged children's creative thinking skills and imagination. Therefore, integrating the places where children live with nature has a crucial role in environmental education (Kavak and Coskun, 2017). In this context, Orr indicates that physical environment and environmental education are two convenient disciplines to be able to integrate (Orr, 2000).

The physical environment in which students undertake their learning also plays a really important role in supporting environmental education. Accordingly, Bingler (1995, as cited in Shapiro, 2016) indicated that the physical learning environment could be used as a resource in teaching and learning (Bingler, 1995, as cited in Shapiro, 2016). Taylor asserts that students interact with and learn from the physical environment of school buildings at many levels (Taylor, 1993). According to Kavak and Coskun (2017), connecting students to the physical environments in which education occurs helps them in improving new skill, environmental attitudes, behaviours and awareness (Kavak and Coskun, 2017).

According to the assertions based on the learning from the literature, both 'a natural environment' and 'a school building' can be used as a learning tool for environmental education. However, the relationship between environmental education and the physical environments in which education occurs has rarely been addressed in the architecture of educational buildings. This study will contribute to the gap in this knowledge. This thesis specifically looks at school buildings as learning or pedagogic environments and how they can be made more sustainable. Making them more sustainable does not mean only improving building energy performance and helping the environment, but also this can help by teaching sustainability with the theories of the 'third teacher' and '3D textbook', which will be explained in the next section. So, students will learn about environmental issues from the school building they're in, depending on whether they need teachers to use the space as a tool for environmental education. In the following section, to influence environmental behaviour and increase environmental literacy, the relationship between sustainable school buildings and environmental education, and how the built environment can be used as an educational tool will be discussed in detail.

2.2.3 The Role of a Sustainable School Building in Environmental Education

Olivier, Janssens-Maenhout and Peters identify that school buildings 'are a substantial proportion of all buildings' (2012) and therefore reducing the environmental impact of this building type is imperative. However, Martin (2006) takes this further, indicating that a sustainable school building not only offers improved environmental performance, but might also have a pedagogic role in the environmental literacy and behaviour of the pupils taught within it.

This section is about how the natural and physical environment of school buildings can promote learning about sustainability. The pedagogical role of school buildings will be discussed in detail below. Environmental educators and theorists have proposed that the school building itself can contribute to environmental education in a number of ways. Within the literature, the two distinct, but related models which demonstrate how the sustainable school building may support environmental education are the building as a '3D (three-dimensional) textbook' or as a 'third teacher'. This section will provide an overview of these two models, including where they each originated, and highlighting how they are different.

For a better understanding of schools in terms of sustainability and pedagogy, this section and its subsection explore the literature about how school buildings can act as 3D textbook or third teacher. As a first step, key resources about school buildings as educational tools are reviewed. Secondly, the terms 3D textbook and third teacher are explained, respectively. Finally, I have discussed the difference in these terms. The following subsection will discuss this in terms of both evidence-based and practice-based research in detail.

2.2.3.1 School Buildings as 3D Textbook and as Third Teacher

In relation to considering the physical environment of schools as an educational tool, this section presents reviews of the literature on 'passive' (three-dimensional textbook) and 'active' (third teacher) roles of the school building educating sustainability, with a series of themed examples which may show active and passive strategies.

<u>The 3D Textbook</u>

Steven Bingler, Bonnie Sherk and Anne Taylor first used the term '3D textbook'—this theory means that students can learn the physical environment by experiencing (Taylor and Enggass, 2009). It is the idea that the physical environment and its elements could be used as a teaching and learning tool in order to understand the issues in textbooks (Taylor and Enggass, 2009). Accordingly, Shapiro (2016) stated that every material in the learning environment has the potential for learning and teaching. Schools are used for education in a variety of ways. The school building itself, for instance, can be an educational tool to teach lessons such as science, math, technology, poetry, and art. With a participatory approach, calculating how much energy saved, how much material recycled, and how much rainwater harvested and making the calculation methods visible in the learning environments might be integrated into math lessons. Similarly, in the case of designing a visible path for rainwater, students can hear the sound of water falling from the roof—they can get inspirations for poetry and art lessons. So, a well-designed school building should be functional, sustainable, and pedagogical. Good examples of a place where students use the building as a 3D textbook will be extensively analysed in precedent studies of sustainable school buildings.

Rather than being simply an educational tool to teach the curriculum, there are numbers of people focusing on how school buildings might be useful for environmental education. As an example, Tasci (2015) stated that a learning environment as a three-dimensional textbook can be material for the learning of sustainability. As part of environmental education, teachers could use aspects of the physical environment in which students are taught such as the building or the natural environment, as a resource (Tasci, 2015). Day and Midbjer (2007), Orr (1997), and Taylor (1993) all assert that using a school building as a '3D textbook' can promote a dynamic relationship between the environment and students who are based within that environment, who learn by means of their interaction with their physical environments (Khalil, 2011). Visual literacy is essential for using school buildings as a 3D textbook. Anne P. Taylor and Katherine Enggass in their book *Linking Architecture and Education: Sustainable Design for Learning Environments* highlighted that visual literacy requires understanding and interpretation of visual messages (Taylor and Enggass, 2009). However, the educational features of school building may be observable but not easily noticed by anyone. Without the help of their teachers, students cannot easily develop their visual literacy to discover the curriculum embedded in the 3D textbook. When classrooms are utilised as a learning tool by teachers, students could understand the physical environment.

Seng Yeap Kong, who has an expertise in 'schools as 3D textbook for environmental education', notes that the concept of 3D textbooks includes architecture, sustainability and education. Kong (2014) also underlines the importance of sustainable design because it does not only improve environmental performance but also defends that the built environment has a potential to teach environmental issues. According to Kong (2014), sustainable built environments are ideal for educational structures since they can motivate students' interest and learning about buildings as 3D textbooks (Kong, 2014). The physical environment as a pedagogical value provides a better understanding of the lessons taught in the classroom. For instance, rainwater harvesting or renewable energy systems, if they are visible, can encourage students' imaginations and learning about sustainability (Nair et al., 2009, as cited in Kong, 2014). Additionally, in one of Kong's case studies, the 3D textbook promoted learning by doing because classroom lessons and books were inadequate to ask students to think critically about recycling and acquire the skills of collecting, separating and processing waste. The 3D textbook had collage walls showing the number of bottles collected. These walls enabled students to observe and then understand the consequences of their behaviour, particularly, the environmental impacts of personal behaviour on the processes and cycles of matter through the school environment (Kong, 2014). So, this is a good example that can be applied in all schools to promote recycling behaviour. In addition, the Alberta Energy program allows students to examine energy education principles by 'using the material structures of the physical learning environment to understand and develop the concepts, energy and heat' (Shapiro, 2016, p. 2). Through this knowledge, they monitor heat loss and energy waste in learning environments and then share their findings with other students and teachers. So, they become 'energy loss activists' (Shapiro, 2016).

Furthermore, as Higgs and McMillan (2006) stated, many schools foster their students' active participation in sustainability-related maintenance and operation within the learning environments (Higgs and McMillan, 2006; Kong, 2014). Incorporating students in the operation and maintenance of schools makes the waste, consumption and expenditure of schools more perceptible (Abrahamse, et al., 2007; Bandura and Houston, 1961; Foster, 2001; Kong, 2014). Another good example might be to design a small organic farming area. Rather than the physical environment, it supports outdoor learning. In Kong's (2014) study, pupils were informed about organic farming as an alternative to using chemical fertilizer and pesticide. They observed the nutrient cycle that food waste from the canteen can be composted and recycled as organic fertilizer (Kong, 2014). In these examples, it has been highlighted that the physical features of learning environments have served as an educational tool and the '3D textbook' has acted as a catalyst for students to take responsibility and action on environmental issues.

A number of researchers agree with Hale, 'as language is a tool to express ideas, the built environment is a tool to express values' (Hale, 2000). According to Deal and Peterson (2009), school buildings as 3D textbooks help students to learn easily and explicitly. Until 12th grade, children spend over 14,000 hours inside school buildings; therefore, they learn sustainability issues from the curriculum and the physical environment which have sustainable values (Deal and Peterson, 2009). Even though students' knowledge about the environment is increased by means of classroom lectures, discussions, and experiments, these ways alone are inadequate to alter students' attitudes or concerns for the environment (Tung et al., 2002; Ramsey, 1993). Yudelson also emphasised that theoretical curriculum is not enough in order to support the approaches that will create environmental sensitivities in children (Yudelson, 2007). In this context, schools should be considered to develop a conscious awareness in children by observing school buildings directly and participating in them. According to Brkovic and Milosevic (2012), sustainable school buildings as 3D textbooks prepare a suitable environment for this, and offer students the opportunity to gain environmental awareness. Also, Boeve-de Pauw and Van Petegem proposed that students' perception, performance and behaviour might be shaped depending on physical settings (Boeve-de Pauw and Van Petegem, 2011). Tung et al. (2002) highlighted that environmental knowledge, attitude and behaviour most probably increase in schools that integrate environmental activities supported by the physical characteristics of buildings into curriculum (Tung et al., 2002). Therefore, it is the right approach in environmental education for both curriculum and the built environment to cooperate.

Research about the effect of the physical environment on environmental literacy have been presented above. Furthermore, a number of researchers such as Taylor (1993), Kong (2014), Taylor and Enggass (2009), Izadpanahi and Tucker (2017), and Gokmen (2010) have contributed to the studies investigating the impact of school design on students' environmental knowledge, awareness, attitude and behaviours.

Taylor asserts that students learn to 'read the environment', interact with and learn from the architecture of school buildings at many levels (Taylor, 1993). For example, Integrated Learning Centre at Queen's University in Canada is known as a 'living building' since students can learn from the building through monitoring systems (Kong, 2014; Taylor and

Enggass, 2009, p. 359). These monitoring systems allow students to see, for example, the energy generated by photovoltaics, the water saved by water recycling system and the carbon saved by recycling. Students could be guided by their teachers to understand functions of the sustainable building. So, students could learn what the benefits of sustainable systems are, and which alternative ways of using natural resources in a building design are through monitoring screens on the wall. However, students' perceptions are different in each age group. School children may develop their understanding with their teachers' explicit use of school buildings as a 3D textbook. The things that students learned in schools might generate an awareness that can lead to pro-environmental behaviours. However, has this theory been fully tested in the field? The next paragraph will examine fieldwork on the issue of how can school buildings most effectively be used as a 3D textbook.

Accordingly, Izadpanahi and Tucker state that students in sustainable schools have more environmental attitudes and behaviours than those studying in conventionally designed schools (Izadpanahi and Tucker, 2017). As a result of the analyses of Izadpanahi and Tucker, this hypothesis was proved by means of the scales using to evaluate children's environmental attitude and behaviour. After the data was collected from 275 children studying in four conventional and three sustainable primary schools, it was analysed with multivariate analyse of variance (MANOVA). The analysis helped to measure the effect of the learning environment on children's environmental behaviours and attitudes. According to the findings, there are significant differences in children's environmental attitudes and behaviours (Children's Environmental Attitudes via ESD at School and Children's Environmental Behaviours towards Resource and Energy Conservation) between sustainably designed and conventional schools. School design had the greatest impact on the variable Children's Environmental Attitudes via ESD at School and Resource and Energy Conservation Behaviours. Therefore, students studying in schools designed for sustainability had higher levels of environmental attitude and behaviour (Izadpanahi and Tucker, 2017). Although it was determined by the correlation analysis that there was a significant difference between different schools in the study, it was observed that there were no questions about the integration of the schools' sustainable features into the curriculum that could be measured in the questionnaire. The survey questions could be further developed.

As Gokmen (2010) states, 'child and architecture' studies such as investigating the awareness of the built environment education and the effects of the school building on students' environmental behaviour, have become important to teach general information to children about architecture, and to understand the designed environment for children (Acer, 2016; Taylor, 1989). Along with the interaction of the designed environment with accurate education, the child will increase his/her knowledge towards the environment, improve quality of life and will become a responsible citizen with an environmental consciousness (Gokmen, 2010).

As a result of the reviewed literature, it can be understood that school buildings have the potential to contribute to students' learning and environmental literacy. A better designed environment supports activities that take place within that environment. Despite the fact that there are studies investigating the potential of school architecture on environmental education as a 3D textbook (Higgs and McMillan, 2006), not enough research about the effectiveness of architectural interventions as an educational tool has been published in the literature (Fink, 2011; Tanner, 1974; Taylor, 1993). There is a gap in this field to investigate— the idea of the teaching potential of refurbished schools through sustainable interventions, and the effects of these interventions on environmental literacy. In addition, more research is needed about the effects of sustainable building certification assessments on the environmental literacy of their occupants in certified buildings and the use of categories of sustainable certification systems as an educational tool. This study will focus on a series of sustainable interventions on systems such as energy, water, solar panel, HVAC, lighting, landscape presented as scenarios in Chapter 4.

The third teacher

Rather than just benefitting from sustainable values of school buildings in the curriculum, making these sustainable features visible has generated the term 'schools as a third educator'. This idea has its roots in the philosophy of Montessori schools. Maria Montessori explained in her book *The Secret of Childhood* that 'the first aim of the prepared environment is, as far as it is possible, to render the growing child independent of the adult.' The environment as 'third teacher' or 'third educator' was an idea first explored by Loris Malaguzzi. The founder of the term considered the three teachers of students to be: adults, other students, and their physical environment. The last one refers to the learning environment as the 'third teacher' (Gandini, 1998, p. 177). Rather than just parents and teachers, the environment is also responsible for educating children.

Newton et al. (2009) noted that buildings having low environment impact have a potential to act as pedagogical tools (Newton et al., 2009). From a slightly different perspective, Nicholson (2005) suggested that 'the built environment cannot just directly, but also overtly and symbolically transmit to children that they are to be inspired, trusted, respected, loved, protected and understood' (Nicholson, 2005, p. 64; Brkovic, 2013, p. 44). According to Brkovic (2013), messages written on the walls, seats varying in size, handles and light switches at children`s height, colour-coded doors, etc. are all physical elements of learning environments that convey various subtle positive messages to children (Brkovic, 2013). For example, sustainability messages can be transmitted through the physical elements of school buildings or signs on walls demonstrating energy and water consumptions, CO_2 footprint, recycled materials, etc. As the authors above stated, sustainability messages in school architecture should be designed in a way that students of all ages can read and understand. Good examples of a place where students use the building as a third teacher will be extensively analysed in precedent studies of sustainable school buildings.

It is possible for schools to be seen as symbols that raise awareness of sustainability in society and children by setting an example in structural dimensions. According to Prakash and Fielding (2007), a dynamic model, which describes sustainable design, architecture, engineering, construction, environmental science and harmony with nature in a school environment, is an excellent learning tool. The use of systems that provide energy efficiency in schools supports children's relationship with the environment, energy conservation and use (Prakash and Fielding, 2007). In this respect, for example, by keeping some of the elements in heating, cooling and ventilation systems open, it is stated that environmental consciousness can be gained under the influence of a museum offering information for children (Taylor, 2009). Accordingly, students could learn how these systems work through observing and informative labelling, so that they are able to be aware of using the resources efficiently.

Schools designed with the principles of sustainability should support the creation of new experiences based on practice (Davis, 2010). If this is possible, sustainable schools communicate with students about the environment through the teaching function. Prakash and Fielding (2007) stated that it would be also useful to have a follow-up system that should be placed in different places in schools—where they can be seen, rather than hiding photovoltaic panels—so that children can acquire consciousness about their energy efficiency activity. Moreover, according to Day and Midbjer (2007), a green roof could raise awareness of nature, allowing students to observe the life cycles of the habitat consisting of a variety of plants and insects (Day and Midbjer, 2007).

In addition, Gelfand and Freed (2010, p. 248) argue that 'school facilities could be a vehicle for learning when environmental sustainability systems are visible; because transparent demonstration of sustainable behaviour has educational potential'. In terms of water conservation, rainwater is harvested and greywater is used in toilets. Students could observe this process on the informative screen on the use of recycled water for irrigating (Gelfand and Freed, 2010). As an example, rainwater harvesting activities of Burton School in Michigan ensure 44.2% of water savings. A visible path for rainwater collected from the roof enables students to hear the sound of falling water and to understand why it is harvested. As Leatherman (2009) stated, students learn rainwater harvesting process from the building as a third teacher (Leatherman, 2009). The system of preserving natural resources could be seen as an educational tool, and adopted by students (Leatherman, 2009). This practice might encourage them to write a poem or design an art project about water management. Students can learn the advantages of conserving water and recycling. In terms of the integrated studies in math and science, students could also learn how much wind turbines produce energy and reduce electricity bills.

School environments are supposed to have lots of visual stimuli to foster the exchange of information in order to encourage learning through exploring, experiencing and playing (Nair et al., 2009; Brkovic et al., 2015).

As Cole (2013) stated, 'sustainable school buildings provide lesson plans on topics such as water-efficient technologies, energy audits and building materials conducted by students. Architectural details support informal learning activities such as green teams or gardening clubs' (Cole, 2013). The article written by Bowker and Tearle (2007) described the positive impact of school gardening on the perception and behaviours of students. This is a case study conducted in 67 schools in England, Kenya and India using contextual observation, interviews and children’s drawings as a method. The study adopts learning through experience (Bowker and Tearle, 2007).

Using timber as an architectural material shows that natural materials, such as timber from trees, can be used to make buildings, as an alternative to using less sustainable materials such as concrete. This could then support a classroom conversation about why it is important to think about what materials things are made of, and that it is better to use sustainable materials. Also, students can be encouraged to think about how recycled materials are recycled, and how they can be recycled later. As a teaching tool, it helps to develop students' learning and imaginations about sustainability. Students studying in sustainable schools could ask questions about the energy they use to heat and cool their buildings, the food they grow and eat, the air they breathe, the electricity to run light bulbs, the materials they recycle, and the waste they create if there is a visible active mechanism to catch and keep their attention or integrate these issues with the curriculum. An intention of this thesis is to evaluate the potential of sustainable features to change students' environmental attitude and behaviour.

In this study, it is defended that lessons learned through the curriculum, or visible sustainable features expressed by the physical environment, can have a positive effect on environmental observations, behaviour, attitude, and awareness of students. Both of them are useful tools to develop environmental literacy—but there are some differences. The difference of the terms which are '3D textbook' and 'third teacher' is based on their function as either active or passive. If the physical environment is thought of as a 'three-dimensional textbook' or 'silent curriculum', which can influence learning experiences (Taylor and Enggass, 2009, p. 25), the school building itself is passive, so teachers use the building as part of a lesson. If the school building serves as a third teacher, the building is an active teaching tool for students.

Tavsan and Yanilmaz (2019) asserted that educational structures with sustainability criteria, are important for children to develop environmental awareness and make it a way of life (Tavsan and Yanilmaz, 2019). Sustainable schools could effectively create environmental awareness for students through experience. In these schools, the emergence of building systems is an example of the role of the school building as third teacher but at the same time including these systems in the curriculum is like a 3D textbook that is easy to read for children. Schools are practical learning environments that are evaluating grey and rainwater for irrigation purposes, using a water system that generates solar-powered energy. For example, how much rainwater harvested could be observed through the monitors (that is, the third teacher), growing plants in the school garden could be taught to students with the help of the curriculum (that is, the 3D textbook).

In addition to the school syllabus, students could learn about their relationship with the environment by observing the architecture of the building to enhance their knowledge and awareness. So, sustainable school buildings raise students' awareness of how school buildings interact with the environment; how much resources they use and what are their effects on the environment and users.

As a result, Cohen and Lovell suggested, like many researchers, that school buildings as living laboratories for environmental education can both educate students and offer solutions on how to use natural resources efficiently (Cohen and Lovell, 2013). According to Munro, school buildings encourage students and community to learn about environment and environmental stewardship. Their physical environment makes contact with their occupants (Munro, 2017; Solak, 2017). The literature review in this research shows that the designed environment could shape its occupants' behaviour and also support interactions between them. In order to support environmental education, refurbishing the physical environment of school buildings as a teaching instrument presents a vital opportunity in terms of topics such as 'conserving natural resources', 'renewable energy' and 'ecosystem' to be conveyed through direct experience. As a result of the reviewed literature based on this issue, there are few empirical studies about using school buildings as an educational tool. It should be considered that existing schools can contribute environmental education while they are improved. Therefore, this research study focuses on refurbishment for environmental education while promoting energy efficient improvement.

2.2.4 Conclusion of the Section

This section has addressed environmental education, environmental literacy, how the school building could have a role in environmental education. Also, it introduces the terms both '3D textbook' and 'third teacher' and what the primary difference is between these two terms. To know the definition of sustainability in words is not enough for putting theory into practice. In addition to this, students learn much more by observing real examples rather than hearing about them (Tasci, 2015). As the researchers pointed out above regarding the use of school buildings as educational tools in environmental education, integrating curriculum with the sustainability features of school buildings could enable students to learn from the building and its communication with the natural environment (Timur et al., 2013; Louv, 2008; Kavak and Coskun, 2017; Prakash and Fielding, 2007; Day and Midbjer, 2007; Nair et al., 2009). So, using the learning environment as the third teacher or 3D textbook will contribute to bridging the gap between education and sustainability. However, it is concluded in this study that the sustainable features of school buildings as an active teaching tool for students cannot be easily noticeable. Sustainable features should be more visible and school buildings as a 'third teacher' should be integrated into the curriculum or reminded by teachers. So, school buildings as a '3D textbook' can influence learning experiences more effectively.

As a result of the related literature, school buildings, if used properly, have a potential to develop environmental literacy of school children. In the studies conducted by the researchers. For example, in the study of Izadpanahi and Tucker (2017) investigating the environmental attitudes and behaviours of primary school students, it was tested that the pedagogical role of sustainable school design had a significant effect on the environmental attitudes and behaviours of the students. However, the number of studies on this subject is not yet enough to be precise about knowledge in this field, and more work is needed to fill the gap. In this context, the sustainable refurbishment of conventional schools and the potential pedagogical aspect of this refurbishment on environmental literacy by integrating it into the curriculum will be evaluated in this study since it should not be forgotten that conventional schools, like sustainable schools, have a potential to improve students' attitudes and behaviours.

Creating awareness of sustainable approaches and environmentally sensitive systems is needed in order to leave a healthy world for future generations. It is a lost opportunity if existing K-12 school buildings are not refurbished with sustainable criteria, on behalf of both raising environmental literate individuals and efficiency in energy consumption.

The next section will explain the principles of sustainable architecture for refurbishment possibilities in terms of adaptable features. These principles are based on sustainable building standards. At the end of the chapter, school building architecture will be mentioned.

2.3 Sustainable Architecture

2.3.1 Introduction

The construction industry is changing in parallel with the increase of urbanisation and the rapid development of the economy. Architecture 2030, a non-profit organisation established in response to the climate change crisis, asserts that the built environment is a leading contributor to climate change due to its significant energy use. The world is estimated to add 230 billion m^2 of building stock over the next four decades (Architecture 2030, 2021). Depending on the information obtained from the same source, the total amount of energy consumed by buildings and their negative environmental impacts will increase daily and continue to contribute to climate change for as long as constructions do not adopt sustainable principles, and do not promote positive environmental behaviour (Architecture 2030, 2021). In this context, sustainable buildings address these issues throughout their life cycle (Sev, 2009, as cited in Kilic and Erikli, 2021, p. 262). Sustainable architectural design helps to minimise negative impacts on the environment by increasing energy efficiency, promoting the use of renewable energy, recycling products and materials, benefiting from local materials, and preventing habitat destruction and loss of biodiversity (Liu et al., 2020; Nair et al., 2009). To summarise and synthesise, sustainable architecture adopts designs that minimise a building's energy consumption in use, and supports the conservation of natural resources. So, sustainable buildings help slow down global warming and make a significant contribution towards combatting climate change.

For a more sustainable built environment, it is obviously necessary that new buildings are constructed sustainably, but also that the existing quantity of unsustainable building stock, which continues to consume energy, is dealt with. However, the demolition and reconstruction of such buildings would waste the embodied energy already in those buildings and then consume yet more natural resources and energy in the construction of their replacements. The alternative is to refurbish existing buildings to make them perform more sustainably. This study discusses opportunities to integrate sustainable design attributes into existing buildings.

This section of the study emphasises the importance and development of sustainable architecture and provides an overview of this field, with a particular focus on sustainable school architecture relevant to the topic of this thesis. In order to understand how to judge buildings in terms of sustainability criteria and how to improve them, an evaluation of sustainable building certification systems is introduced after the sub-section on sustainable architecture principles. International building rating tools, BREEAM (UK) and LEED (USA) are presented as well as a national certification system in Turkey, CEDBIK. Finally, this section will evaluate the key features of precedent studies of sustainable schools, which have high scores in BREEAM and LEED, and focus on specific techniques of sustainable design, many of which can be found across the examples; then it will conclude with a presentation of their detailed comparison.

2.3.2 Sustainable Architecture

This section deals with the definition of sustainable architecture, its impacts on schools and its contributions to environmental behaviour. After the environmental concerns of the 1960s and 1970s (as previously mentioned in the Environmental Education section), approaches in the field of architecture have increasingly incorporated principles of sustainable building design to limit energy and resource consumption in construction and use. According to Dr Arsan, an architect and a researcher working in the field of sustainability and architecture, it can be observed from her 2008 study on sustainable architecture in Turkey that these approaches have been discussed using a variety of terms in different periods (Arsan, 2008). Environmental design was the term first used in the 1970s. Green design in the 1980s, ecological design from the late 1980s–early 1990s, and sustainable architecture from the mid-1990s to the present. These have been the evolving names for this concept up to today (Arsan, 2008, pp. 21-30).

Some researchers defined sustainable architecture. According to Wines (2000), there are two meanings of sustainable architecture. The first refers to buildings which are durable, low-maintenance, low-cost, and energy-efficient, so sustainable buildings have limited negative impact on the environment; the second relates to the relationship that architecture and the environment establishes with people (Wines, 2000). Regarding this definition, Sev (2009) expressed the concept of sustainable architecture as the art of creating buildings that effectively use renewable energy sources, water and materials by considering future generations, as well as taking care of people's health, comfort and aesthetics (Sev, 2009). In addition, Yang et al. introduced the idea that thermal comfort is a significant factor in terms of the sustainable energy consumption of buildings (Yang et al., 2014, pp. 164-165). According to ASHRAE (thermal comfort standard for occupants of buildings), the basic meaning of thermal comfort is satisfaction with the thermal environment and the optimal levels are 30-60% relative humidity and 20-25.6 °C temperature (ASHRAE Standard 55, 2013). Sustainable buildings are able to provide comfortable conditions, suitable for human health, with much less energy input in the building's use, and may be able to more easily achieve the required levels of comfort.

As the authors have mentioned, sustainable architecture can be considered to be a design approach that does not harm the natural environment and ecological balance. Furthermore, the elements of sustainable architectural design are integral parts of vernacular architecture (Salman, 2018; Nguyen et al., 2019). As an example, it has been observed that harvested rainwater from the roof was used for toilets and garden irrigation in the Ottoman Architecture of the 19^{th} century, e.g., Abbaszade Mansion in Beypazari, Ankara, which serves as a living museum today (Halac and Bayram, 2019, p. 60). Then from a similar perspective, like Salman (2018) and Nguyen et al. (2019), many researchers in this field agree that sustainable architecture can be considered as the synthesis of the principle of efficient use of natural resources with traditional architecture (Salman, 2018; Nguyen et al., 2019). In addition, different climatic regions of the world have distinctive building techniques and a wide range of vernacular building typologies—depending on cultural, social, and economic needs. Local resources and regional climate are prioritised in sustainable design and planning. According to Guy and Farmer, and Abusafieh, sustainable architecture takes advantage of natural materials and reduces ecological footprint and negative environmental impact. Also, it reuses traditional construction techniques to promote cultural sustainability (Guy and Farmer, 2001; Abusafieh, 2019, p. 144). In order for a deeper understanding of sustainable architecture and improving school buildings sustainably, the following sub-section explains the principles of sustainable architecture.

2.3.3 Principles of Sustainable Architecture

The sustainability of buildings should not be restricted to just construction—occupation, refurbishment, demolition and reconstruction should also be considered. The whole life cycle of buildings that are designed through sustainable principles aims to have the minimum adverse effects on the built and natural environment. For this purpose, the main topics of sustainable architecture criteria are climate, site location, orientation, energy conservation, Indoor Air Quality (IAQ), thermal insulation, sustainable materials, high-performance window glazing, use of renewable resources, energy-efficient lighting, built form, efficient landscape design, water efficiency, and so on (Yuksek and Tikansak Karadayi, 2017). This is a long list of all of the criteria that can contribute to reduction in energy use of buildings because there is not just *one* thing required to make a building sustainable. This study focuses on sustainable refurbishment of school buildings. So, the sustainable architectural principles presented below are evaluated in the context of school architecture for the refurbishment of the case study school in the scope of this thesis, with a special focus on especially energy and water usage as key performance indicators of sustainability.

• **Energy Usage**

Buildings consume energy for cooling, heating, lighting and ventilation (Yilmaz et al., 2015). The amount of energy consumed in heating and cooling buildings constitutes a large part of the total energy consumed. Therefore, energy is the most important category in this section. This study firstly focuses on the efficient use of energy for heating, cooling, lighting and ventilation in buildings, one of the most important principles concerning sustainable architecture. According to Turkish and EU legislation regarding energy efficiency in buildings, old buildings have difficulty complying with current energy conservation standards and regulations (Yuksekkaya, 2016). As they have not specifically been designed to conserve energy, they have excessive energy consumption in use, and as they mostly rely on non-renewable sources like fossil fuels, they contribute to greenhouse gas (GHG) emissions, have negative environmental impacts, and cause global warming. In terms of environmental and economic sustainability, it is necessary to enhance the energy efficiency for heating, cooling, lighting and ventilation of these buildings (Yuksekkaya, 2016). Yontem (2016) suggested that this might be possible with an 'integrated design approach' (Yontem, 2016: 5). High performance buildings are designed with this approach to minimise their energy use and their negative impacts on the environment. As pointed out by Yontem (2016), an integrated design approach can be adopted in order to minimise the high energy consumption of existing buildings and the damage they cause to the environment (Yontem, 2016).

Energy efficiency in the majority of buildings could be primarily achieved through systematic reduction of heating and cooling demand which constitutes a large part of the total energy consumed. So, energy use will be shortly investigated under the sub-titles of renewable energy, building envelope, insulation, window glazing for energy efficient refurbishment of the case study school building.

Renewable Energy

Renewable energy supplies are the most important opportunities of the 21st century in terms of combating climate change, which is caused by excessive greenhouse gases released into the atmosphere due to the energy consumed (IEA, 2003). As Sokulski et al. (2022) stated, energy-generation technologies such as wind, photovoltaic, solar heating, hydroelectricity, biomass and geothermal energy could be integrated into buildings to provide maximum energy efficiency, and keep a minimum level of energy usage while creating appropriate living conditions in the context of sustainable architecture (Sokulski et al., 2022: 3). For example, solar energy is clean, renewable, the oldest energy resource known, and is becoming increasingly becoming important all over the world. Solar energy is the energy that comes from the sun in the form of heat and light. It can be harnessed in a few different ways. Photovoltaic technology directly converts sunlight into electricity, while solar thermal technology harnesses its heat to produce hot water or steam. Also, passive solar heating simply contributes to heat in buildings by letting the sunshine through windows. Using solar energy to reduce electrical energy demand in buildings through photovoltaic cells and to obtain hot water through solar thermal collectors is one of the significant principles of sustainable architecture.

The consumption of approximately 40% of global energy is in buildings (Yang et al., 2014, p. 164; Monna et al., 2022) which has increased the importance of the use of photovoltaic (PV) panels in the building and refurbishment sector. It is possible to meet some of the electrical energy needs of a building by means of photovoltaic and thermal panels. For example, OIB Technical and Vocational High School, a sustainably designed school building, meets nearly 30% of the building's electricity thanks to the solar photovoltaic panels on the roof, according to the information obtained from the school archive. A more detailed overview of this precedent school is in Appendix J. Altin pointed out that the most important characteristic of photovoltaic panels in terms of sustainable architecture is that they help buildings to be a low or zero carbon building that generates as much energy as it consumes (Altin, 2006). According to Birturk et al., photovoltaic applications play a major role in achieving the goal of zero energy buildings (Birturk et al., 2021). The case study school in this thesis is evaluated in regards to whether it can be a zero-carbon school building through the improvement with PV panels.

The amount of energy generated in the building depends on the technology, energy sources and the site conditions. Also, the use of PV panels depends on its initial cost, the climate conditions, and also which hemisphere the building is in. For example, the efficiency of solar energy generation would be lower on roofs of the buildings not facing south in the northern hemisphere. Moreover, the construction of the roof should be strong enough to support the weights of the panels. Despite these restrictions, the potential for photovoltaic installations is immense. Dondariya et al. state that the electricity generated by PV is widely utilised all around the world (Dondariya et al., 2018).

- **Heating, Cooling and Relative Humidity**

Conventional buildings consume lots of energy to be thermally comfortable (Liang et al., 2017). Yuksek and Tikansak Karadayi (2017) state that buildings consume energy at different levels in every stage of the life cycle (Yuksek and Tikansak Karadayi, 2017). Energy consumed for heating buildings in their occupation phase produces the majority of GHG emissions (Toller et al., 2011; Brown, Olsson and Malmqvist, 2014). The amount of energy required for heating and cooling can vary according to climate zones (Lee et al., 2015). Cooling buildings in hot and humid climatic regions, like the case study building in this study, accounts for most of the energy consumed. Okafor (2017) reported that the two most important parameters for cooling systems were determined as air temperature and humidity (Okafor, 2017).

As Akerman et al. (2007) pointed out, energy demand in buildings will be reduced through the improvement of building performance (Akerman et al., 2007). In this context, it is significant to consider sustainable principles and technologies that cost less to heat and cool the air, especially in schools (Ali and Hashlamun, 2019). In buildings where there is a significant temperature difference between outside and inside, most of the energy is used for heating or cooling. Renewable technologies for heating, cooling and ventilation have been developing as sustainable architecture is a field that is changing extremely rapidly. There are several ways to reduce the heating and cooling energy costs both in the design and operation periods. In order to reduce the requirement for heating and cooling demand, there are some principles examined below, such as improving building envelope and using heat pumps.

Heat Pumps

Using heat pumps is an energy and cost-efficient way of heating buildings if there is a big temperature difference between inside and outside. Heat pumps transmit heat energy from a low-temperature environment to another high-temperature environment (Bilen and Demir, 2021, p. 690). They principally collect heat from air, water, or the ground so they are commonly called air source heat pumps (ASHP), water source heat pumps (WSHP), or ground source heat pumps (GSHP), then they transfer thermal energy from the outside into the building as shown in Figure 2.1. So, they are not based on burning fossil fuels (Rogelj at al., 2018, p. 142). They use electricity but solar panels could be used as the heat source rather than the energy taken from the grid. GSHPs can have higher energy efficiency than ASHPs because soil temperature changes less than air temperature (Bilen and Demir, 2021, p. 689). A GSHP unit can produce up to 4.4 kWh of thermal energy into a building while consuming 1 kWh of electrical energy (Mengjie and Shiming, 2019).

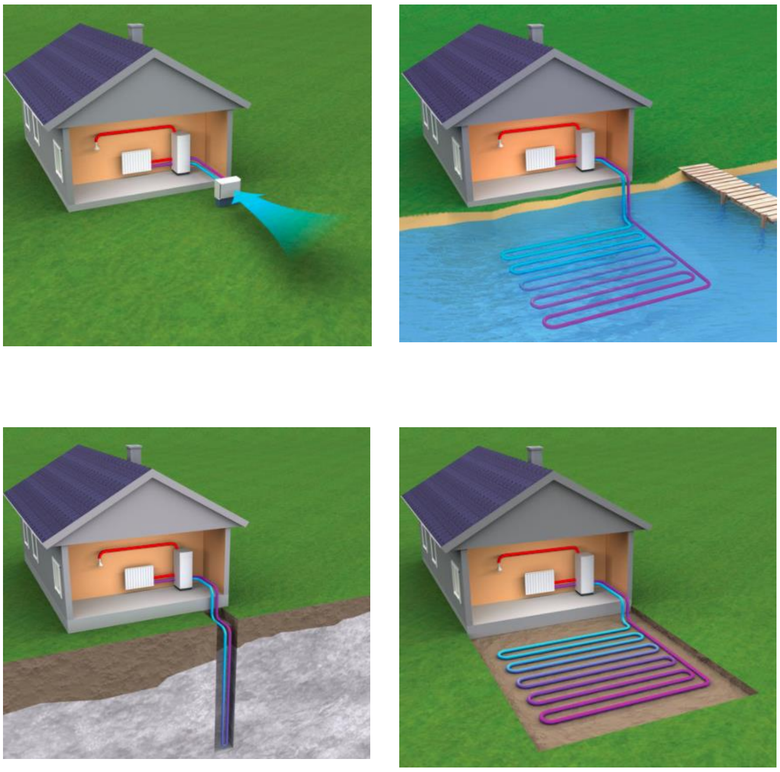


Figure 2.1 Most common types of heat pumps: ASHP (above left); WSHP (above right); GSHP with vertical pipes (below left) and horizontal pipes (below right) (Incognito, n. d.)

There is a technically similar technology with GSHPs, called Interseasonal Heat Transfer. Howe Dell Primary school in Hertfordshire, (which is presented as a precedent school in Appendix J), uses a heating system in order for passive gain and heating by using lots of pipes under the surface of the school playground as shown in Figure 2.2 below (Georgiou, 2016). During the summer, the temperature of the ground can reach from its natural temperature of 10 °C to over 25 °C (MBS, 2008). A high-temperature heat source is achieved by collecting and storing energy under the tarmac-surfaced playground. Water pipes warmed by the sun in the storage heats the school in winter. This system saves nearly 50% of the CO_2 emissions (Georgiou, 2016).

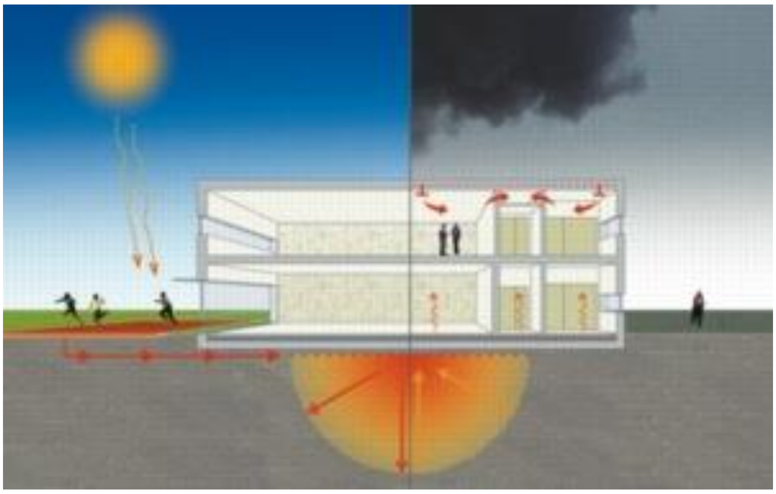


Figure 2.2 Howe Dell Primary School powered by Interseasonal Heat Transfer (MBS, 2008).

Due to its easy availability, the most common type of heat pumps is the ASHP that transfers heat between inside and outside (Bilen and Demir, 2021, p. 691). Additionally, ASHPs are energy-efficient heating, cooling and ventilation systems, which have good environmental benefits (Wang at al., 2020). They are a use of renewable energy rather than electrical energy to provide heating and hot water, and they use a small amount of energy to extract a much larger amount of heat energy already in the environment. For example, Raees et al. (2014) investigated the impact of air source heat pumps in schools in different USA locations on the annual energy consumption and determined the potential savings achieved. For this purpose, the author studied a 12375 m^2 existing middle school building located in North Carolina. The heating and cooling system of the middle school includes a total of 49 wall-mounted air source heat pumps located in classrooms. Then, the simulations of the school were taken to compare the energy consumptions over five years, and to estimate the energy savings in different climate zones. The savings could vary from 19 to 26% depending on the locations and actual occupancy profile drafted from the design occupancy. As another example, a 2,219 m^2 school in Warrington takes advantage of hot water up to 70°C and heating provided solely by air source heat pumps (Mitsubishi Electric, n. d., pp. 2-3). Chapelford primary school could achieve BREEAM 'Very Good' ratings thanks to these pumps. The ventilation units keep the classrooms full of fresh air while extracting up to 80 % of the heat from the outgoing air and transferring it to heat up the incoming air flow. The installation can deliver 172 kW of heat at an outdoor temperature of -3°C. Drop off is minimal down to -20°C, including defrost (Mitsubishi Electric, n. d., p. 4). 69% of the energy delivered is renewable (Mitsubishi Electric, n. d.). Moreover, Hade Edge Junior and Infant School in Yorkshire has a 12kW air source heat pump to power the extensive underfloor heating system and also provides space heating even when outdoor temperatures reach -20.

Thanks to the heating system, the school can save £1000 and 2900 kg CO_2 emissions can be reduced per year (IMS Heat Pumps, n. d.). In addition, it is estimated for King Edward VII School in King's Lynn, UK that the heat pump will reduce 70-75% of the annual heating demand and provide £12,500 which was used for the capital cost of the renewable heating installation. Also, savings for energy and carbon emissions will be over 30% (EOC Services, n. d.). Furthermore, Zhou et al. (2019) suggested air source heat pumps providing floor heating for a teaching building in China. According to their field experiment, they provided 38.6% heat savings and 31.5% electricity savings, and environmental benefit with a 37.2% reduction in emissions. Also, the payback period would only be 1.46 years (Zhou et al., 2019). Therefore, when air source heat pumps use renewable electricity generated by solar photovoltaic (PV) panels installed on school buildings, green energy from the environment replaces the need for high carbon-emitting gas boilers in many school buildings and helps to reduce operating costs and carbon emissions.

- **Building envelope**

The term 'building envelope', addressed in this study in terms of energy efficiency, means a range of physical components such as roofs, walls, windows, doors, foundations, ceiling, and their related barriers and insulation, etc. that protect the internal environment from the effects of the outdoor environment such as precipitation, wind, temperature, humidity, and ultraviolet radiation (Donev et al., 2021). According to Yi and Bing (2017), 'building envelope has a very close relationship with building energy consumption' (Yi and Bing, 2017, pp. 16-17). Heat losses and gains in buildings occur with all these building envelope elements which separate the inside from the outside of the building (Aydin and Biyiklioglu, 2019). When the inside and outside of the building are at different temperatures, the function of the envelope is to stop the movement of energy (in its various forms)—this then prevents the consumption of more energy to replace that which has been lost through the envelope.

According to Minsolmaz and Yeler (2017), building envelope design is a very significant part of sustainable architecture (Minsolmaz and Yeler, 2017). Improving building envelopes plays a significant role in terms of energy efficiency and offers minimum environmental impact. Moreover, high performance building envelopes provide thermal comfort to the occupants and reduce building energy consumption (Yi and Bing, 2017). Making the building envelope perform well is very important in terms of both economic and environmental sustainability. So, the external envelope of the case study school building will be refurbished to control energy conservation in accordance with the climate and the requirement for heating or cooling.

Window glazing

Window glazing undertakes a variety of functions such as daylighting, establishing a visual relationship with the outdoor environment, natural ventilation, and preventing noise from the outside. Providing daylight is the main function of a window. Buildings using natural light compared to artificial light will be more energy efficient. To refurbish existing buildings (especially K-12 school buildings) to use energy efficiently, besides building envelope improvement, interventions to be applied to transparent surfaces will be beneficial.

Kocu and Dereli supported Hakkinen et al. by saying that approximately 30% of heat losses in a typical building, which covers both domestic and non-domestic buildings in Turkey, are caused by double-glazed windows, with 40% due to exterior walls, 7% roofs, 6% floors and 17% air leak (Kocu and Dereli, 2010, as cited in Koyun and Koc, 2017: 2). According to Hakkinen et al., heat loss through windows is quite a lot even if they are relatively small and this is due to the fact that 'the thermal conductivity of windows is significantly higher than walls' (Hakkinen at al., 2012, p. 74). When windows are closed, there are two ways that energy gets through them. Basically, energy moves through heat and sunlight. Another reason for heat loss is air leaks and cracks around the windows. There are several ways in which windows can be designed to have less heat loss. One of the easiest and most economical way of sealing any type of building is to seal the joints between windows and the external walls (Hakkinen at al., 2012, p. 74). Also, the design and materials are important in terms of reducing heat loss, for example louvre windows perform very poorly while fixed casement windows perform better (Bulut et al., 2021).

In addition, one of the most efficient ways is to determine glazing types in order to stop energy moving through a window. Advanced technologies about window glasses have been significantly developed to reduce heat loss, and glass types such as single glazing, double glazing, and triple glazing have an impact on energy consumption. Whereas a single glazed pane of glass is not a very good insulator, double glazed glass is a better insulator. A triple glazing is an even better insulator. In an empirical study, Ferreira works with collaborators, analysing the most cost-effective solutions to achieve net-zero carbon emissions for a building in Portugal. In order to improve the building’s energy performance, nine retrofit scenarios were compared to the original case. As part of their improvement proposals, Ferreira et al. (2014) found out the most cost-effective combination of retrofit measures that replaces single glazed windows with aluminium frames with double glazed windows with PVC frames in addition to 5 cm insulation to walls (EPS), roof (XPS) and floor (XPS) (Ferreira et al., 2014).

Solar Shading

In addition to window glazing interventions for enhancing energy efficiency, window coatings mostly preferred in a hot climate can be used to prevent unwanted heat gain through windows and reflect invisible solar heat, and so to decrease cooling loads. Sunlight entering through windows increases temperatures of surfaces in rooms. This is sometimes needed for heating in colder months but sometimes unwanted in hotter summer months. In winter, sunlight reaching the south-facing facade can provide passive solar heating and this brings about reducing heating loads. However, buildings get excessive solar heat in summer; they consume greater energy due to their increased cooling load requirement (Babota et al., 2013). An effective way to help prevent undesirable heat is adding window coverings and shadings (Rasheed, 2019). Moreover, the use of tinted glass and shadings for window glass could reduce the cooling load of buildings in hot climatic regions. As south-facing facades (in the northern hemisphere) get more sunlight than north-facing facades, external shading systems could be preferred on south-facing facades (Napier, 2015; Egitmen Varoglu, 2017). So, horizontal shading as shown in Figure 2.3 should be proposed for south elevations. However, horizontal shading elements for windows are not preferred on facades facing east and west that need sunlight entering through windows and solar heat gain to reduce heating energy consumption based on non-renewable sources in winter but vertical shading is useful for east and west walls and windows to protect from the sun in summer (Babota et al., 2013).

Figure 2.3 Aluminium sun shade, horizontal sun control device and vertical fins (Prowler, 2016).

Pacific Northwest National Laboratory recommended that exterior window shading should be preferred for school buildings in accordance with climate conditions (PNNL, 2013). In terms of financial considerations and ease of implementation, energy-efficient interventions on window glazing, the size of the windows, and shading elements will be simulated for the case study school in this research.

Insulation

One of the most effective ways of reducing energy used in buildings and achieving the energy efficient buildings standards is to use passive design systems (Cabeza and Chàfer, 2020; Elnagar and Köhler, 2020). These systems adopt 'the climate and site conditions of a location to maximise the comfort and health of building users while minimising energy use' (Alagbe et al., 2019, p. 2). Their aim is directly to use natural resources such as sunlight, wind, vegetation, and reduce the use of any active mechanical systems so they are more cost-effective (Alagbe et al., 2019). Building orientation, daylighting and natural ventilation, solar shading and adjustments of the building envelope, and green roofs are passive energy-saving techniques to reduce the energy demand for heating, cooling, ventilation and lighting. Passive houses, having high performance insulations, are one of the most successful examples of using these techniques.

Stevanovic, who evaluated passive climatisation strategies, emphasised that thermal insulation applications are the most efficient method to increase the thermal performance of a building envelope (Stevanovic, 2013). Accordingly, Unalan and Tokman (2011) suggested that high thermal performance insulation should be applied to the walls in line with passive design criteria (Unalan and Tokman, 2011, p. 147). The climate region and use of locally-sourced insulation material are efficient in increasing thermal comfort performance and energy saving. Different climates require different levels of performance from their insulation, i.e., a cold climate requires the insulation to perform very highly; while in climates where there is not much difference between the external ambient temperature and the desired indoor temperature, much insulation may not be necessary. Also, the insulation value changes considerably with some variables, such as material thickness, specific heat and thermal conductivity.

Provision of thermal insulation is closely related to the selection of materials for the building envelope. Achieving high thermal performance and reducing energy consumption of a building depend on thermal transmittance of materials that is called the 'U-value'. It determines the rate of transfer of heat loss through a given thickness of a particular material and is expressed as watts per square metre, per degree Kelvin (W/m^2K). The U-value judges the ability to resist heat transfer of a material. Therefore, in principle, the lower the U-value, the better the insulating performance is (O'Hegarty et al., 2021). Different types of insulation materials can perform diversely. The table below shows U-value of different insulation materials with a thickness of 0.20 m (Lucchi et al., 2017, p. 416).

	EPS (Expanded Polystyrene)	XPS	Foam Glass	Rock Wool	(MW) Stone Wool
U-value (W/m^2K)	0,16	0,15	0,17	0,15	0,17

Table 2.1 U-value of different insulation materials with a thickness of 0.20 m (Lucchi et al., 2017, p. 416)

In this regard, Ozkan et al. stated that the efficient use of energy in buildings depends on the use of the right insulation material and thickness to reduce heating requirements (Ozkan et al., 2009). Recyclable insulation materials should be a priority in terms of environmental and economic sustainability. Gaoa et al., investigating the environmental impacts of insulation materials, suggested the use of recyclable and environmentally friendly raw materials for insulation as a result of life cycle assessment (Gaoa et al., 2014, p. 490). The type of insulation materials determines the thickness needed in order to achieve the desired performance. However, regardless of the type of thermal insulation materials such as foam polyurethane, mineral wool, fiberglass, and polystyrene, the national standard in Turkey defined the insulation thicknesses for the existing buildings in the four different climate regions (TSI, 2008; Caglayan et al., 2020, p. 7). According to the national standard, it is recommended for hot and humid climates that the thickness of an insulation material for the exterior walls should be at least 5 cm (TSI, 2008; Caglayan et al., 2020, p. 7). The thickness of the insulation material has a direct proportional relationship with operational cost (Koca et al., 2017, p. 76; Kecebas and Kayveci, 2010, p. 118).

If the insulation thickness increases, the initial cost also increases. They cannot afford to have insulation materials that are too thick or have too low U-value, therefore the lowest limit of insulation thickness will be chosen for the case study school with a limited budget. A 5-cm thickness of insulation may give very different U-values dependant on the type of insulation. Therefore, building envelope interventions in Scenario 1 for the case study school will identify the most thermally performing insulation material after simulating 5 different types of insulation materials, all at 5 cm, which is the limiting insulation thickness determined in the national standard. In addition to exterior walls, insulation for foundations, roofs, floors, windows, etc. will also contribute to stopping energy transfer and conserving energy (Schiavoni et al., 2016). As an example, an insulation of 5 cm of extruded polystyrene on the walls and horizontal roof surfaces of a typical school building in Cyprus provided nearly 32% savings (Katafygiotou and Serghides, 2014, p. 14).

- **Energy-Efficient Lighting**

Natural light is a cost-free resource that has a positive impact on people while living, studying and working. In terms of providing physiological and psychological comfort especially in school buildings, effective use of daylight for students should include proper natural lighting (Celik and Unver, 2019). Additionally, natural light enhances students' concentration and satisfaction, reduces absenteeism, and results in higher test scores (Elzeyadi, 2008; Boubekri, 2008; Maesano and Annesi-Maesano, 2016). Martirano and Senior identified that a large part of energy in all types of buildings was consumed widely through lighting (Martirano and Senior, 2014, as cited in Kaminska and Ożadowicz, 2018, p. 1). However, Balocco and Volante (2019) expressed that the efficient use of light source is achieved and the energy load is reduced by means of sustainable lighting (Balocco and Volante, 2019). Moreover, energy efficiency of lighting systems plays a vital role in reducing carbon emissions. So, LED bulbs are commonly used and a particular study resulted in a big saving. For example, Maldonado et al. (2018) replaced the current luminaires in the classrooms of the Technical University of Ambato, Ecuador with LEDs. The result showed 25 MWh/month more savings; this means about 200 tons less CO_2 emissions every year (Maldonado et al., 2018, p. 6).

- **Indoor Air Quality (IAQ)**

As stated by Cilingiroglu, as many human beings spend 90% of their time in indoor places, providing healthy IAQ in living surroundings through fresh and clean air, natural ventilation and lighting will ensure physical comfort and desired levels of occupants' health and performance (Cilingiroglu, 2010; Zhao et al., 2018, p. 108).

There are many studies about the impact of IAQ on the comfort and health of people living in different environments. A study by Asadi et al. (2013) on IAQ in public buildings in Portugal, a hot Mediterranean country, indicated that air pollution has a major impact on public health (Asadi et al., 2013). In cases where IAQ is not adequately provided in schools, the consequences are likely seen as allergy, health problems, thermal discomfort, absenteeism, low performance and productivity (Mujeebu, 2019). This situation referred to as 'sick building syndrome' might also cause attention deficit disorder and learning difficulties (Amouei et al., 2019). Levasseur et al. stated that being sensitive in material selection in all phases from the production process of the building to the final inspection process will reduce indoor air pollution helping to increase IAQ (Levasseur et al., 2017).

Basically, indoor environmental quality is assessed by sustainable ratings tools (Cole, 2003). In this context, the assessment criteria consider all physical factors within the building such as optimum humidity, air temperatures and quality, activity levels, clothing insulation, adequate lighting and sufficient acoustic conditions (Baird and Field, 2013). School buildings are awarded by sustainable certification systems under the title of IAQ and Health and Wellbeing (BREEAM, 2015; LEED, 2019a).

- **Ventilation**

Ventilation, which is an important part of IAQ, provides fresh air for buildings by bringing in fresh outdoor air and removing stale indoor air. Buildings are naturally ventilated for cooling indoor air if the outside air temperature is cooler than the indoor air temperature. Also, natural ventilation in schools is significant for students' learning ability (Biler et al., 2018). For an example, the classrooms in Kingsmead Primary school are naturally ventilated through windows and rooflights which are controlled automatically using the Window Master system. In winter, they open a small amount at break time and during the lunch hour to bring down CO_2 concentrations (Mahyuddin and Awbi, 2007, p. 7).

On the other hand, natural ventilation might not be available in some cases such as in terms of maintaining a sealed thermal envelope, where there is a temperature differential between interior and exterior or adverse weather conditions. Natural ventilation is enabled through opening doors and windows by wind pressure differences from one part of the building to another, whereas mechanical ventilation tends to be driven by fans (Zero Carbon Hub, 2012). For example, the thermal envelope of super airtight buildings or proper Passive House keeps all the heat energy in buildings in a cold climate. However, when a window needs to be opened for fresh air, then mechanical ventilation systems are activated to get fresh air into a building and provide controlled ventilation (Raji et al., 2020, pp. 25-26). If heating, cooling and humidity control are provided by mechanical ventilation system, this is called Heating Ventilation and Air Conditioning (HVAC) (Afram and Janabi-Sharifi, 2014; Seyam, 2018). It is very important to express that there are a number of reasons to use mechanical ventilation, i.e., when cross ventilation is not possible and certain conditions are not met for natural ventilation to work. Large buildings, tall buildings, commercial buildings, civic buildings have difficulties to get cross ventilation. It is hard to occur in a deep plan, single aspect spaces with no opportunity for cross ventilation, i. e. when the classrooms in schools all have single aspect, it might not be possible to have cross ventilation. The installation of mechanical ventilation systems is especially needed in large buildings (Kutz, 2018, p. 534), since natural ventilation cannot provide suitable indoor conditions for all times of the year or these buildings might not be suitable for natural ventilation due to a deep plan or i.e., inability to remove odour because of the humidity (Sev and Aslan, 2014, p. 855).

However, a mechanical system is needed to allow the air movement and also prevent losing heat in a cold country. For example, Mechanical Ventilation with Heat Recovery (MVHR) systems are commonly used in colder climates to cut out ventilation heat losses. MVHR systems work basically by extracting moist, stale and polluted air from inside and replacing it with outdoor air, while transferring the heat from the expelled air into the new, fresh air, via a heat exchanger mounted within the MVHR unit. Also, tall office buildings designed in different shapes to get adequate daylight might have design constraints that do not enable natural ventilation via operable windows because of the depth of floor plans (Sev and Aslan, 2014, p. 855). They might also be air-conditioned to give close control of the internal environment under all conditions (Etheridge and Ford, 2008: 2). Mechanical ventilation should be preferred where building floor plans, building structure and regional climatic conditions are unsuitable for natural ventilation, the air outside is too dirty, the outside is too noisy, or if windows cannot be opened (Sev and Aslan, 2014, p. 855). Sometimes, this ventilation type is also required in spaces that have no windows and are acoustically sealed, e.g., auditoria.

Installing HVAC systems requires some cost according to projects. Since there is no capital, operating and maintenance costs, natural ventilation is often used more than mechanical ventilation. In some cases, natural ventilation could be combined with mechanical ventilation where necessary. Such combinations are called mixed systems.

• **Water Usage**

Although water is considered a renewable resource, the high consumption of water has caused significant food and water scarcity, and threatens to cause even greater harm in the future (Hakyemez, 2019). So, water is reused not only to prevent water shortages, protect natural resources of the water itself, but also to limit the energy and resources used in purifying the water to make it drinkable. Sustainable buildings and their principles promote water efficiency. From the perspective of sustainable building assessment programs, buildings use 'one-eighth of our water' (LEED, 2019a, p. 78).

As a sustainability principle, there are several ways to use water efficiently in buildings (e.g., conserving clean water resources, reducing water consumption, harvesting rainwater, water saving approaches in landscape irrigation, and wastewater treatment and reuse) (EL-Nwsany et al., 2018, p. 304). According to Farina et al., the basic water demand is an average of 18 litres per elementary school student per day in case there is no water saving fittings such as dual flush toilets (Farina et al., 2011). In this context, Gecer et al. highlighted that water efficient armatures use less water (Gecer et al., 2018). The water savings aspects in sustainable schools are motivated by an awareness of the need to carefully manage the limited water supply.

- **Rainwater collection**

In terms of using water efficiently in buildings, rapid consumption and pollution of existing freshwater resources bring the use of rainwater as an alternative resource onto the agenda. By means of systems to be installed particularly on roof surfaces, rainwater can be reused after simple purification processes (Hafizi Md Lani et al., 2018).

The oldest and most efficient method known in the collection of rainwater is the establishment of cistern systems. Rainwater harvested in cisterns is filtered, purified, pumped, and used in required places of dwellings where potable water is not needed, such as washing machines or toilet tanks (Sahin and Manioglu, 2011). For instance, in Malaysia, non-potable uses of harvested rainwater such as toilet flushing, irrigation and car washing do not need treatment (Hafizi Md Lani et al., 2018, p. 12). Also, Contreras et al. identified that collected rainwater was used in Philippines for irrigation, inland fish production, domestic purposes, and also for recharging of groundwater (Contreras et al., 2013, p. 56). Figure 2.4 depicts rainwater collection systems that have storage under the ground.

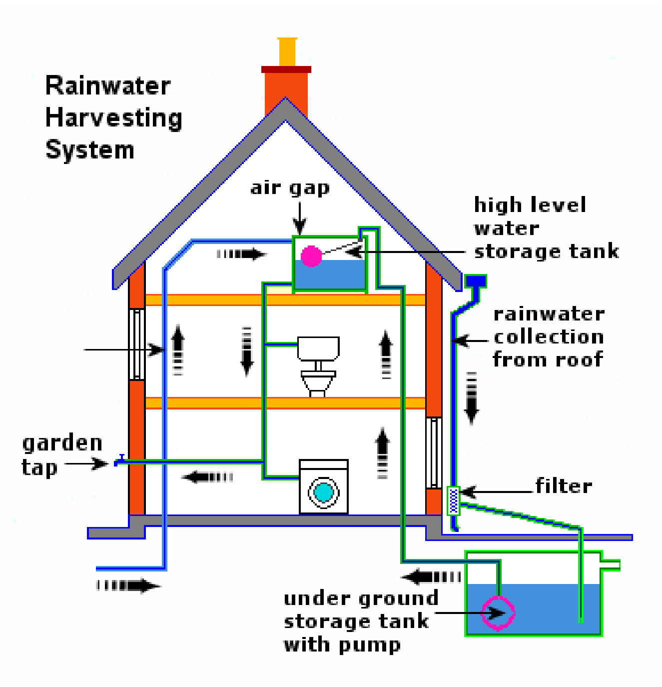


Figure 2.4 Rainwater collection systems (CCCLab, 2013)

Many researchers evaluated that rainwater recovery systems are economic and ecological systems to be adapted to existing buildings (Jaber et al., 2012; Muftuoglu and Percin, 2015). Therefore, the existing precedent school buildings that have a rainwater harvesting unit will be investigated and a cistern system will be evaluated to calculate the volume of collectable rainwater for the case study school in Chapter 4. However, there are some challenges with adapting rainwater harvesting unit to existing buildings. For example, digging the underground of an existing building for a big tank might be more difficult and have higher initial cost than a new building that has the grounds to put the tank under the building. Nevertheless, there are certain conditions in which it will work better if it is a refurbishment project. So, it needs to go under the ground next to the building, if there is enough ground next to the building or it can be applied on the roof, if the building has a large rooftop catchment area and its construction is strong enough to weigh (Hafizi Md Lani et al., 2018).

As a conclusion of this section, the sustainable principles mentioned above have mainly focused on energy and water. It would be very useful to integrate them into the selected school in this study. The principles are also based on sustainable building certification systems, assessing the sustainability of school buildings and aiming for them to have net zero energy and water use. The section below analyses these systems that are part of sustainable architecture.

2.3.4 Sustainable Building Certification Systems

Sustainability rating tools are referenced to determine the level of sustainability in buildings and to obtain a comparison between each building. There are a number of tools, methodologies and standards such as LEED, BREEAM, DGNB and CASBEE used in assessing environmental performance with regard to building stock (Yucel Isildar and Gokbayrak, 2018, p. 47). These rating tools vary from country to country, depending on the individual characteristics of each country, such as types of building stock and the climate. Each rating tool for different countries has different parameters. Figure 2.5 below shows some countries and their most popular building environmental assessment methods (Macka Kalfa, 2018).

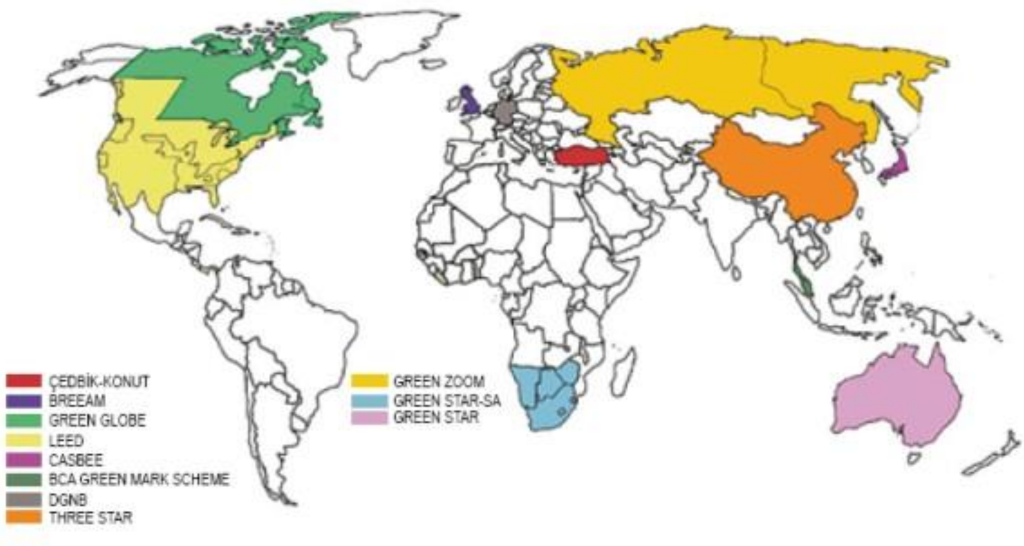


Figure 2.5 Countries and applicable sustainability assessment systems (Macka Kalfa, 2018, p. 49).

Many certification systems use the same assessment criteria for both new construction and renovations, but BREEAM and LEED include a different category for sustainable renovation of existing buildings (Grillo, 2014). Moreover, these certification systems have versions for schools. Therefore, this section below discusses BREEAM and LEED.

2.3.4.1 BREEAM (Building Research Establishment Environmental Assessment Method)

BREEAM, the first version of which was introduced by the UK in 1990, is a rating tool to evaluate the environmental performance of almost any type of building whether they are new or existing. Buildings outside UK are also assessed using BREEAM International version presented in 2008 (BREEAM, 2015). For more detail, the aims and weightings of this assessment tool are demonstrated in Appendix A.

There are 10 prerequisites and a possible 151 points in BREEAM. A set of environmental weightings in BREEAM enable the credits to be added together in order to produce a single overall score as shown in Table 2.2.

Categories	Points
Management	20
Health & Wellbeing	22
Energy	34
Transport	11
Water	9
Materials	14
Waste	13
Land Use & Ecology	5
Pollution	13
Innovation	10
Total	151

Table 2.2 BREEAM Categories (BREEAM, 2015, p. 29)

As a result of the assessment, the building is rated as Pass, Good, Very Good and Excellent (BREEAM, 2015). The BREEAM certifications are available only if the construction is finished and they are awarded based on the scale of unclassified (<30 points), pass (≥ 30 points), good (≥ 45), very good (≥ 55 points), excellent (≥ 70 points), outstanding (≥85 points). Some of the schools examined in this research project are assessed within the scope of BREEAM Education. BREEAM Education covers the types of education establishments such as preschool, primary school, secondary school, non-acute special educational needs

(SEN) school, sixth form college, further education or vocational colleges, and higher educational institutions (BREEAM, 2015).

Also, sustainable certified schools need to achieve some standards. For instance, St Francis of Assisi Academy and Howe Dell Primary School (as indicated in Figure 2.6) were awarded BREEAM Excellent ratings thanks to sustainable features (DfES, 2006; ICAX, n. d.). One of the most essential features to meet the requirement of the certificate is that the academy has photovoltaic panels compromising 144 modules and meeting about 10 % of its own electricity (DfES, 2006: 56), while the primary school has GSHPs saving nearly 50 % of the CO_2 emissions (ICAX, n. d.) (see Appendix J for the detailed precedent studies).

Figure 2.6 The PV installation at St Francis of Assisi Academy (left) (DfES, 2006, p. 56); GSHPs at Howe Dell Primary School (right) (ICAX, n. d.).

2.3.4.2 LEED (Leadership in Energy and Environmental Design)

The first version of the LEED green building rating system was launched in 1998 (Lee and Kim, 2008). For more detail, the aims of this assessment tool can be seen in Appendix B. In the LEED certification system, points among credits are distributed considering the human benefits of each credit and the potential environmental impacts (LEED, 2019a). LEED for Schools deals with design and construction activities for both new school buildings and major renovations of existing school buildings. Some of the schools examined in this study are evaluated within the scope of LEED for Schools Major Renovations. In LEED for Schools, there are 110 possible points (LEED for Schools, 2020). There are many credit categories such as sustainable sites, water efficiency, energy and atmosphere, materials and resources, innovation in design, regional priority indoor environmental quality. These seven categories are explained in the table below (Table 2.3).

Credit Categories	**Points**
Sustainable Sites	26
Water Efficiency	10

Energy & Atmosphere	35
Materials & Resources	14
Indoor Environmental Quality	15
Innovation in Design	6
Regional Priority	4
Total Credit Points	110

Table 2.3 LEED-NC credit categories analysis (LEED, 2019a).

LEED for Schools New Construction and Major Renovations certifications are awarded with four ratings based on the scale of certified (40–49 points), silver (50–59 points), gold (60–79 points), and platinum (80 points and above). For more detail, the comparison of LEED and BREEAM is shown in Appendix C.

Sustainable certified schools achieve high points thanks to their sustainable features. To set an example from the precedent school projects in Appendix J, Marin Country Day School (as indicated in Figure 2.7) was refurbished and awarded LEED Platinum (AIA, n. d.). The school benefits from daylight for both student's well-being and less electrical lighting energy consumption.

Figure 2.7 Daylighting in Marin Country Day School Learning Resource Centre (AIA, n. d.)

2.3.4.3 Green Building Certification System in Turkey

In Turkey, CEDBIK, which is a member organisation of the World Green Building Council, was founded in 2007. Rivera stated that many other rating systems have used BREEAM as their development basis (Rivera, 2009). For example, Green Building Certification System in Turkey has been developed by adapting BREEAM system to the conditions of the country

(Kilic and Erikli, 2021). A green building certification system for the schools in Turkey is in progress.

CEDBIK formed the Green Housing Certification System to be implemented in new housing projects and the system was introduced in the 2nd International Green Building Summit, 2013 (CEDBIK, 2014). The Green Housing Certification System assesses domestic buildings according to the extent of the eight categories (CEDBIK, 2014). Table 2.4 points out Green Housing Certification System Categories and Criteria and possible points in every category.

Category	**Credits**
Integrated green project management	9
Land use	13
Water use	12
Energy use	26
Health and comfort	12
Materials and resource use	15
Living in housing	14
Operation and maintenance	7
Innovation	2
Total	110

Table 2.4 Green Housing Certification System Categories and Criteria (CEDBIK, 2014).

Buildings could be qualified with four levels of certification that can be seen in Figure 2.8 below. A building can be rated as Certified, Good, Very Good and Excellent after an assessment.

Figure 2.8 Levels of CEDBIK Certification to Assess Buildings (CEDBIK, 2017)

The system has remained in the background for non-domestic buildings. Turkey has not yet developed its own specific assessment tool for educational buildings. The learning environments are still being certified by LEED for School and BREEAM Education. Therefore, creating a sustainable building assessment system for schools in Turkey is a gap to fill in this field. While creating this assessment system, the use of the school building as a pedagogical tool or the integration of the school building into the environmental education curriculum can also be evaluated as a category. Another gap, when compared to many certification systems, is that there is a lack of a separate rating system for the refurbishment of existing buildings in Turkey. The category to be added for the refurbishment can encourage existing buildings to be assessed for their environmental performance. In terms of sustainability, the thoughtful refurbishment of existing buildings is as important as the construction of new and sustainable ones.

The following section is all about a comparison of all the key features of precedent studies of sustainable schools, which have high scores in BREEAM and LEED, and a focus on specific techniques of sustainable design explained above, many of which can be found across the examples.

2.3.5 Precedent Studies of Sustainable School Buildings

As part of my wider review into sustainable building systems, a number of precedent school buildings have been examined. A detailed presentation of the case studies, which covers a collection of precedent studies of sustainable school buildings, is shown in Appendix J. However, those precedents have been referred to provide examples of different types of sustainable architectural design in this section.

This section also investigates principles of sustainable design by comparing five sustainably built and two sustainably refurbished school building examples across the world. When the sustainable school examples were examined, it was observed that they aim to minimise the damage to the environment and also integrate their architectural elements as teaching tools into the curriculum. The adaptation of the sustainability features of these precedent study buildings would be beneficial to unsustainable K-12 school buildings in Turkey, especially the case study school. All the key features of the precedent schools and their environmental curricula are compared in Tables 2.5 and 2.6 below. Then, it is presented in Table 2.7 comparing the schools in terms of their learning cultures, socio-cultural context and social sustainability.

	St Francis of Assisi Academy	Howe Dell Primary School	Manassas Park Elementary School	OIB Technical and Vocational High School	TED Renaissance College	Sidwell Friends School	Marin Country Day School
Country	**UK**	**UK**	**USA**	**Turkey**	**Turkey**	**USA**	**USA**
Certification	BREEAM Excellent	BREEAM Excellent	LEED Gold	BREEAM Very Good	LEED Gold	LEED Platinum	LEED Platinum
Energy							
PV panels							
Solar hot water							
Wind turbine							
South-facing atrium							
Shading devices							
Lighting control sensors							
Water							
Rainwater harvesting							
Smart sensors for water consumption							
Using local plants in the landscape design							
Recycling waste water							
Heating							
Solar energy for heating and hot water							
GSHP							
Green roofs							
Insulation of the building envelope							
Insulation of the window glazing							
Natural gas							
Solar tube skylights							
Solar chimneys							
Ventilation							
Natural Ventilation							
Operable Windows			Green Lights				
Rotating glass louvres							
Sloped ceilings							
Mechanical Ventilation							
HVAC systems							
Mixed systems							
Food and drink							
Growing vegetables in garden							
Seasonal, organic, and local products for school meals							
"Family Market" program							
Food waste composted for soil							
Materials							
Concrete walls to reduce maintenance costs and to store heat in winter							
Local materials							
Recycled materials							
Renewable materials i.e. bamboo covering materials							
Sound Insulation							
Coloured flexible ceramic tiles for orientation							
Low-emitting interior materials							
Non-toxic materials							

Table 2.5 A comparison of all the key features of the sustainable schools

Environmental Curriculum	**St Francis of Assisi Academy**	**Howe Dell Primary School**	**Manassas Park Elementary School**	**OIB Technical and Vocational High School**	**TED Renaissance College**	**Sidwell Friends School**	**Marin Country Day School**
Establishing Eco-councils	■						
Social clubs for environmental activities				■	■		
Green screens to monitor the environmental systems	■	■	■				■
Rainwater harvesting units as a teaching material	■					■	■
Rainwater harvesting activity with buckets					■		
Solar panels as a teaching tool	■			■		■	■
Eco-School Committee					■		
Being involved in the refurbishment process							■
Collaborative works with parents, teachers and staff to improve environmental education in the curriculum				■			
Being thought about recycled materials		■			■		
Workshop activities enable students to create products from recycled materials					■		
Lessons about cultivating the vegetables in the garden			■		■		■
Smart sensors remind students using energy and water efficiently				■			
The Pedagogical Role	3rd Teacher	3D Textbook	3rd Teacher	3rd Teacher/3D Textbook	3D Textbook	3D Textbook	3rd Teacher

Table 2.6 A comparison of the environmental curricula in the sustainable schools

Schools	Socio economic context and learning cultures
St Francis of Assisi Academy	The school has guiding values (care for on self and others and to care for the environment). The school integrates sustainability into the curriculum in order the students to see the importance of these values and to put these values into practice. For this purpose, the students are involved through an Environmental Action Team (SEED, n. d.). For example, activities such as growing vegetables in the garden, painting outside walls convey a message and each new group of students (different age, ethnic group, identity) will understand the message.
Howe Dell Primary School	Students reused and redesigned an old bus (Eco Discovery Bus) to enrich outdoor learning. Parents and neighbouring businesses are informed and enhanced their conscious through Eco Conference (Howe Dell Primary School, n. d.). The activities made for the student groups in the observatory (star-planet) helped to improve their respect for the environment and their behaviour (ICAX, n. d.).
Manassas Park Elementary School	The school serves a diverse population of students—many from immigrant families. Parents have a great contribution in building at the school sustainably (AIA, 2017). All existing trees were protected and the benefits of the urban tree canopy has extended to neighbouring homes (AIA, 2017).
OIB Technical and Vocational High School	The school contributes to the formation of the social and cultural environment necessary for an education building, beyond the transparency of the building blocks, the general layout and the functionality of the interior arrangement (Arkitera, 2016). Students were also actively involved in the school's reforestation efforts. It is a male-dominated high school in terms of demographic characteristics.
	(continues on next page)

Schools	Socio economic context and learning cultures
TED Renaissance College	Community service work carried out at school consists of studies for the environment and nature, studies for animals, and studies for the elderly. All community service work is planned interdisciplinary. The program encourages the students to explore, develop, gain self-confidence and self-discipline, entrepreneurship and creativity, take responsibility, get to know and understand different cultures, and respect nature (AIA, n. d.).
Sidwell Friends School	Through the eco conferences in the sustainability curriculum, the students develop confidence, self-efficacy and understand the importance of empathy and respecting diverse perspectives. They learn about consent, respecting others' boundaries, and developing healthy relationships (Sidwell Middle School, n. d.).
Marin Country Day School	As its strategic plan, the school aimed to reflect ecological literacy in its curriculum. For this, the school included students from all age groups in the refurbishment phase. Afterwards, the students observed the renewal process on campus and they shared these studies and their impressions with their families (AIA, 2013).

Table 2.7 A table comparing the schools in terms of their learning cultures, socio-cultural context and social sustainability

There are key strategies that could be applicable to the main case study school presented in Chapter 3. Adapting renewable systems in schools such as photovoltaic panels, solar chimneys and wind turbines and ensuring the readability of these systems by students could contribute to the refurbishment of the main case study school building in Turkey and improve its energy performance. The country has quite a lot of sunny days. Therefore, solar energy through photovoltaics[7] is relevant and another key sustainable strategy is to generate electricity from solar panels. This system used in Howe Dell Primary School, OIB Technical and Vocational High School, TED Renaissance College, Sidwell Friends School, and Marin Country Day School can be adapted to the case study school because it has great potential for solar energy use—the roof and climatic conditions are available for the installation of solar panels. For example, Sidwell Friends School uses 60% less energy thanks to passive solar systems. Also, the curriculum in the precedent schools encourage a software interface enabling students to understand the environmental systems and observe generated energy by solar panels. Students in these schools can be informed about energy consumption and generation by the monitor.

Additionally, the sustainable approach used in the refurbishment works of Sidwell Friends School would be efficient for improving the building envelope of the existing building. Refurbishing the windows would reduce the heating load in winter. This intervention can be offered for the main case study school depending on climatic conditions. Also, green roof systems in OIB Technical and Vocational High School and Marin Country Day School would be beneficial for the insulation of the main case study school both in winter and summer. According to Alparslan et al. (2009), a roof garden reduces the building temperature and improve thermal performance (Alparslan et al., 2009). A green roof potentially acts as insulation materials and reduces the demand for heating and cooling energy (Ahmadi et al., 2015). Therefore, this useful strategy could keep the school cooler in hot summer season with less energy consumed for cooling, while it would also reduce heat loss in winter. Also, the average amount of annual precipitation in the area where the school is located is over 1000 mm (MGM, 2021). So, there is potentially a lot of water for both keeping a green roof alive, and rainwater harvesting. This is an issue to be considered in a number of different schools before the implementation.

As an important sustainable principle that can be adapted, a rainwater collection tank is a useful example to be easily adapted in a number of schools like the main case study school. The school is in an area receiving a lot of rainfall during winter months, so harvested rainwater from the roof can be utilised in toilets and irrigation of the garden. St Francis of Assisi Academy Howe Dell Primary School, Sidwell Friends School, and Marin Country Day School achieved excellent environmental education in the curriculum on this sustainable

[7] At the time of writing, the role of photovoltaics in individual buildings is changing in the building industry as the source of green energy at the source of electricity becomes more and more green than fossil fuel generated electricity. The current state of this useful strategy that could be applicable would need reviewing.

feature. For example, students are able to learn from the digital monitors showing the amount of water harvested and share their experience about the system with their peers. So, both they and the social environments in which they communicate, become conscious of the effective use of water. Eco-councils to tackle environmental issues can be easily established—even in schools that do not have sustainable certificates, like the school selected in the case study.

In addition, solar shading prevents overheating in the summer period. This is a useful strategy for improving the main case study building, which has a hot and humid climate. This is learned from a couple of schools such as St Francis of Assisi Academy, Sidwell Friends School and Marin Country Day School. Moreover, a mixed system ventilation unit, in which natural ventilation is combined with mechanical ventilation can be adapted to promote passive ventilation in schools and its pedagogic role can be used. For example, in case mechanical ventilation is not used in Manassas Park Elementary School, 'green lights' notify favourable conditions for natural ventilation. The signal lights remind students to open windows for fresh air. This might be an effective model for improving existing K-12 school buildings in terms of both sustainable refurbishment and pedagogical purposes.

Utilising recycled materials is also another important strategy while refurbishing a school building. Sidwell Friends School and Marin Country Day School used recycled and local materials in their refurbishment. Furthermore, active participation in the design stage allows students to comprehend the refurbishment process. For example, Marin Country Day School and Sidwell Friends School can serve as a teaching tool of sustainability through making the sustainable intervention implementations visible to students. Also, all precedent schools have the opportunity to give the love of nature to their students by allowing them to consume their vegetables. These initiatives would have a positive effect on students studying in K-12 schools in terms of their environmental education.

2.3.6 Unsustainable K-12 School Projects in Turkey

This research project mainly focuses on making existing school buildings in Turkey more sustainable. So, this section starts with investigating the current situation of K-12 school buildings in Turkey. There are very few studies examining the mistakes and deficiencies in the implementation of architectural plans of K-12 schools—the failure to consider sustainable criteria in their design, and their current situation. In this context, Kose and Barkul undertook a comprehensive review on the problems of standard projects of K-12 school buildings in Turkey (Kose and Barkul, 2012). Due to the urgent need to design new K-12 school buildings for the increasing number of students, in 2000 The Turkish Ministry of National Education requested professionals in the departments of architecture in the most respected five universities (Istanbul Technical University, Yildiz Technical University, Mimar Sinan University of Fine Arts, Gazi University and Erciyes University) and expert architects to prepare standard projects. So, they designed 27 projects depending on the number of students and the type of schools. In the study conducted by Kose and Barkul (2012), among these 27 projects, the K-12 schools built in Turkey have been mostly designed in accordance with five types of standard school architecture projects as shown in Table 2.8 below:

School type	**Number of classrooms**	**Number of students**	**Number of floors**	**Floor area (m^2)**	**Total floor area (m^2)**
2000-41	17+(2)	240	B + G + 3	591	2955
2000-42	23+(6)	720	B + G + 3	1258	6328
10 025R-480	24+(3)	660	B + G + 3	864	4325
10 025R-720	29+(3)	810	B + G + 3	1121	5100
RAGIP AKIN	21+(4)	720	B + G + 3	789	3985

Table 2.8 K-12 school project types in Turkey which are widely applied today (Kose and Barkul, 2012)

These school buildings do not satisfy a majority of the criteria of sustainable building assessment systems (like LEED and BREEAM), such as utilising renewable energy sources, using energy and water efficiently, benefitting from recycled materials, etc. and by this measure would therefore be classified as 'unsustainable'. There are some samples from standard K-12 school projects in Figure 2.9 below.

Figure 2.9 Some examples of standard K-12 school types (Kose and Barkul, 2012)

There are some benefits of these projects that they are able to provide a school building quickly for students who do not have a building in which to learn. Implementing these five types of standard plans is easy, fast, and cost effective but being able to adapt to all types of land and different climate conditions is the main challenge (Kose and Barkul, 2012). That is because every climate region has different architectural characteristics. Applying the standard plans to each region will not meet the needs of the projects. So, universities emphasised that it is inappropriate to design school buildings as 'standard projects' for different climate regions (Kose and Barkul, 2012; Gedizlioglu, 2004; Aysel, 2014, p. 45).

The emphasis was put on flexibility, functional distribution, natural lighting, multi-purpose uses, outdoor organizations, and spatial organizations. However, Ministry of National Education (MEB) continued the application of these standard projects in all different climate regions of Turkey. Since 2000, the different types of standard plans have still been implemented for K-12 school building as demonstrated in Table 2.8 above.

When education buildings in Turkey are examined from the last quarter of the 20th century to the present, it could generally be seen that spatial organizations underwent a change according to the social and political structure of that period. Nowadays, students receive education in buildings that have similar problems and similar spatial features because public schools have been applied as 'standard projects' due to time and budget constraints. However, the number of schools are not sufficient enough for the number of students. The number of schools and students at different educational levels in Turkey is indicated in the table in Appendix K.

With the difficulty of finding land within the city and the reason of rapid population growth, financial inadequacy, and limited time, these 'standard' plans have needed to be significantly modified (Kose and Barkul, 2012). This often involved sacrificing places such as the library, gymnasium, laboratory, or by narrowing closed indoor and recreational areas in order to obtain more classrooms (Kose and Barkul, 2012). As an example, a floor plan and its revised version in one of these school types is shown in Figure 2.10 below. According to the plans, the boiler room was converted into two classes; music and servant rooms were also organised as classrooms and the capacity of an existing class was increased. Thus, it is possible to express that school projects designed as 'standard projects' still have problems about the increasing number of students. They need to be modified in case of need and students are deprived of some facilities since they do not have places such as a music room and a laboratory.

Figure 2.10 An example from a standard (10025R-480 code**)** K-12 school's floor plan (above) and revised floor plan (below) (Kose and Barkul, 2012)

Kose and Barkul (2012) has provided a useful review of the problems of standard K-12 school buildings and has briefly analysed the spatial organisation of one of these schools whose plans are shown in Figure 2.10. Although the building programs of these standard K-12 schools met the need of the educational curriculum, spatial organizations show that these projects could not create effective learning environments (Kose and Barkul, 2012, p. 102). In this school, this is due to the lack of educational spaces where the students interact to learn new skills and experiences, such as a music room that was converted into a class according to the revised plan. Since there are few studies on dealing with the problems of standard K-12 school buildings, I mainly reference their study. However, they did not extensively examine how this school dealt with sustainable building assessment systems in their study—they only evaluated the physical features of its classrooms, its relationship between the shape and the environment of the land.

2.3.7 Sustainable Refurbishment of School Buildings

For a sustainable development, there is a need to refurbish existing school buildings by meeting sustainability standards and improving their performance. There are many reasons for the refurbishment of existing school buildings. Firstly, as Trachte and De Herde pointed out, outdated technologies are used by many school buildings in terms of ventilation, heating, cooling, lighting, acoustic (Trachte and De Herde, 2015). Accordingly, a high level of energy is consumed, high level of CO_2 emissions is produced and poor lighting is utilised in these schools. These kinds of insufficient facilities affect students' health, individual development and academic performance. Hence, K-12 educational buildings should be designed by meeting users' requirements. The opportunity of renovating school buildings offers healthier and more comfortable learning environments for students. Secondly, sustainable refurbishment of schools contributes to economic sustainability. Since school budgets are generally limited (Katz, 2008), instead of pulling down old school buildings and constructing new ones, old school buildings should be renovated for benefits in terms of both environmental and economical sustainability. According to Olson and Kellum, making existing school buildings sustainable through renovation and then operating these buildings sustainably require a lower cost than conventionally built schools (Olson and Kellum, 2003). Österreicher and Geissler also highlight that refurbished schools have economic advantages over new schools (Österreicher and Geissler, 2016). Greim also states that operational costs will reduce in general, if an existing school building is improved with energy-efficient systems (Greim, 2005). So, sustainable improvement would reduce economic consumption.

The reasons explained above lead to decisions about which sustainable design solutions should be integrated to educational structures. In this regard, school architect and academic Lisa Gelfand (2010) sets out the key elements of the main design strategies that sustainable schools should consider: daylight, building structure and shell, heating, ventilation, cooling and sanitary installations, landscape and residential area design (Gelfand and Freed, 2010). These strategies should be taken into consideration during the refurbishment process. Some of these elements will be discussed in the next Chapter.

Moreover, sustainable refurbishment has positive contributions to environmental literacy. Research shows that the behaviour and attitude of students have a relationship with the physical learning environment. Students are able to present their knowledge about sustainability as behaviour, thanks to sustainable schools (Clarke, 2013; Rokosni, 2019). In order for information to reach the behavioural dimension, the building should be used as a laboratory, attending to issues such as recycling, wastewater, solar energy, ecological design (British Columbia Society of Landscape Architects, 2016, p. 8). So, sustainable refurbishment of the physical environment is important in terms of being used as an educational tool. Finally, Bissoli expresses that the built environment, where education is provided, is important for people and societies since these structures have an impact on children's psychological, physical, social development and personality formation (Bissoli, 2014). The design of K-12 schools, in which children first gain an identity and skills, should be sustainable, not just for children, but for society as well.

2.4 Chapter Summary

Designing buildings sustainably is an important step in tackling climate change, and this should also include the environmental awareness of people spending time in these buildings. Therefore, this research concentrated on the sustainability of buildings, especially K-12 educational buildings, where environmental awareness can be improved.

This chapter provided a comprehensive summary of two different disciplines—environmental education and sustainable architecture. It also explained how environmental literacy and the physical built environment have a relationship. Then, the principles of sustainable architecture are summarised. These principles that should be taken into consideration from the construction of a building to the occupation phase are site selection, orientation, structural form, efficient energy usage, energy efficient lighting, IAQ, using sustainable materials, efficient landscape design, and using water efficiently. Accordingly, this thesis focuses more on the principles concerning energy and water use within the scope of refurbishing the case study school in Turkey. When sustainable building certification systems such as LEED for schools and BREEAM education were examined in the literature, it was observed that the principles of sustainable design are divided into the design of new school buildings, and the renovation of existing school buildings in terms of sustainability.

Accordingly, sustainable architectural criteria, strategies, principles, and systems that can be adapted to existing school buildings are presented with the related examples on an international scale. By presenting some successful examples of sustainable K-12 school buildings that were awarded high scores by LEED and BREEAM certificates, the key points from the precedent school buildings to refurbish existing school buildings sustainably were referred in this chapter and their detailed analyses can be found in Appendix J. Furthermore, the analyses in the Appendix indicate where the school buildings can contribute to environmental education. The sustainable schools, presented in the Appendix, reflect sustainability on their architecture and the buildings themselves teach students this, or students can learn environmentally friendly practices through the curriculum. All their key features and environmental curricula are compared in the Tables 2.5 and 2.6. They could contribute to sustainable refurbishment opportunities as a sample model.

The next section provided an overview of school architecture in Turkey. When the architecture of these school buildings was examined, it was observed that these public schools are constructed with five standard school types, regardless of the climate conditions and only six of them have been awarded by a sustainable certification system. Compared to the total number of schools, the number of sustainable schools in Turkey is very low. Therefore, the last section highlighted the importance of refurbishing existing K-12 school buildings in Turkey. Despite the environmental and economic aspects of sustainable buildings, the issue of environmental education in sustainably refurbished buildings is not well explored in the literature. Therefore, this chapter establishes a link between sustainable refurbishment for school buildings and its contributions to environmental literacy.

The next section will evaluate the existing energy performance analyses of the main case study school building (Tekeli Secondary School) using a range of methods (measurements, actual energy usage, information of the school building, sustainability of the school according to LEED and BREEAM criteria, and a simulation model of the building’s energy performance) in order to improve the performance of the building.

CHAPTER 3
CASE STUDY AND FINDINGS

3.1 Introduction

Defining the Problem

In recent years, sustainability issues in building design, construction and operation processes have been important in Turkey. However, there are so many unsustainable school buildings in Turkey, which have lots of embodied energy in them. They are used intensively and therefore consuming a huge amount of energy. Their energy consumption is much higher than it could be if they were sustainable, and in many instances the lack of sustainable design is leading to poor comfort conditions for the pupils because of the climatic conditions in Turkey. As noted in the literature review, good comfort conditions in schools have been linked to good academic performance (Maesano and Annesi-Maesano, 2016; Celik and Unver, 2019)—this suggests that improving the performance of Turkey's school buildings will help students' educational outcomes—which ultimately helps the country if its future adults are better educated.

Both in terms of energy and cost, it is more sensible to refurbish the existing buildings than to knock them down and re-build them. Therefore, this suggest that priority should be given to the sustainable design of educational structures and the energy-efficient refurbishment of existing K-12 school buildings in order to consume less energy and provide more comfortable conditions. In summary, this study examines the intervention possibilities for the sustainable refurbishment of the existing educational building, aiming to improve the comfort conditions of the building for its users, to reduce the energy consumption of the building in use, to conserve natural resources, and in doing this, to consider how the interventions might support and enable environmental education.

Public schools in Turkey have been mostly designed as standard projects, in which the government works with just five universities to prepare. The designers of these standard models may therefore not be those most experienced in the practice of designing school buildings. The unsustainable K-12 school buildings, whose current situation has been evaluated in the previous chapter, are not sustainably certified and also have standard plans despite different land and climate conditions. This chapter identifies an example of the unsustainable ones, then addresses the existing conditions of the designated school building (Tekeli Secondary School) as a main case study.

Furthermore, as mentioned in Chapter 2, the US's LEED and the UK's BREEAM certification systems both have sub-sections for educational buildings, but in Turkey's own developing environmental assessment system, there is, as yet, no specific category for educational buildings. As such, this study could also be helpful for the development of such a new system.

While there are more than 66,000 K-12 school buildings in Turkey (National Education Statistics, 2018/19, p. 54), by the year 2020 only six of these[8] had been awarded by sustainable certification systems. More information about the number of students and educational institutions in Turkey can be found in Appendix K. Among them, OIB Technical and Vocational High School (Turkey's first and only educational public building with a Green Building Certificate) and TED Renaissance College (the first private school in Turkey to achieve LEED Gold Certificate) were investigated as successful examples of sustainable school buildings in the previous chapter (their detailed analyses can be found in Appendix J). The lessons learned from these precedents could be evaluated as interventions for the existing schools in terms of environmental education and sustainable refurbishment opportunities. As an additional benefit in making school buildings more sustainable, there is also the potential for a school building itself to be used as a learning resource and to serve as a laboratory for environmental education, as addressed in Chapter 2.2.3.

Part of the literature review chapter presented a range of factors contributing to sustainable design, and demonstrated how these might be used in education buildings by presenting precedents of existing sustainable school buildings in Turkey, the UK and US. These successful examples of sustainable school buildings in Turkey and the world can shed light on this project and further studies in terms of adaptable architectural systems and will act as key references to specify the aspect of proposed changes. These changes could be considered in many different unsustainable schools.

3.2 EXISTING BUILDING ANALYSIS

[8] These are OIB Technical and Vocational High School completing BREEAM in-Use Schools standard, TED Renaissance College receiving the LEED Gold certification, Erkut Soyak awarded the BREEAM In-Use certification, Cihangir College and Mavisehir Schools having a Certified score, and Terakki Tepeoren K-12 Schools achieving LEED Gold Certificate (BREEAM, 2019; LEED for Schools, 2020). Although Erkut Soyak High School was awarded a BREEAM certificate, it has no longer met the sustainable building certification criteria. Also, Mavisehir and Cihangir Schools have not a high score in LEED. Terakki Tepeoren School has recently received a LEED Gold Certificate.

This section deals with the existing building analysis of Tekeli Secondary School in terms of different techniques such as briefly introducing the school building, broadly looking at the current spatial arrangements and comfort conditions, talking to school teachers and the principal, examining the sustainability of the school according to sustainable rating systems, and undertaking building simulations to calculate the existing energy use. So, I will make proposals for the refurbishment according to the analysis undertaken in this chapter.

The first sub-section gives the information about Tekeli secondary school in Serik, Antalya, which is selected as the main case study school for refurbishment with sustainable interventions. Secondly, analysis and observations of tekeli secondary school building are presented. Then, this school is examined according to the LEED and BREEAM rating systems. By means of these sustainability checklists, the school is evaluated under energy, materials, indoor air quality (IAQ), water, and waste headings. In the following sub-section, the DesignBuilder simulation tool is used to analyse the building's energy performance, in order to identify the aspects whose performance may be improved through refurbishment.

3.2.1 Description of Tekeli Secondary School Building

Tekeli Secondary School, which is located in Serik district of Antalya, was selected as a main case study for the sustainable refurbishment through energy performance simulations. The school building was built in 1977. The aerial imagery of Serik district of Antalya and the location of selected school building can be seen in Figure 3.1. It is easily accessible and located in the centre of the district. Antalya is a contained area, surrounded by agricultural land. So, climatic data in the simulation program could be obtained easily through the location of the school.

Figure 3.1 The satellite image of Serik district of Antalya (Google, n. d.).

Figure 3.2 The general view of examined secondary school building

Around 750 students study in the school building and there are 39 teachers, one school principal and three administrative staff. The school covers an area of 450 m^2, the interior and exterior spaces of the school cover 4500 m^2. Figure 3.2 shows the general view of the school building. The school is located in the most central region of the city in terms of transportation. As seen in Figure 3.3, the old building (highlighted in red) is surrounded by official institutions such as a library, shops, and other buildings and there are a few trees, which are indicated with green circles in the master plan, in the garden. A primary school building and other additional buildings were built in 2003 on the same plot, since the secondary school building could not meet the increasing number of students.

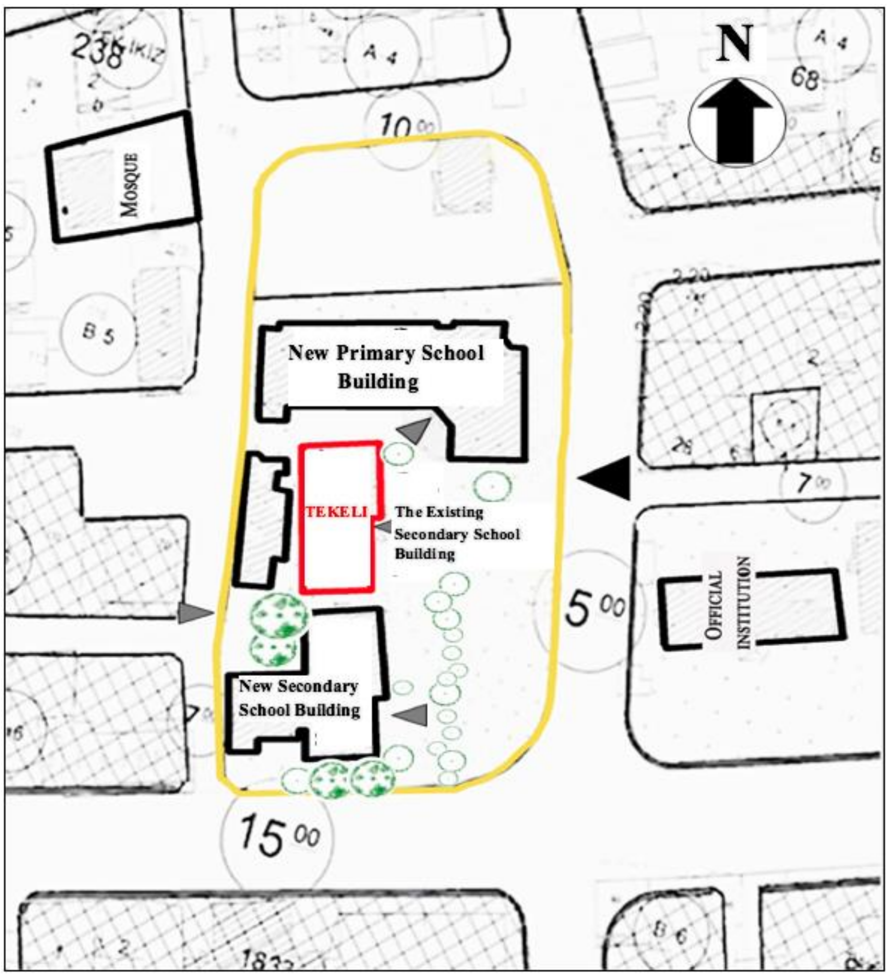


Figure 3.3

The master plan of the secondary school (From the archive of the school).

Scale: 1/1000

3.2.2 Analysis and Observations of Tekeli Secondary School Building

I visited Tekeli Secondary School to gather further information about the historical process and facilities of the school, and environmental activities. In the context of my research, some information about the energy consumption of the school, any energy efficient measures taken by the school and sustainability activities in the curriculum, and also a copy of the school's master and floor plans were obtained from the school archive.

Then, according to my observations, in the old building with 19 classrooms, there is a lack of storage space and the teachers' room and classrooms are often too small for the number of students being taught in them. Also, all the rooms except the administrative rooms, teachers' room and toilets were converted into classrooms as the number of classrooms is insufficient. The former laboratory and library, where students would make experiments and observations, are also now serving as classrooms. Currently, there are not any labs or library in the secondary school building.

According to the information obtained from the school's archive, the annual average total energy consumption of the old school building (electricity for heating, cooling and lighting) varies between 62,500 and 75,500 kilowatt-hours. The old building uses a lot of energy, which is bad for the environment, and so it has high energy bills. To make a comparison, a typical secondary school in Antalya, which has four floors, covers an area of 3700 m^2, and has no insulation, annually consumes 72 kWh/ m^2 TS825 (TSI, 2008; Republic of Turkey Ministry of Environment and Urbanization, and Climate Change, 2020, p. 72).

According to my analysis and observations, this building would achieve high energy savings if energy consumption could be reduced by refurbishment proposal. Interventions for the building envelope are in more urgent need of work than others. Also, energy-efficient design approaches that consider climate conditions and reduction of electricity bills should be implemented for the building. There is, therefore, a great opportunity to encourage energy savings in the educational building and in doing so, to potentially raise awareness about low-carbon energy use among students.

The newer additional buildings perform better than the older building in several ways. They are more sustainable in their energy conservation and construction materials, and in their use of sunlight, natural ventilation, and lighting. They also offer better levels of environmental comfort, and have good space standards, and so these newer school buildings need relatively less refurbishment. Therefore, the old building was primarily chosen as a case study since it is the building in this school most in need of improvement.

There is a real urgency to refurbish it for a better performance because the building consumes too much energy and does not perform environmentally. However, this school in a developing district close to the centre of Antalya does not currently implement any energy saving measures, and so is a good candidate for improvements in this area. Although the school building is in the hot-humid climate zone, there is not any shading component in windows to limit solar gain in summer as seen in Figure 3.4, which results in poor comfort conditions because of high internal temperatures and energy expenditure through air conditioning to cool the spaces. Also, there is no insulation material in its thermal envelope. So, this is a problem to stop energy moving from one side to the other when energy is consumed for heating and cooling. High electricity use should be reduced with sustainable interventions in terms of building energy performance.

Figure 3.4 Air conditioners used for heating and cooling

Tekeli secondary school does not have centrally controlled heating and cooling systems. Separately installed and locally controlled air conditioners are used for heating and cooling the classrooms, as shown in Figure 3.4. There is no heating and cooling in the corridor and restrooms. In the administrative room, the teachers’ room, and classrooms heating and cooling is provided by the air conditioner units—heating for five months in winter and cooling for the summer months of May, June and July.

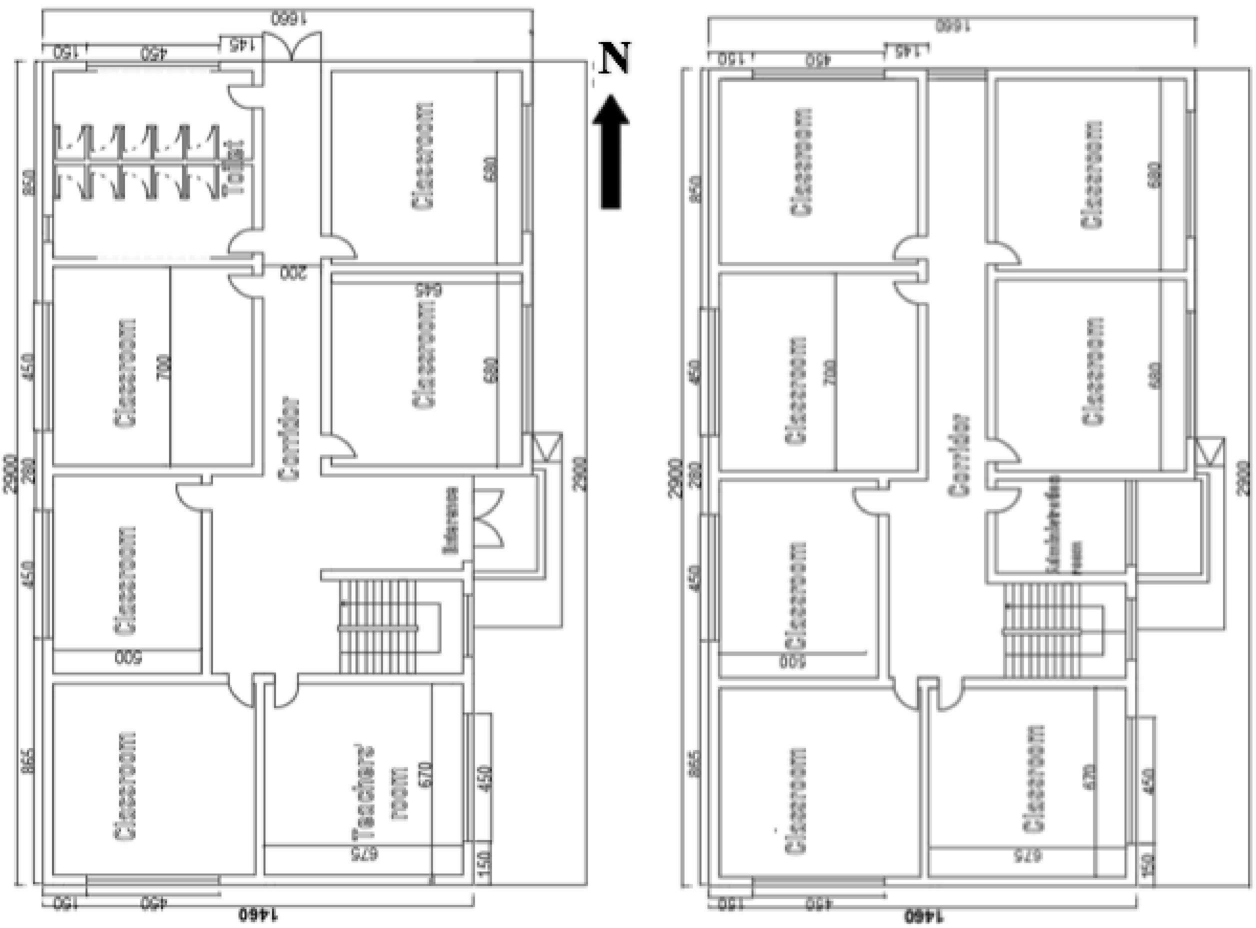


Figure 3.5 Ground (left) and 1st & 2nd (right) floor plans (Redrawn by author, based on plans from the archive of the school).

As the floor plans indicate in Figure 3.5, the classrooms on the ground, first and second floors have either east or west facing windows in most instances. There is no design for solar orientation and the overall design of the different sides or elevations has same sized windows. Only one classroom on each floor in the school has a south facing window and the classrooms in the first and second floors are too hot and suffer from issues of solar gain in summer. It can be seen in Figure 3.2 and 3.4 that there is no form of solar shading. Thus, thermal comfort of south facing classrooms is negatively affected. Also, the teachers said that those classrooms are too hot for teaching in summer whereas the north facing classrooms are too cold in winter. As part of my own experience, I remember being taught in those classrooms and they were always too hot but in winter that was an advantage for the spaces because we had solar gain. According to my observations and analysis, they have not used sustainable principles so I will address this aspect as being part of the problem in my refurbishment proposal. However, only the ground floor of the south elevation of the existing building is shaded by the new secondary school building adjacent to it. So, it would not be necessary to put solar shading for the ground floor as the adjacent building will provide a little bit of solar shading on this elevation. However, there might be a need for solar shading for not only the 1st and 2nd floor on the south elevation but also the floors on the east and west elevations, because students have problems concentrating, as the sunlight shines too much at certain times of the day through the east and west facing windows.

However, using daylight and sunlight efficiently creates an opportunity in terms of environmental satisfaction of students, high energy performance of educational buildings, and economic sustainability. While some classrooms in the school use artificial light, some of them benefit from natural light and save electricity for heating, cooling and lighting by taking advantage of the orientation of the windows. Therefore, the classrooms in the north facing façade are too cold in winter and need more heating, whereas the ones in the south facing façade are too hot in summer and need cooling. Nevertheless, sustainable systems such as solar shadings for the south facing windows to reduce the energy consumption, and light shelves for the north facing windows to get more daylight have not been integrated and no precautions have been taken in this respect. An east facing classroom interior and the second-floor corridor are shown in Figure 3.6.

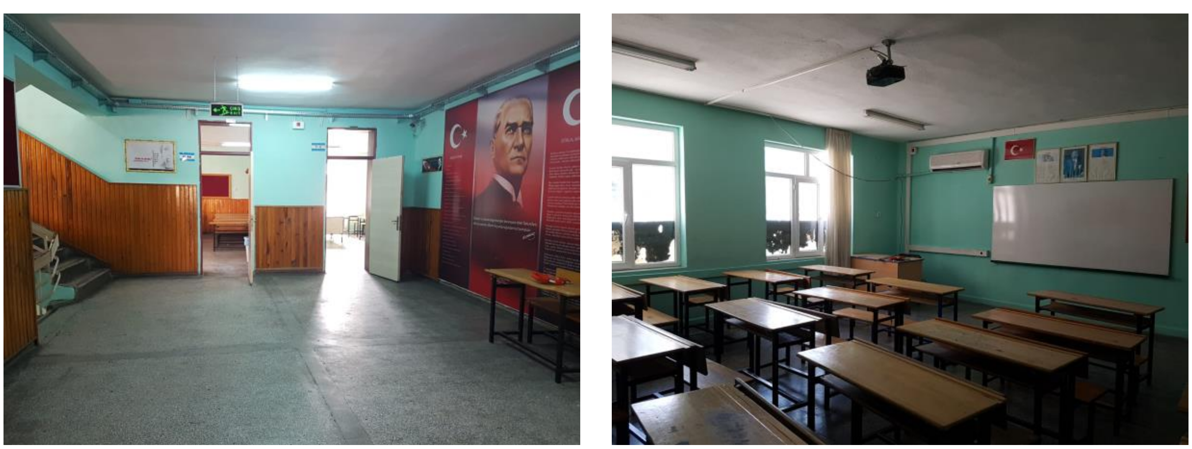


Figure 3.6 The second-floor corridor and a classroom from east façade

Furthermore, the playground is limited for all students of the school. A small pergola provides shade in the sitting area, however, as it is sized for use by only 25–30 students, its capacity is not high enough for all of the students. The shadowed area is vital to protect from the harmful solar rays in the hot Mediterranean climate conditions. There is no flora in the garden except a few trees for shading. If there were more green spaces, it would help cool the air as trees release water into the atmosphere from their leaves via transpiration. Outdoor flooring consists of roughly finished concrete as seen in Figure 3.7 below. Although the concrete floor allows children to play ball games and run around, it makes the space hotter in summer as it retains heat.

Figure 3.7 The school garden

There is research showing that students in school gardens with natural environments have safer and more creative games (Cheskey, 1994; Malone and Tranter, 2003; Moore, 1996), increase their social relations (Dyment and Bell, 2008; Robinson and Zajicek, 2005; Thorp and Townsend, 2001; Titman, 1994) and improve their academic performance (Ernst and Monroe, 2004; Graham et al., 2005; Klemmer et al., 2005; Lieberman and Hoody, 1998; Simone, 2002; Sparrow, 2008). In this school, the playground is both a meeting space for announcements and an outdoor sports area. Natural playgrounds are not offered for children. Thus, there is not currently opportunity for pupils to interact with plants and undertake activities, such as growing their own food as seen in some of the precedent study schools. According to what is learned from the case study schools, students could have a chance to interact with plants and learn how to grow their own food if such an opportunity is provided in their garden.

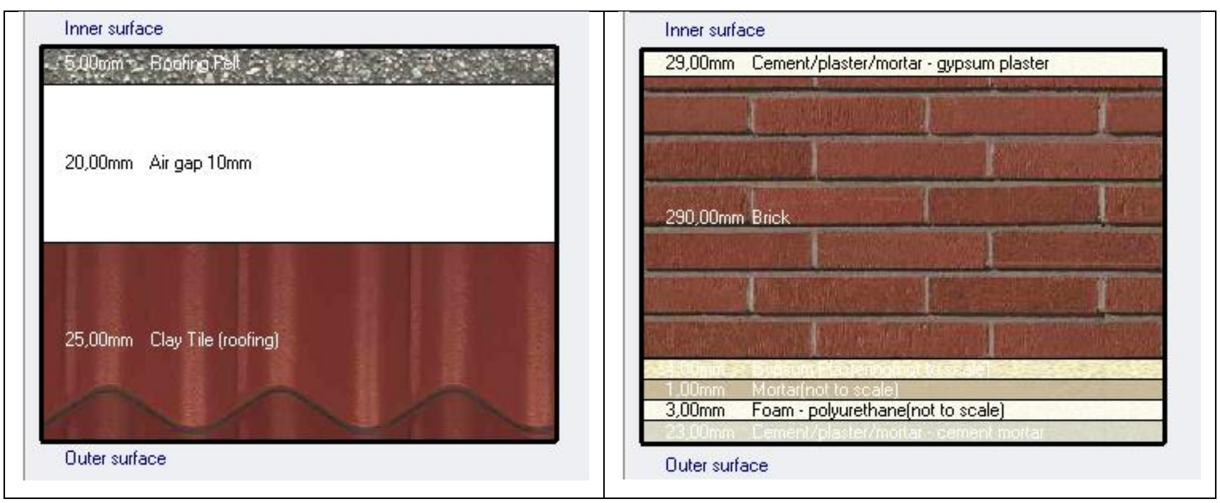
3.2.3 Examining the Sustainability of The School According to Sustainable Rating Systems

As part of my overarching methodology for analysing the school, the sustainability of the Tekeli school building is investigated in this section using 'LEED for schools' and 'BREEAM Education' assessment criteria which contain the main subjects of environmental design principles that a sustainable school must acquire (see Table A2 and A3 in Appendices). While these evaluation checklists have not been formally assessed by BREEAM or LEED experts, they offer an informal evaluation of the existing school building as a result of the observation according to LEED for Schools and BREEAM Education criteria (see Appendix D). I will make reference to these as relevant. According to the evaluation checklists in Appendix D, it was seen in the observation made under the Energy and Atmosphere title of the BREEAM and LEED evaluation checklists that energy saving LED lamps and wind and solar energy were not utilised. The school gets all its energy from the grid. It does not generate any energy on its own. It was also observed that there were not any insulation materials under the Materials and Resources. This might be something to look at in refurbishment options. Also, it was determined that recycled materials were not utilised in the construction and management phase of the building.

According to the Water Efficiency criteria, it was observed that water-efficient landscaping was not planned, and there was no water saving armature. Greywater recovery for use in toilets and rainwater recovery were not performed. As part of the problem, the school does not take care of natural resources, and they are wasting water. All their water comes from the mains. This is not very sustainable. Also, they do not have features that enable students to integrate aspects of the building and its surroundings into environmental education. However, a system in the precedent schools for dealing with water may help when proposals for the refurbishment of the school are presented. In terms of Waste Management, although there were glass and paper recycling boxes placed for a zero-waste project in the school, it was observed that teachers and pupils have not been involved in creative projects and activities using recycled materials. Moreover, the school management policies have not encouraged waste reduction initiatives to improve its economic and environmental performance. In the Indoor Environment Quality (IAQ) category, it was seen that there was no mechanical ventilation system, and that natural lighting was insufficient. Windows and doors have been used for natural ventilation, but this ventilation could not be used sufficiently since the windows could not be opened on hot days in terms of comfort conditions. In terms of Sustainable Sites criteria in LEED and BREEAM certification systems, there is public transportation access, but the school does not have bicycle storage in the garden. In the category of Innovation in Design, students could not benefit from the school building as a teaching tool, and Building Energy Performance Simulation tools have not been utilised in the construction and management phase of the building. Therefore, as a consequence of the investigations conducted, it was determined that the middle school building has poor scores due to not meeting sustainable criteria. The following section uses energy simulation modelling software in order to investigate the energy performance of the existing building.

3.2.4 Examining the Environmental Performance of the Envelope of Tekeli Secondary School Building

The general information and the building component materials of the Tekeli Secondary School were examined. Its load bearing system is totally reinforced concrete. Thanks to the school archive, I got information about the building elements. As seen in illustrations of the layers of the wall and roof in Figure 3.8, the building envelope is 35 cm and comprises hollow bricks. The brick wall is solid, with no insulation. In terms of openings, window systems are double glazed but they do not have any shading features to prevent solar gain in summer in a hot Mediterranean climate. There were some good examples of these in some of the precedent schools in the previous chapter. The roof of the school building is completely built with clay tiles, and again, with no insulation. This study aims to reduce heat losses in winter, to reduce cooling loads in summer, by improving the performance of the building’s thermal envelope.



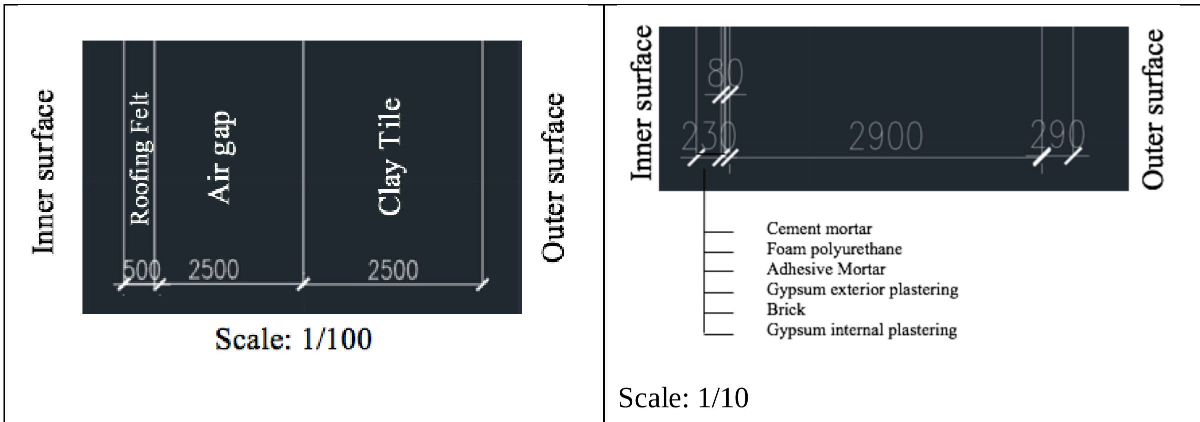


Figure 3.8 Images (above) and sections (below) of the roof covering and building envelope materials

3.2.5 Analysing Data of Existing School Building with DesignBuilder Simulations

The refurbishment will be made with 3-scenario interventions for the case study school. For this purpose, DesignBuilder was used as an energy simulation software. Building envelope, window glazing and LED lighting interventions will be simulated in Scenario 1, while solar panels will be installed in Scenario 2 in addition to the first scenario. Then, HVAC unit will be added in Scenario 3 in addition to the second scenario. Selecting the right energy simulation software is the key to success to create reliable results (Erten and Yilmaz, 2012). In the early stages of architectural design, simulation should be an integral part of the design process to minimise energy consumption (Lee et al., 2021). Different software programs serve different purposes. For building performance optimisation, Energy Plus is the market leading software. A highly complex software package, Energy Plus is one of the most utilised energy simulation software tools. Its development began in 1996, sponsored by the Department of Energy (DOE) in the United States of America (USA) (Drury et al., 2005). Energy Plus analyses the energy and thermal load of the building. Therefore, engineers, architects and researchers prefer it to illustrate the energy consumption of buildings (Crawley et al., 2001). Simulations of heating, cooling, lighting, ventilation, energy and water use are created in this tool (Simulation and Energy Plus, 2012).

The Energy Plus simulation tool allows software programs to work well together or independently (Drury, et al., 2005). A visual interface, which gives an opportunity for users to see the building, is not used in this software. For this purpose, other software tools are required (Westphal, 2006). There are a number of software alternatives that utilise EnergyPlus, such as RIUSKA, eQUEST, DesignBuilder, and IDF Generator (Maile et al., 2010). Among these alternatives, DesignBuilder using the Energy Plus algorithm is a widely used software for energy simulation. Non-expert users can simply and rapidly model complex buildings thanks to the software (Pawar and Kanade, 2018: 71). Also, Rallapalli states that DesignBuilder has a basic interface, templates, and systems to use with EnergyPlus (Rallapalli, 2010). Heating-cooling, ventilation, lighting loads, climate data, and CO_2 emissions in Energy Plus can be integrated with the building modelled in DesignBuilder software. Alternative solutions can be explored with simulations by entering data about the parameters mentioned above. Thus, energy performance of buildings could be easily analysed by using the databases available on Energy Plus (DesignBuilder, n. d.).

DesignBuilder first determines the location and weather data, then creates a building model through the integrated CAD interface. In order to simulate the thermal performance of the building, the building geometry is used. In addition, DXF (Drawing Exchange Format) files might be imported to create the building model (Rallapalli, 2010). Many different country or region-specific templates could be selected as parameters regarding materials and construction. Other parameters cover occupancy activities, construction types, glazing systems, lighting, and ventilation systems. After all input parameters are defined, simulations of annual, monthly, daily, hourly, sub-hourly energy consumption could be performed. Additionally, the thermal model of a building could be validated through the energy code used for the location of the building (Rallapalli, 2010). Generally, DesignBuilder analyses daylighting, visualises site layouts and solar shading, creates thermal simulation of natural ventilation, dimensions, HVAC equipment, and systems (Rallapalli, 2010).

So, due to its ease of use, DesignBuilder was chosen as a building performance simulation tool in this study aiming to quantify the effects of building parameters on building energy performance. Firstly, the Tekeli Secondary School building was modelled in DesignBuilder with reference to the floor plans. Then, zones, architectural elements, materials, working schedules etc. were defined. In each school building, there are different functional areas or zones such as classrooms, study rooms, offices, canteens, libraries, sports centre, sanitary facilities and playground which have different occupancy and hours of use leading to different energy consumption levels. Thereafter, climate data was entered into the program by selecting the coordinates of Antalya. Within this model, CYP_LARNACA_IWEC (international weather data of Larnaca, Cyprus for energy calculations in the simulation program) was selected for Antalya as the basis of appropriate regional climatic data. Since there was not any option to choose Antalya weather data in DesignBuilder, CYP_LARNACA_IWEC was the closest option to select under the simulation weather data in the software. The orientations of the buildings were then defined in the program.

3.2.5.1 Antalya and Climate

Antalya is the tourism capital of Turkey and also one of the most urbanised and migrant-occupied provinces. Antalya is located at 36,70° latitude, 30,73° longitude. Antalya climate data, latitude-longitude information, altitude, start and end of summer and winter seasons were automatically selected in DesignBuilder. In order to develop sustainable intervention opportunities, DesignBuilder building energy performance simulation tool was used to simulate and visualise the daylight shadow values on the Tekeli secondary school building by following the sun’s hourly, daily and monthly path.

There are three other school buildings around the case study building. The four-storey primary building situated on the east of the secondary building and two single-storey buildings situated on the west and north of the secondary building had an effect on day-light modelling. The school with the other buildings situated around it was modelled in the software as seen in Figure 3.9. All school buildings are close to each other on the same campus. As the other buildings situated around the school affect the daylight–shadow values of the school building, the modelling process was based on the four buildings including the case study school building itself and surrounding buildings on the campus. The time for daylight modelling was determined by summer and winter solstices. The model showing daylight–shadow values of the building is demonstrated in Figure 3.10. The values were measured on 21st of June which is the period when cooling is widely used and on 21st of December which is the period heating is utilised most intensely.

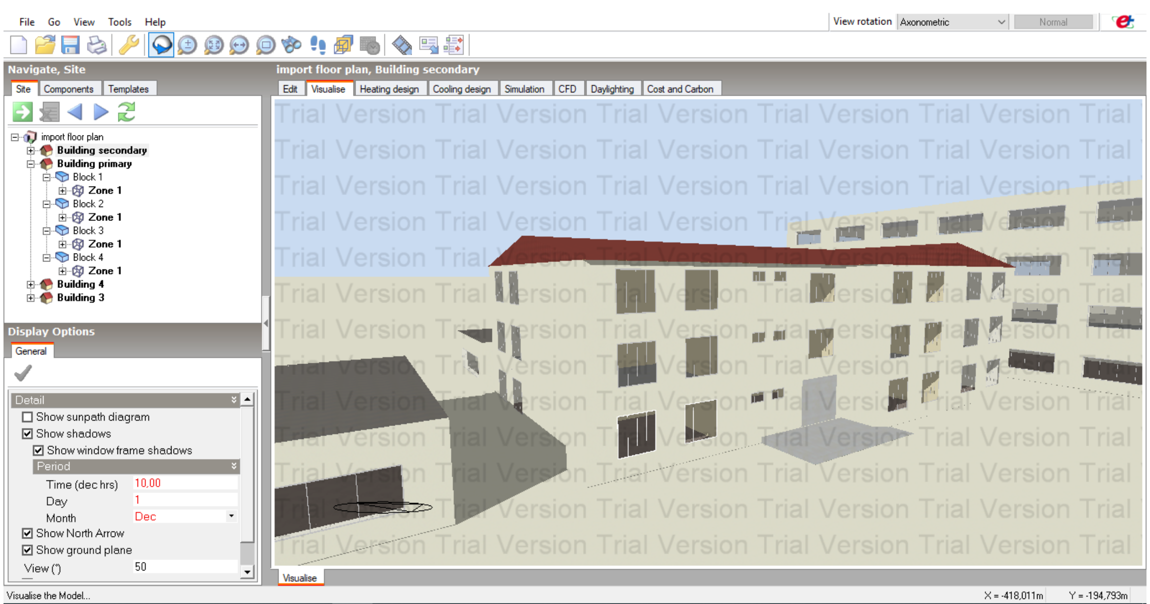
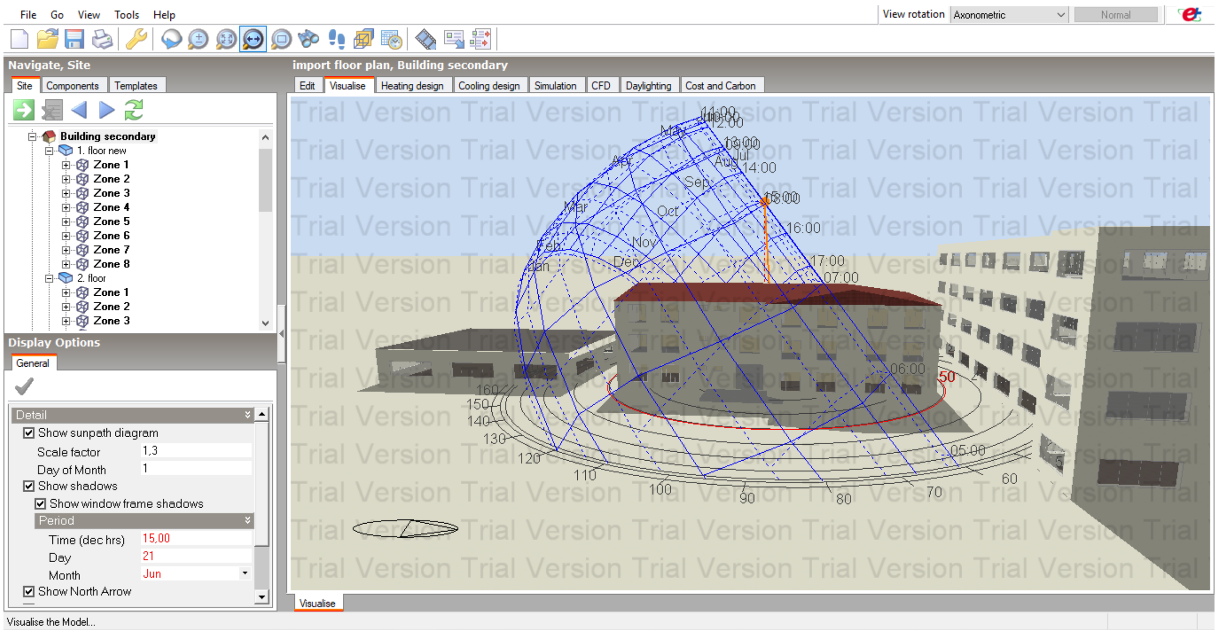


Figure 3.9 The model of the building



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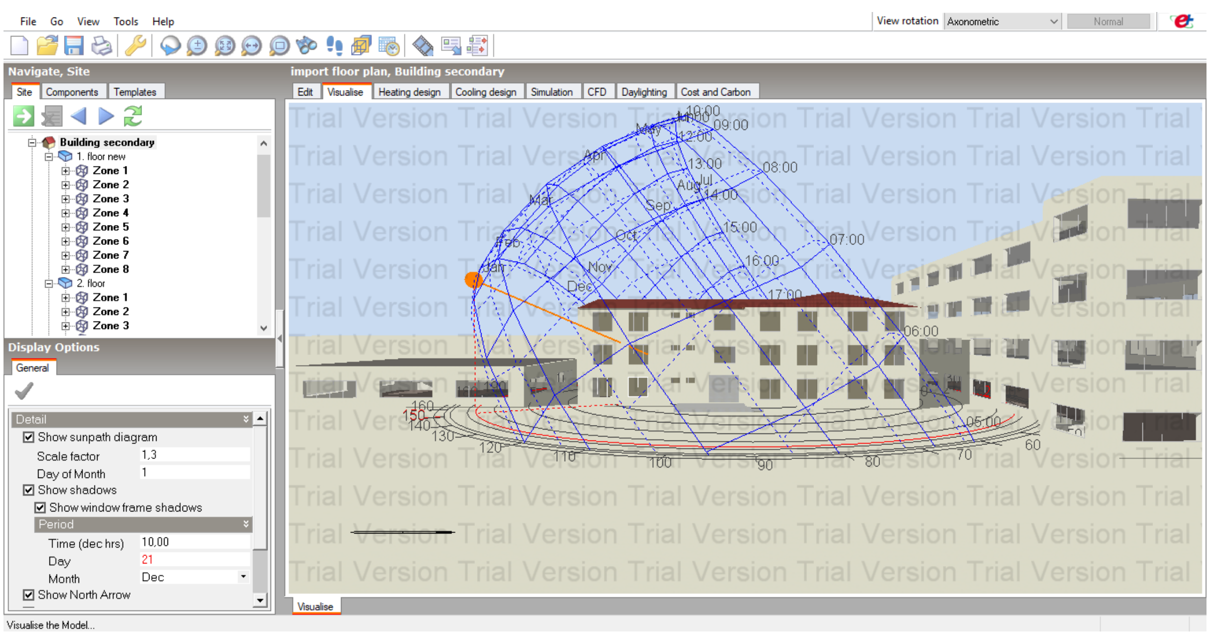


(10.00 AM, 21 December)

Figure 3.10 Sun path diagram of the Tekeli secondary school building

Also, data related to occupants were inserted into the software. Holidays, occupancy details according to the function of the structure, occupancy density (people/m^2), and heating and cooling set point temperatures were defined in the activity template. Holidays were determined as 111 days for Turkish schools as seen in Figure 3.11. In the environmental information section, the ideal temperature for heating, cooling, ventilation systems, and the lowest or highest temperatures providing the operation of the system were described. There is a significant study published by Akyol (2012) which is appropriate to the context of the case study school in Turkey. According to Akyol (2012), while ideal comfort temperature in classrooms is defined as 22 ^{O}C in winter, the activation temperature of heating systems should be 20 ^{O}C. While ideal comfort temperature in classrooms is defined as 24 ^{O}C in summer, activation temperature of cooling systems should be 26 ^{O}C (Akyol, 2012).

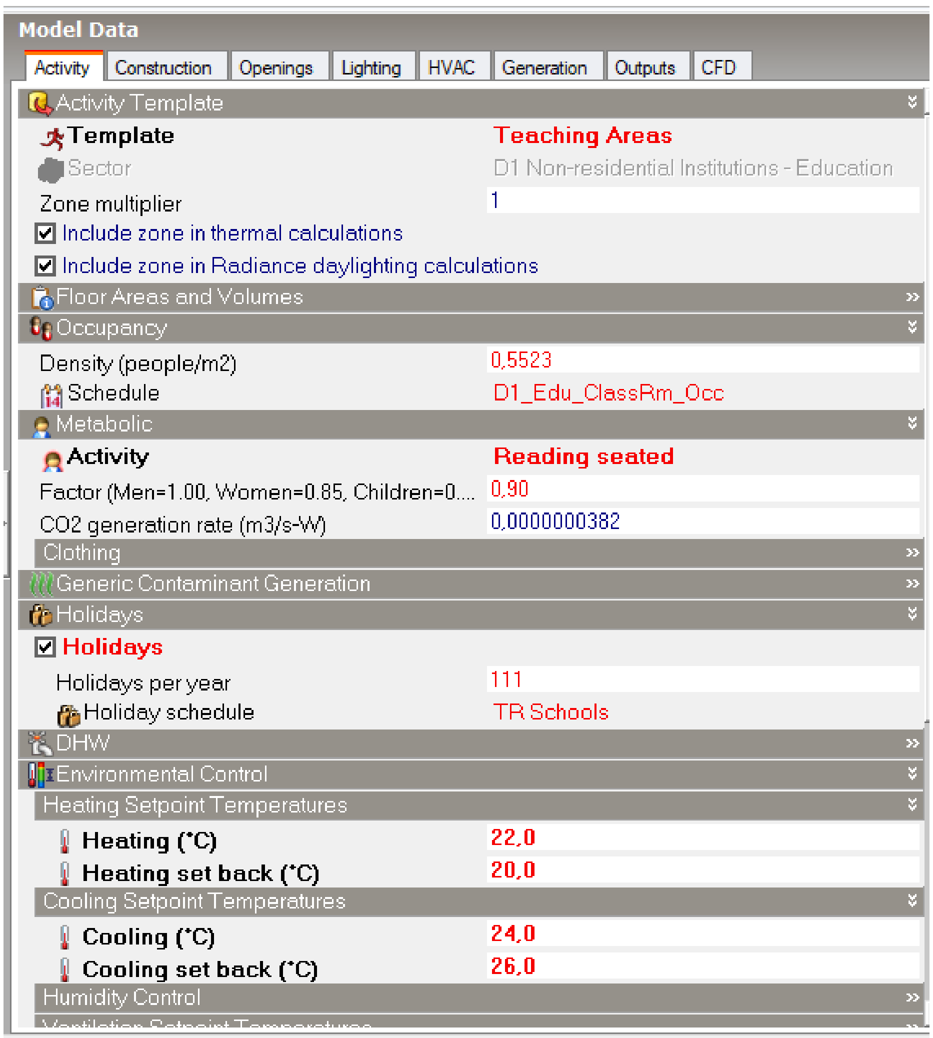


Figure 3.11 Activity sheet for the sample school in DesignBuilder

After inserting all of the physical features of the Tekeli Secondary School building into the program, the heating and cooling energy consumption of the building was determined by the simulation. According to this, the heating value in the winter months (November, December, January, February and March) was 7,634.56 kWh and the cooling value in the summer months (May, June, July and August) was 37,643.46 kWh, as shown in Figure 3.12. Also, detailed

Figures A1 and A2, which show line graphs regarding energy consumption for the heating and cooling before the intervention, are attached in Appendix E. Simulation values before the intervention, were based on the school building using electricity (for heating and cooling) for eight months. 45,278.02 kWh energy is consumed in five months for heating and three months for cooling in a year on average. An education year covers 10 months. The school building uses electricity for lighting throughout the school year. The existing electricity consumption for lighting is 29,973.12 kWh in a year. It is clear that cooling is a bigger problem to tackle than heating, but that lighting is a place for big savings to be made as well. Recommendations on this subject will be discussed in the next chapter. So, simulation results before the intervention have 75,251.14 kWh energy consumption in total. Also, the electricity bills paid by the school building indicate that the school consumes between 62,500-75,500 kWh energy in an education year. The existing energy consumption of the school matches up with the value calculated before the intervention.

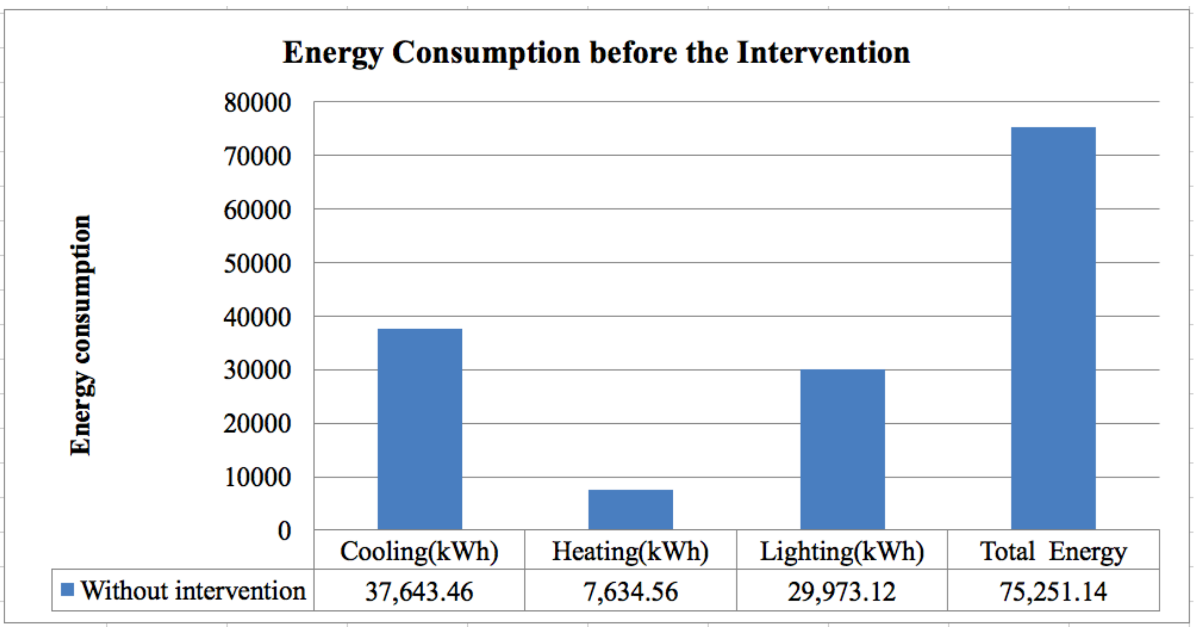


Figure 3.12 Energy consumption for cooling, heating and lighting (before the intervention)

This selected case study school is a public school and the school budget for energy expenses is limited. Therefore, the aim in sustainable refurbishment of the existing K-12 school building should be to minimise energy consumption. According to the calculated heating and cooling energy consumption results, there could be an opportunity for decreasing these consumption values. Adding an insulation material to the building envelope can reduce electrical energy consumption and CO_2 emission. The renovation of the building envelope and window glazing types and the integration of PV panels and mechanical ventilation systems can reduce heating and cooling energy costs if the components are chosen from materials appropriate for the regional climate. In this context, appropriate interventions could be determined by simulating refurbishment scenarios.

3.3 Chapter Summary

The starting point of this research is to make a contribution to the prevention of environmental problems caused by buildings, and the promotion of environmental literacy. In this research, making school buildings energy efficient and improving the environmental comfort conditions of the pupils are main priorities. Additionally, there is other benefit in a sustainable school building as a teaching tool. The use of tools that represent sustainability within the school building will be effective for both students and their families and society in terms of environmental literacy. Therefore, this research has focussed on the opportunities for the sustainable refurbishment of existing K-12 school buildings from a holistic perspective.

For this purpose, this chapter covered information, measurements, and observations about Tekeli Secondary School building and also evaluated the current situation of Tekeli Secondary School. As a result of the observations made, it was determined that the school building has not been assessed according to LEED or BREEAM certification systems yet and has not complied with their criteria. Precautions for water-saving such as rainwater collection and recycling greywater have not been taken. Recycled materials were not utilised in the construction phase. The school garden used by children during break times has not been equipped and designed to connect them with nature. The existing needs of the school were identified in line with sustainable building certification systems such as LEED and BREEAM.

The refurbishment study was carried out in line with two basic approaches. Firstly, energy performance simulations were prepared to evaluate opportunities for sustainable improvement, and the existing energy performance of the case study building was simulated to compare energy consumption values after the sustainable refurbishment interventions addressed in the following chapter. Then secondly, the pedagogical impacts of these interventions will be evaluated at the end of Chapter 4. These two holistic approaches can be important in terms of the three pillars of sustainability. As a result of the investigations, the energy performance of the existing building was simulated with the DesignBuilder software and the energy consumption for heating, cooling, and lighting in a year was calculated. In total, 75,251.14 kWh energy is consumed throughout the whole year. According to the energy performance simulations of the existing building, it is clear that standard projects like Tekeli secondary school are lacking sustainability. Thus, there is a need to research sustainable refurbishment strategies for standard school buildings.

Existing school buildings in Turkey are in need of urgent basic renovation in terms of sustainability; most of them are old, worn-out and poorly insulated, and have outdated heating and inadequate ventilation systems—if they have them at all. The refurbishment of the existing old buildings and the construction of new buildings in a sustainable way play an essential role in terms of time and cost savings. Sustainable and cost-effective refurbishment of K-12 school buildings will offer a real opportunity for environmental awareness. Planning and renovating a school building in a sustainable way allows users, especially children, to be aware of their energy consumption. In other words, designing educational buildings with sustainability criteria has positive contributions to users' development as environmentally conscious individuals. Living in a more sustainable building teaches children to think, behave and consume responsibly. In this way, teachers and families, through students, will be involved in the refurbished learning environments and this awareness will have a significant contribution to shaping society in a short time.

The next chapter will make sustainable refurbishment suggestions in terms of energy, water, material, and landscape efficient interventions for existing school buildings in Turkey. Then, it will evaluate the role of the interventions in terms of pedagogic purposes.

CHAPTER 4

SUGGESTIONS FOR REFURBISHING TEKELI SECONDARY SCHOOL BUILDING AND OTHER K-12 SCHOOLS IN TURKEY

4.1 Introduction

This chapter deals with a detailed set of proposals for the sustainable refurbishment of Tekeli secondary school building, including a DesignBuilder simulation proposal for energy improvements, and other proposals such as landscape, material, and water conservation then suggests how the refurbishment might be used to educate students about environmental issues. These proposals support the use of school buildings as a teaching tool. The chapter concludes with a national proposal for refurbishment of other similar schools in Turkey.

In order to make this happen, sustainability targets as part of Turkey's environmental strategies should be enshrined in legislation. In this regard, Turkey's strategic action plans for the year 2023 aim to reduce the total energy demand by 14 percent (YEGM, 2018). The Ministry of National Education and the Ministry of Environment and Urbanisation collaboratively work for the studies aimed at raising environmental awareness. Non-governmental organisations support Turkish public schools to arrange social responsibility projects and competitions concerning the environment. Moreover, the Directorate of National Education and Provincial Directorate of Environment and Health developed a project to encourage schools to keep the environment clean and, since 2006, a white flag has been given to schools that are successful examples in environmental cleaning.

Thus, environmental awareness has come into prominence (Ministry of National Education, n. d.; Baykal, 2010). The sustainable development goals for the future address key issues such as global warming, climate change, energy conservation, reduction of fossil fuel consumption and CO_2 emissions, recycling and environmental education. Development plans of Turkey cover legislation changes and practices in accordance with the principle of sustainability (Kaya, Cobanoglu and Artvinli, 2011). In addition to the strategies mentioned, this research will contribute to increasing the number of sustainable schools in Turkey.

4.2 A Proposal for Sustainable Improvements to Tekeli Secondary School

This section will demonstrate how the DesignBuilder simulation tool was utilised to test a number of alternatives for how the Tekeli secondary school building could be refurbished to improve its environmental performance. Firstly, energy-efficient intervention proposals present three scenarios considered for sustainable refurbishment of the Tekeli school building. According to the results of the analysis, which shows the effects of the interventions on heating and cooling energy use, appropriate intervention alternatives will be determined and the energy-efficient refurbishment possibilities will be presented. Additionally, other suggestions will be offered on water, recycling, waste management, efficient landscape design and sustainable materials, which are the main components of sustainable assessment criteria. Finally, the pedagogic effects of the sustainable interventions for the case study school will be explained.

4.2.1 Proposed Energy-Efficient Interventions with DesignBuilder Energy Performance Simulations

Three scenarios have been developed for energy performance simulations. The energy-efficient intervention possibilities of the first scenario are limited to building envelope insulation, window glazing, and LED lighting. The second scenario considers solar panel integration in addition to the changes of the first scenario. Then, the third scenario includes mechanical HVAC systems in addition to the second scenario. Energy savings will be determined by simulating each intervention. Additionally, the cost of the interventions will be calculated and the payback periods of each one will be estimated. The second and third scenario have higher initial cost and longer amortisation periods, compared with the first. For the purpose of refurbishing K-12 school buildings, the decision makers in Turkey could assess these improvement scenarios and take appropriate steps in order to implement the interventions, depending on the available budget and time.

SCENARIO 1

In order to improve energy performance of the existing case study school building, the first scenario focuses on envelope insulation, window glazing, and LED lighting.

4.2.1.1 Energy Performance Evaluation with Building Envelope Intervention

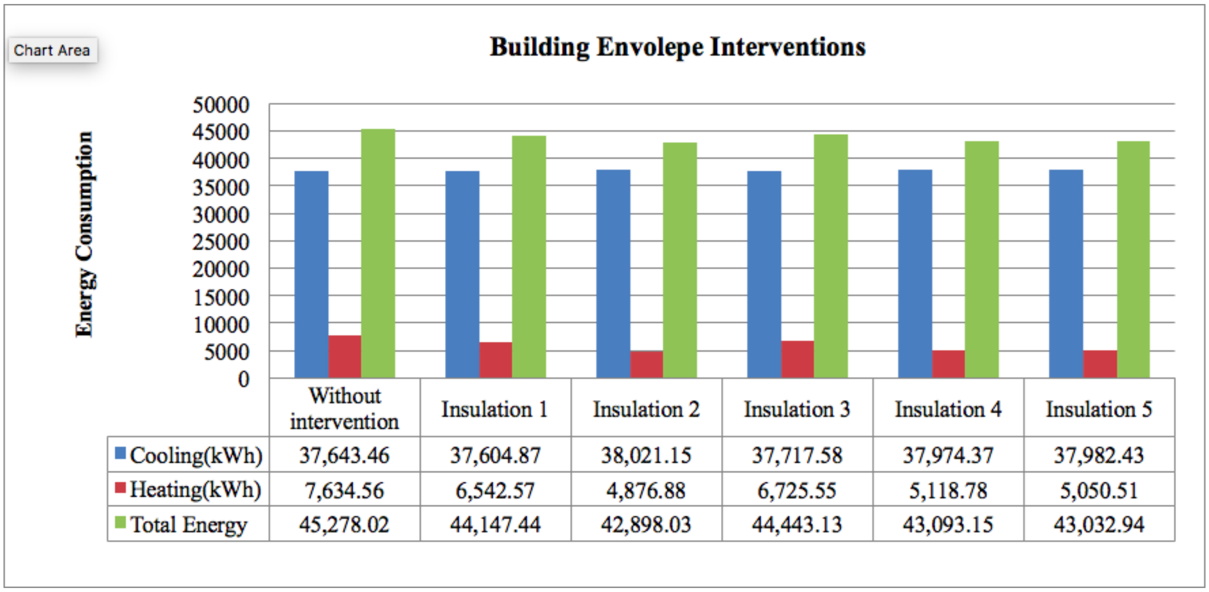
This section describes energy performance simulations (in DesignBuilder) of Tekeli school building. The existing energy consumption for heating and cooling was compared with the results of the simulations after the interventions to the building envelope. According to the thermal insulation standards for buildings in Turkey, it is estimated that school buildings in hot climate regions can have approximately 5 cm insulation thickness (TSI, 2008; Caglayan et al., 2020, p. 7). Therefore, the insulation thickness for building envelope interventions was taken as 5 cm.

In terms of refurbishment strategies, a lot of insulation materials have been tested and five different insulation materials, which provide the most energy savings and cost efficiency among them, have been selected for energy-efficient refurbishment of the building envelope. The visible and physical features of these insulation materials used in the simulations could be seen in Appendix L. Then, electricity consumption value for cooling (for summer months) and heating (for winter months) were calculated.

INSULATION	INSULATION MATERIAL	COOLING (kWh)	HEATING (kWh)	TOTAL (kWh)
Without intervention	Existing construction materials	37,643.46	7,634.56	45,278.02
Insulation 1	5 cm Thermalite high strength + 2.3 cm cement mortar	37,604.87	6,542.57	44,147.44
Insulation 2	5 cm Foam polyurethane + 2.3 cm cement mortar	38,021.15	4,876.88	42,898.03
Insulation 3	5 cm Vermiculate insulating brick + 2.3 cm cement mortar	37,717.58	6,725.55	44,443.13
Insulation 4	5 cm MW stone wool (standard board) +2.3 cement mortar	37,974.37	5,118.78	43,093.15
Insulation 5	5 cm EPS expanded polystyrene (heavyweight) +2.3 cm cement mortar	37,982.43	5,050.51	43,032.94

Table 4.1 Cooling and heating values according to different insulation materials.

The heating and cooling loads were calculated by simulating five different kinds of insulation materials and are presented in Table 4.1.



	Without intervention	Insulation 1	Insulation 2	Insulation 3	Insulation 4	Insulation 5
Cooling(kWh)	37,643.46	37,604.87	38,021.15	37,717.58	37,974.37	37,982.43
Heating(kWh)	7,634.56	6,542.57	4,876.88	6,725.55	5,118.78	5,050.51
Total Energy	45,278.02	44,147.44	42,898.03	44,443.13	43,093.15	43,032.94

Figure 4.1 Energy consumptions according to building envelope interventions

In the simulations performed, it was observed that insulation interventions reduce energy consumption. When the five different insulation types are compared with each other, the best energy saving is achieved with foam polyurethane. However, this is not appropriate for public buildings such as schools because of it is both highly flammable and releases toxic gases when burning. The most appropriate intervention therefore is 5 cm MW stone wool (standard board) + 2.3 cm cement mortar, which had the second-best performance, but which is much safer.

The savings in energy consumption for heating were 2,515.78 kWh with this insulation, as shown in Figure 4.1. Since this insulation prevents cooling at night, the insulation material decreases the energy required for heating in the winter but also increases the cooling load slightly in the summer. Thus, suitable interventions to overcome this effect will be addressed in the following section. Furthermore, the solar gains through windows could be controlled using shadings, as in some of the precedent school buildings in Chapter 2. Therefore, the result should focus on the overall energy load both for heating and cooling.

4.2.1.2 Energy Performance Evaluation with Window Glazing Intervention

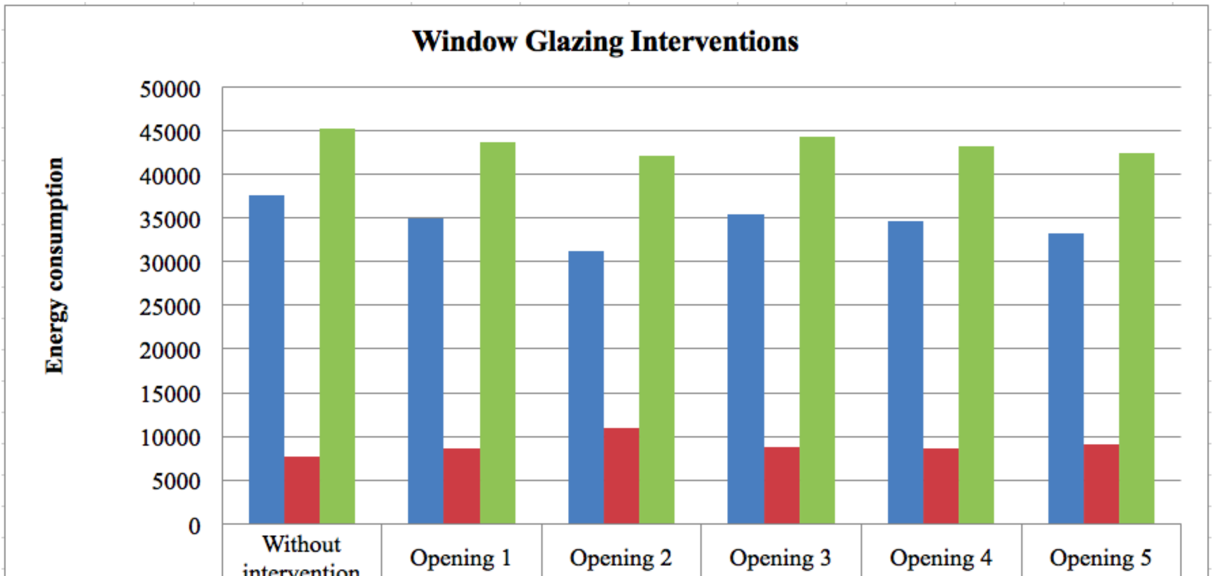
In this section, window glazing refurbishments of Tekeli secondary school building will be evaluated with regard to energy performance. The existing energy consumption for heating and cooling were compared with the results of the simulations after the interventions to window glazing type. Simulation calculations were made using five different window glazing types and using louvres and overhangs as shading devices. Also, summer months were considered in terms of the energy consumption value for cooling, while winter months were taken into consideration concerning energy consumption for heating. Five intervention possibilities were considered for refurbishment of the openings, as indicated in Table 4.2. The features of these openings and glazing types used in the simulations could be seen in Appendix M.

Openings	WINDOW GLAZING TEMPLATE AND TYPE	COOLING kWh	HEATING kWh	TOTAL kWh
Without intervention	Existing window glazing type	37,643.46	7,634.56	45,278.02
Opening 1	Triple glazing, clear, mid-pane blinds + Trp, Clr, 6mm/30mm, Air for mid-pane blinds	35,009.71	8,597.03	43,606.74
Opening 2	Double glazing, clear, 1 m louvres + DBL, Elec, Ref, Coloured, 6mm/13mm, Air	31,165.18	10,983.32	42,148.5
Opening 3	Double glazing, clear, internal blinds + Dbl, Clr, 6mm/13mm, Air	35,432.07	8,858.73	44,290.8
Opening 4	Local shading + 1.0 m Overhang	34,638.6	8,604.36	43,242.96
Opening 5	Local shading + 1.0 m projection Louvre	33,285.52	9,171.64	42,457.16

Table 4.2 Cooling and heating values according to different openings.

Different opening types were selected to test the effects on heating and cooling load. All of these glazing types and shadings increase the heating energy requirement. For example, openings 2, 4 and 5 provide solar shading and reduce the sunlight coming in. Since Tekeli secondary school is in the hot climate region, more energy is used for cooling than for heating. So, louvres, overhangs, solar shadings, coloured and triple glazing types are preferred and they offer passive cooling. Briefly, window glazing interventions increased the heating load slightly, while they reduced the cooling load. Cooling load changed in contrast with heating load. A balance should be achieved. Therefore, the overall energy loads both for cooling and heating should be taken into consideration.

In order to explain the difference in double and triple glazing, opening 1 and 3 could be observed. The comparison shows that opening 1 decreased the cooling load by means of triple glazing more than opening 3. Opening 1 is better than opening 3 for the case study school building in the hot climate zone. Opening 2, which had the lowest energy consumption for heating and cooling, was selected, since the total energy requirement should be considered. This intervention saved 6,478.28 kWh cooling energy, as demonstrated in Figure 4.2.



	Without intervention	Opening 1	Opening 2	Opening 3	Opening 4	Opening 5
Cooling(kWh)	37,643.46	35,009.71	31,165.18	35,432.07	34,638.60	33,285.52
Heating(kWh)	7,634.56	8,597.03	10,983.32	8,858.73	8,604.36	9,171.64
Total Energy	45,278.02	43,606.74	42,148.50	44,290.80	43,242.96	42,457.16

Figure 4.2 Energy consumptions according to window glazing interventions

Increasing the insulation performance of the glazing could always result in an increase in the heating load. The reason for this is that solar gains in winter are less, however energy-efficient interventions were mainly proposed to reduce the energy requirements for cooling, as this consumed much more energy. Coloured glazing types limit direct sunlight to prevent heat gain in summer, while they slightly increase the heating load in winter because of this feature. However, this study takes the overall gain in energy consumption for heating and cooling into account.

4.2.1.3 Energy Performance Evaluation with LED Lighting Intervention

In this section, energy performance simulations of lighting interventions will be evaluated in order to reduce the annual electricity consumption of Tekeli secondary school building. When LED lighting is compared with conventional lighting sources, LED lighting is both longer lasting and more energy efficient. Therefore, the building has significantly reduced the electricity consumption for lighting, as shown in Table 4.3, when LED lighting is integrated. One reason for this is that LED lamps heat the environment less. So, the lighting intervention will contribute to the energy savings of the selected school building by reducing the cooling load in the summer.

	Electricity Consumption for Lighting (kWh)
Without intervention	**29,973.12**
With LED lighting	**3,622.13**

Table 4.3 Electricity consumption according to LED lighting intervention

The electricity saving was 26,350.99 kWh with LED lighting.

The Budget Required for Scenario 1

The budget required for Scenario 1 consists of the cost of insulation material, window glazing, and LED lighting.

The cost of the selected insulation material (105,750 Turkish Liras (TL)/ £ 5,566) could be calculated by multiplying the total surface area of the building except the openings (705 m^2) by the price of stone wool insulation material per unit area, with labour costs (150 TL/ £ 7.89).

The cost of the selected window glazing type (18,954 TL/ £ 997.6) could be calculated by multiplying the total number of openings (54) and the price of reflective and coloured glazing with louvres per window with labour costs (351 TL/ £ 18.5).

The cost of the LED lighting (9,810 TL/ £ 516.3) could be calculated by multiplying the total number of required LED lights (60) and the price of LED lighting per unit with labour costs (163.5 TL/ £ 8.61). The overall cost of Scenario 1 is 134,514 TL/ £ 7,080.

The Payback Period for Scenario 1

The payback period would be estimated by calculating the annual earning obtained from Scenario 1. Since the existing school building consumes 75,251.14 kWh electricity in a year, its electricity costs are 142,224.66 TL/ £ 7,485.50 (1 kWh = 1.89 TL/ £ 0.099 for schools). The energy saving through Scenario 1 is 49.66% according to the energy consumption results from simulations. So, the saving would be 37,369.7 kWh or 70,628.7 TL/ £ 3,717 (37,369.7 kWh x 1.89 TL/ £ 0.099).

As a result, Scenario 1 amortises its expenses in 2.01 years, if the total cost of Scenario 1 (142,224.66 TL/ £ 7,485.50) is divided by the annual savings (70,628.7 TL/ £ 3,717). This is a headline figure that will be compared to the payback period of other scenarios. In less than three years, the interventions will have paid for themselves and will start generating annual savings for the school. The immediate benefit will be a reduction in the use of fossil fuel for cooling and heating, and students can learn from this.

SCENARIO 2

In order to improve energy performance of the case study school building, the second scenario focuses on photovoltaic solar panels in addition to Scenario 1. Tekeli secondary school is in a hot climate zone and has a large number of sunny days. Also, solar panels promote renewable resources rather than fossil fuels.

4.2.1.4 Energy Performance Evaluation with Solar Panel Intervention

After the intervention in Scenario 1, a total energy saving of 49.66% was achieved in the case study school. In order to meet the rest of the energy requirements, energy generation from different sizes of PV panels was investigated in DesingBuilder. According to the energy requirements, the appropriate surface area of the solar panels was determined as 140 m^2. Then, the solar panels were located on the south facing roof of the school building, as demonstrated in Figure 4.3, in order to make more use of solar radiation and prevent overshadowing that might limit their effectiveness. It was calculated according to the simulations with DesignBuilder that 40,088.21 kWh electricity can be generated in a year.

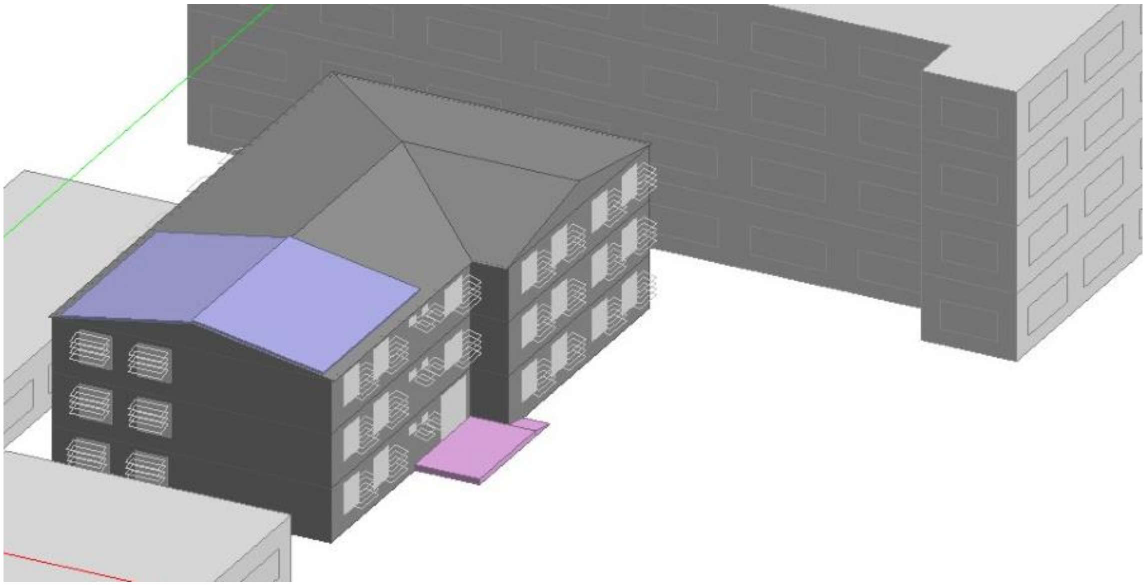


Figure 4.3 Solar panels on the roof of the case study school building in DesignBuilder simulation.

The energy requirement after the first scenario (37,881.44 kWh) is completely met by the electricity through the second scenario. Moreover, 2,206.77 kWh electricity can be stored. Thus, Tekeli secondary school will have achieved the goal of a zero-energy building if Scenarios 1 and 2 are applied together. Also, photovoltaic panels for hot water have not been considered since there is no shower unit, dormitory, or kitchen and winters are warm. The total cost of Scenario 1 and 2 together is calculated below.

The Budget Required for Scenario 2

The budget required for Scenario 2 covers the cost of Scenario 1 in addition to solar panels. The installation cost of a PV panel, which can generate 1000 kWh electricity in a year, would be 11,970 TL/ £ 630 on average. Since 40,088.21 kWh electricity has been generated through the integrated solar panels, 40 PV panels are required. So, the cost of the integrated photovoltaic panels for electricity (478,800 TL/ £ 25,200) could be calculated by multiplying the total number of required solar panels (40) and the installation price of photovoltaic panel per unit, with labour costs (11,970 TL/ £ 630). The overall cost of Scenario 2 is 621,025 TL/ £ 32,685 in addition to Scenario 1.

The Payback Period for Scenario 2

The payback period would be estimated by calculating the annual savings obtained from Scenario 2. Since the existing school building consumes 75,251.14 kWh electricity in a year, it needs 142,224.66 TL/ £ 7,485.50. The total energy saving through Scenario 2 would be expressed as 77,457.91 kWh or 146,395.45 TL/ £ 7,705.02.

As a result, Scenario 2 (the implementation of the first two scenarios together) amortises its expenses in 4.24 years, if the total cost of Scenario 2 (621,025 TL/ £ 32,685) is divided by the annual earning (146,395.45 TL/ £ 7,705.02). The payback period of this scenario is more than the headline figure in Scenario 1, and the interventions will start generating annual savings for the school in six years. However, the energy savings after the payback period would be higher compared to the first scenario. If the sale of excess electricity generated by the PVs is considered, the payback period could also be reduced.

SCENARIO 3

In order to improve energy performance of the case study school building, the third scenario focuses on HVAC systems in addition to Scenario 2.

4.2.1.5 Energy Performance Evaluation with HVAC Systems Intervention

In addition to the first two scenarios, the third scenario includes HVAC mechanical systems (heating, ventilation and air-conditioning). For this purpose, both natural and mechanical ventilation (mixed-use) were considered together in the simulations. Also, natural gas for heating is not available in the school so that electricity has been used from the grid for heating, cooling and lighting through the simulations. Then, the annual energy requirement of the three scenarios after the installation of HVAC systems would be 52,484.07 kWh. Whereas the annual energy consumption of the existing school building is 75,251.14 kWh, the consumption value would decrease 22,767.07 kWh with the implementation of the first three scenarios. 30.3% energy would be saved with Scenario 3, while Scenario 2 offers 103.7% energy savings which mean that all of the energy consumed is met and more energy can be generated. Therefore, the third scenario has not been preferred as an energy-efficient intervention in the model below due to a reduced savings rate, and high installation cost. However, this scenario could be preferred in case more budget is allocated and more solar panels are added, in addition to HVAC system, to reduce the energy consumption.

The Budget Required for Scenario 3

According to a local company, the installation fee of a HVAC system for educational buildings is 345 TL/ £ 18.16 per square foot depending on the types of heating, cooling and ventilation systems. As Tekeli secondary school building has 1,616.83 m^2 total building area, the initial cost of Scenario 3 will be 557,806.35 TL/ £ 29,358.22. At the end of Scenario 3, the annual saving is 22,767.07 kWh energy or 43,029.76 TL/ £ 2,264.72.

The Payback Period of Scenario 3

As a result, Scenario 3 amortises its expenses in 27.40 years, if the total cost of Scenario 3 (1178,831.35 TL/ £ 62,043.76) is divided by the annual earning (43,029.76 TL/ £ 2,264.72). The payback period of this scenario is more than the headline figure in Scenario 1, and the interventions will start generating annual savings for the school after more than 20 years. So, this scenario is not recommended since the school will not be able to amortise this expense for a long time. However, the payback time of the HVAC system could change depending on the size of the school and climate.

Currently, there are more than 60,000 K-12 school buildings in Turkey and the decision-makers in the Education Department of Turkey have limited budget for renovating these schools. Therefore, it is not possible to realise HVAC intervention in Scenario 3 due to the high electricity consumption and high installation costs of HVAC systems. So, the last scenario would not be a cost-effective intervention for the case study school and would not be recommended. The summary of the scenarios is presented below in Table 4.4.

	Interventions	**Energy Savings**	**Total Cost**	**Payback Period**
Scenario 1	Building envelope, window glazing, LED lighting	37,369.7 kWh (49.66%)	134,514 TL/ £ 7,080	2.01 years
Scenario 2	S1 + Solar panel	77,457.91 kWh	621,025 TL/	4.24 years

		(103.7%)	£ 32,685	
Scenario 3	S1 + S2+ HVAC intervention	22,767.07 kWh (30.3%)	557,806.35 TL/ £ 29,358.22	Very Long

Table 4.4 The comparison of three scenarios

4.2.2 Information about the Advisable Model

This section presents the information about the advisable model regarding intervention possibilities. In terms of cooling and heating, the most energy-efficient building envelope, which has the second-best energy performance, fire-resistant building materials, and window intervention model was chosen from the simulations.

After the examination of sustainable design interventions to Tekeli secondary school building in the DesignBuilder software, openings intervention 2 reducing cooling loads, and insulation intervention 4 reducing heating loads, were most effective.

As a result of the selected wall insulation material, it has been determined, as shown in Figure 4.4, that there is a 330.91 kWh increase in cooling load for summer months and a 2,515.78 kWh decrease in heating load for winter months by means of the insulation intervention. In total, 2,184.87 kWh energy was saved with just Insulation 4 intervention. Thus, changing building materials or renovation of the building envelope has reduced the energy consumption of the building. The materials chosen for the intervention should be local and natural in terms of cost-effectiveness and sustainability.

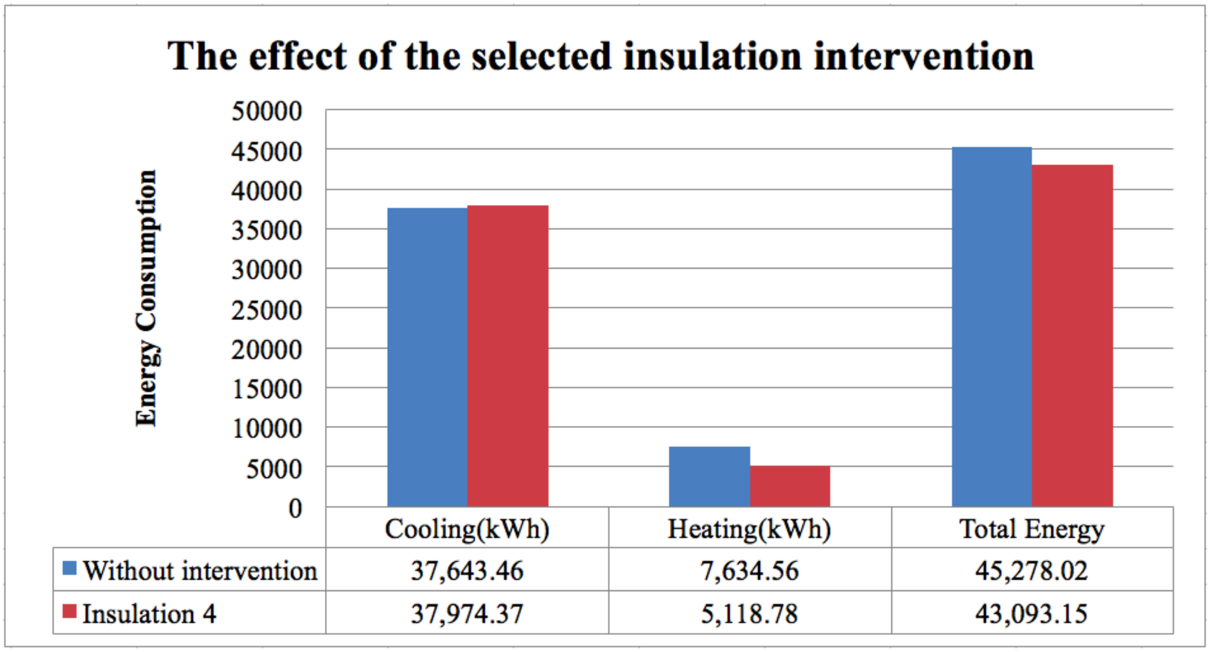


Figure 4.4 The effect of the selected insulation intervention on energy consumption before and after the interventions

According to Figure 4.5, following the selected window glazing intervention, there was a 6,478.28 kWh decrease in cooling load and a 3,348.76 kWh increase in heating load. In total, 3,129.52 kWh energy was saved with just Opening 2 intervention.

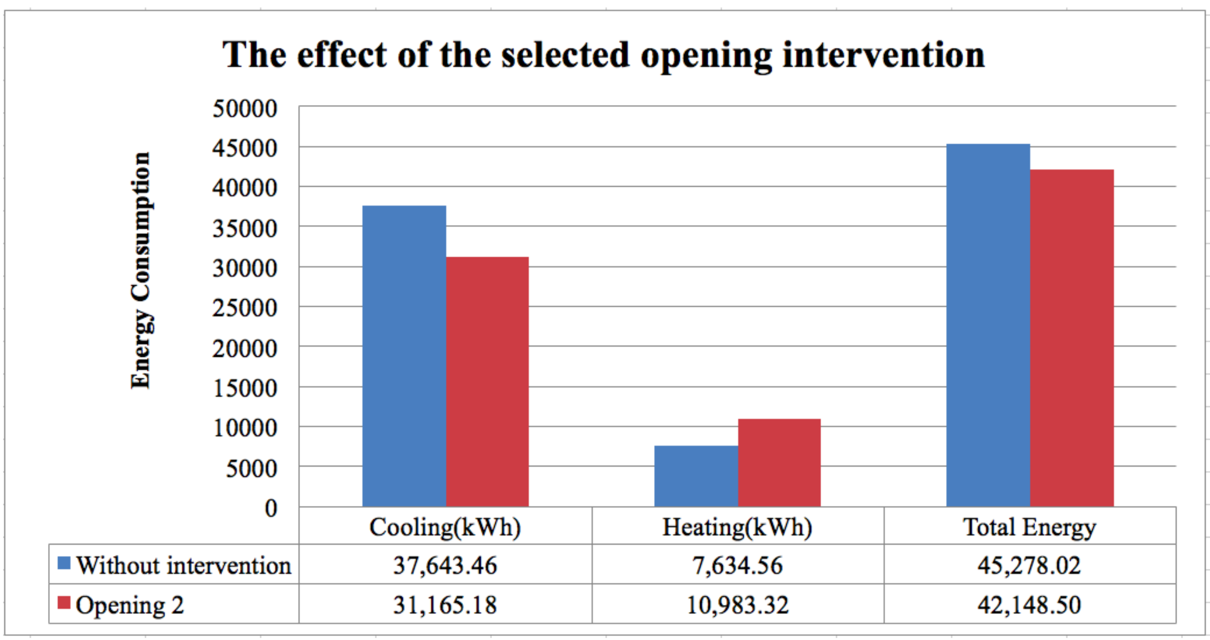


Figure 4.5 The effect of the selected window glazing intervention on energy consumption before and after the interventions

Furthermore, electricity consumption for lighting is 29,973.12 kWh without intervention and the consumption is 3,622.13 kWh with LED lighting. So, there was a total 26,350.99 kWh decrease in electricity consumption for lighting through the LED lighting intervention. Explaining the system to the students in Tekeli Secondary School will automatically raise awareness about the reduced release of greenhouse gases by the controlled use of energy for lighting.

In case these three interventions referred to above are applied together (Scenario 1), it is expected that the case study school building would consume 37,877.19 kWh energy. So, the total saving is 37,373.95 kWh energy in the heating, cooling and lighting energy after the intervention. In other words, a total reduction of 49.7% was achieved with these interventions, as demonstrated in Figure 4.6.

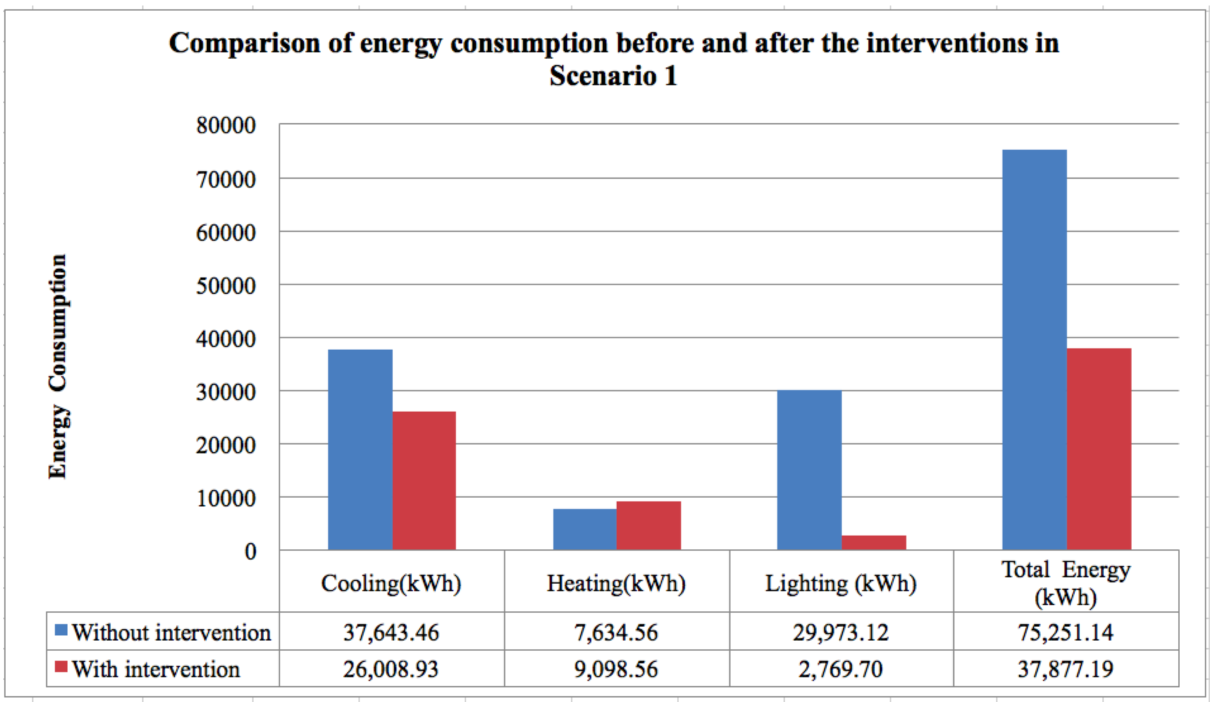


Figure 4.6 Comparison of energy consumption before and after the interventions in Scenario 1

In addition to Scenario 1, 140 m^2 of photovoltaic panels were integrated to reduce electricity consumption. 40,088.21 kWh electricity was generated using PV panels. Students are able to observe how much energy is saved through the panels, which is demonstrated by the monitors. So, the school building as a 'third teacher' would support environmental education in this intervention. The generated energy meets the energy requirement after the first scenario and saves an extra 2,211.02 kWh. The total energy demand of the school building was reduced by

77,462.16 kWh after the intervention. In other words, a total reduction of 103.7% was achieved with this intervention in Scenario 2. CO_2 emissions released into the atmosphere will have decreased in direct proportion to this. Energy consumed for the heating, cooling and lighting in the school is shown in Figure 4.7 below.

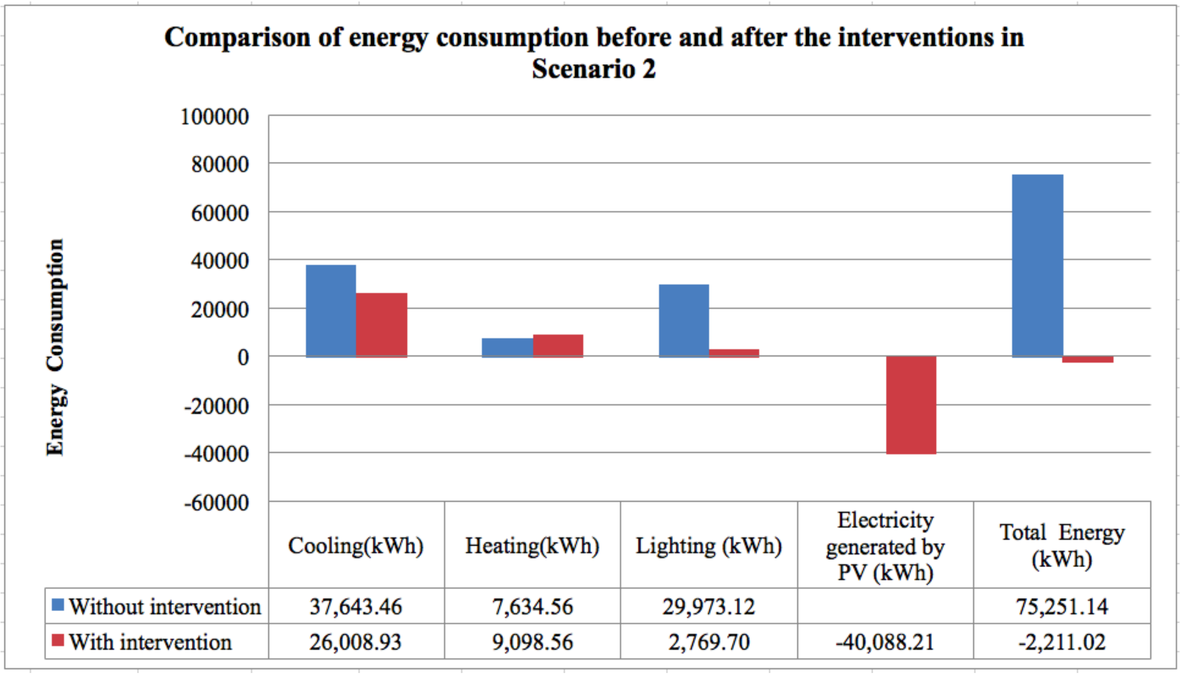


Figure 4.7 Comparison of energy consumption before and after the interventions in Scenario 2

Table 4.5 below constitutes the best overall solution with Scenario 1 and 2 covering the envelope, glazing type, LED lighting, and PV panel options. Also, it presents the component features of the building envelope and window glazing types before and after the intervention.

As the cooling constitutes the largest energy demand in a school in a hot and humid climate, the evaluation emphasized cooling energy. As it is seen from Table 4.5, the building envelope in the first case consists of 2.3 cm cement mortar, 0.3 cm foam polyurethane, 0.1 cm mortar, 0.4 cm gypsum plastering, 29 cm brick, 2.9 cm gypsum plaster. Additionally, the second case has an extra 5 cm MW stone wool (standard board) and 2.3 cm cement mortar. Also, window glazing was changed from double glazing, no shading/ Dbl, LoE (e^2=4) Clr 3mm/13mm air to double glazing, clear, 1 m louvres / DBL, Elec, Ref, Coloured, 6mm/13mm, Air. Then, LED lighting and photovoltaic panels on the south facing roof were integrated.

<table>
<tr><td colspan="6">Tekeli Secondary School</td></tr>
<tr><td colspan="3">After the intervention</td><td colspan="3">Before the intervention</td></tr>
<tr><td colspan="6">Building envelope materials</td></tr>
<tr><td colspan="3">Cement mortar 2.3 cm</td><td colspan="3">Cement mortar 2.3 cm</td></tr>
<tr><td colspan="3">Foam polyurethane 0.3 cm</td><td colspan="3">Foam polyurethane 0.3 cm</td></tr>
<tr><td colspan="3">Mortar 0.1 cm</td><td colspan="3">Mortar 0.1 cm</td></tr>
<tr><td colspan="3">Gypsum plastering 0.4 cm</td><td colspan="3">Gypsum plastering 0.4 cm</td></tr>
<tr><td colspan="3">Brick 29 cm</td><td colspan="3">Brick 29 cm</td></tr>
<tr><td colspan="3">Gypsum plaster 2.9 cm</td><td colspan="3" rowspan="3">Gypsum plaster 2.9 cm</td></tr>
<tr><td colspan="3">MW stone wool (standard board) 5 cm</td></tr>
<tr><td colspan="3">Cement mortar 2.3 cm</td></tr>
<tr><td colspan="6">Glazing template</td></tr>
<tr><td colspan="3">Double glazing, clear, 1 m louvres</td><td colspan="3">Double glazing, no shading</td></tr>
<tr><td colspan="6">Glazing type</td></tr>
<tr><td colspan="3">DBL, Elec, Ref, Coloured, 6mm/13mm, Air</td><td colspan="3">Double, LoE (e^2=4) Clear 3 mm/13 mm Air</td></tr>
<tr><td colspan="6">Lighting</td></tr>
<tr><td colspan="3">With LED Lighting</td><td colspan="3">Without LED Lighting</td></tr>
<tr><td colspan="6">Photovoltaic panel</td></tr>
<tr><td colspan="3">140 m^2</td><td colspan="3">Not available</td></tr>
<tr><td>Cooling (kWh)</td><td>Heating (kWh)</td><td>Lighting (kWh)</td><td>Cooling (kWh)</td><td>Heating (kWh)</td><td>Lighting (kWh)</td></tr>
<tr><td>26,008.93</td><td>9,098.56</td><td>2,769.7</td><td>37,643.46</td><td>7,634.56</td><td>29,973.12</td></tr>
<tr><td colspan="3">Total</td><td colspan="3">Total</td></tr>
<tr><td colspan="3">37,877.19 kWh – 40,088.21 kWh (electricity savings/generations from PV)
-2,211.02 kWh</td><td colspan="3">75,251.14 kWh</td></tr>
</table>

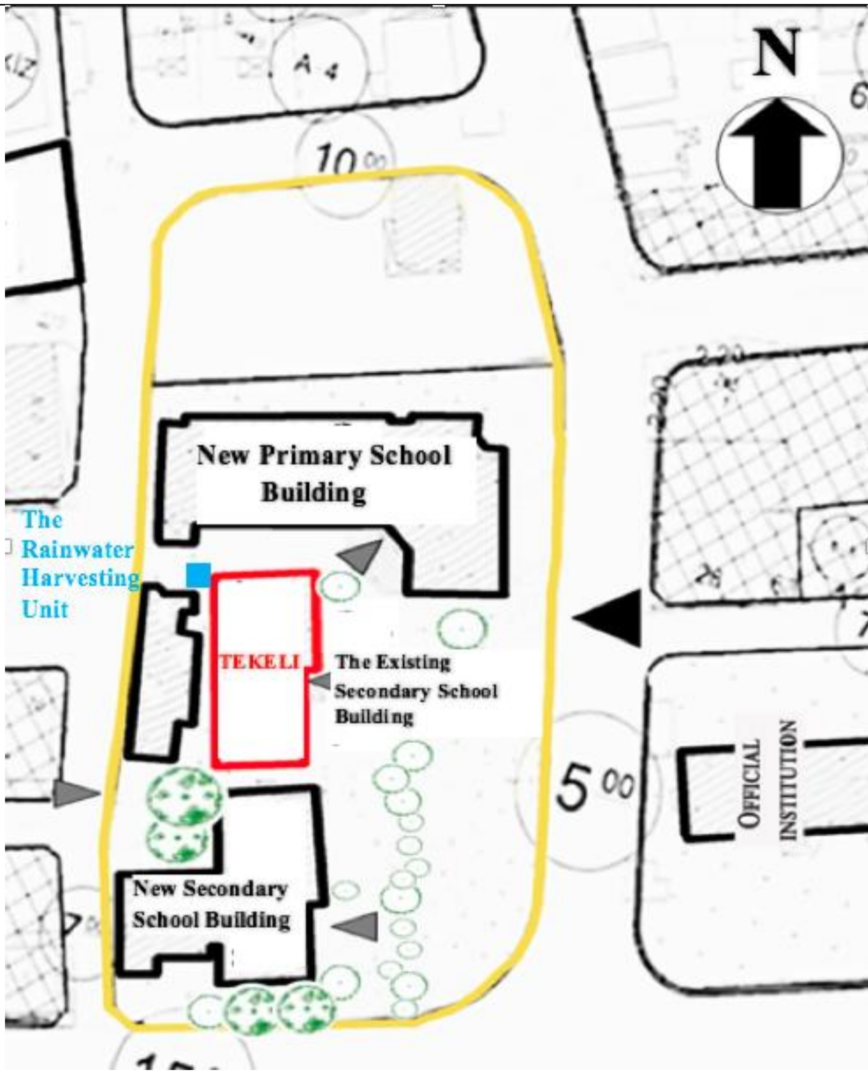
Table 4.5 Components of the building envelope inputs for the simulation, and heating, cooling, and lighting energy consumption results before and after the interventions.

In order to improve energy performance of the case study building, the first two scenarios focused on envelope insulation, window glazing, LED lighting and PV panels as the energy-efficient intervention possibilities. Since the HVAC system in the third scenario decreases the total energy requirements from 75,251.14 kWh to 52,484.07 kWh, it is not preferred as an appropriate intervention. And so, Scenario 1 and 2 are both cost and energy-efficient interventions for the selected school building as a case study.

4.2.3 Suggestions about Other Sustainable Interventions for Tekeli Secondary School

In the light of information obtained from the precedent schools in the literature review, some other sustainable interventions are presented below for the refurbishment of Tekeli secondary school in terms of using water, landscape, and materials sustainably.

In addition to the energy-efficient refurbishment of Tekeli secondary school, water-efficient fixtures such as waterless urinals and dual flushing toilets, such as those in Marin Country Day School, could be suggested for water efficient refurbishment. These are not currently required by law for all new school buildings in Turkey, as they are in other countries. Also, Sidwell Friends School could be a useful example of using a rainwater harvesting unit. The rainwater harvesting unit can be embedded under the ground on the north-west side of Tekeli secondary school building, as shown in Figure 4.8, due to its location close to the toilets and could easily be retrofitted to an existing toilet plumbing system. The purpose of this is to reduce the installation cost. The vegetable garden could be arranged on the unit.



Scale: 1/1000

Figure 4.8 The proposed location of the rainwater harvesting unit

According to the formula from the BREEAM guidance (BREEAM, 2015, p. 29), the volume of collectable rainwater is calculated as follows:

$$\sum (A_{RF} \times C \times R_{co\text{-}ef} \times F_{co\text{-}ef} \times D_{col})$$

"A_{RF} = Annual rainfall for the site location (mm)

C = Rainwater catchment area (m^2)

$R_{co\text{-}ef}$ = Run-off co-efficient

$F_{co\text{-}ef}$ = Filter co-efficient

D_{col} = Defined period of collection: x days/365 days" (BREEAM, 2015, p. 29).

Tekeli school has a low-pitched roof. Depending on the type of roof specified for the school, the run-off co-efficient factor could be determined as 0.75 and the filter co-efficient factor could be defined as 0.9 according to BREEAM (2010) Scheme Document. Total rainwater catchment area of the school's roof was calculated as 465 m^2 in the simulation model.

The calculation for Tekeli secondary school:

A_{RF} (1058.3 mm) x C (465 m^2) x $R_{co\text{-}ef}$ (0.75) x $F_{co\text{-}ef}$ (0.9) x D_{col} (1 = 365 days/365 days) = **332,174** l/year. A rainwater collection tank with a capacity of 10,000 litres would be adequate for a ten-day period of collection. Therefore, savings would be achieved on the water bills of Tekeli secondary school, located in a city with lots of rainfall.

As Farina et al. stated in the literature review, the basic water demand is an average of 18 litres per elementary school student per day in case there is no water saving fittings such as dual flush toilets (Farina et al., 2011). So, Tekeli secondary school consumes nearly 2,500,000 L/year water. For around 750 students, the calculated rainwater is not enough to meet the total water consumption in toilets even if there are no shower units. The total predicted rainwater in the case study school could meet approximately 13% of the annual water requirement in toilets, or approximately 10% of the harvested rainwater could be enough for irrigation of the vegetable allotment facility in a 100 m^2 garden for students.

Also, Tekeli secondary school could use water efficiently by integrating water-efficient vacuum-assisted toilets and pressurized reservoirs. The volume of the old system in the toilet reservoirs has a capacity of 8 litres. On average, 750 students consume 2,160,000 litres of water in the toilets over a one-year education period (in case each student uses an 8-litre reservoir in the toilets twice). If dual flush toilets cannot be integrated due to the cost of their implementation, the volume might be reduced by a simple method (i.e., leaving 4 one-litre plastic bottles filled with water in the reservoir). Accordingly, this water-efficient method reduces the water consumption by 1,080,000 litres.

Furthermore, a dripping tap causes a significant water loss. Approximately 6,200 litres of water are wasted in a year because of a dripping tap (Deniz et al., 2012). In order to prevent this, damaged taps should be repaired. Also, school buildings could be refurbished with sensor-equipped armatures to use water efficiently. So, the saving would be 2.25 litres per hand wash for each student (Deniz et al., 2012). In comparison with standard taps, 750 students would consume 607,500 litres less water through water-efficient armatures over a one-year education period (in case each student washes his/her hands twice in a day).

In terms of sustainable refurbishment proposals regarding landscape intervention, St Francis Assisi Academy, which is investigated as precedent school building in Chapter 2, gives the example of arranging vegetable gardens for ecological learning. However, Tekeli secondary school is surrounded by buildings. So, the students' communication with nature has been negatively affected by the lack of green space. The planting of the case study school would allow its students to connect with nature. A vegetable garden could be designed near the rainwater harvesting unit in Tekeli secondary school for the students to learn through experience. Also, evergreen trees might be planted both for shading in the garden and along the school garden wall facing the main street with the purpose of traffic noise screening. Moreover, a green roof to be implemented for insulation could improve energy efficiency.

In this regard, Marin Country Day School has a roof garden to reduce the building temperature and improve thermal performance (Alparslan et al., 2009). According to Kiper et al., the use of vegetation may reduce air temperatures by 6-12 °C in summer. Grass could be preferred as ground covering alternatives to reduce the outside temperature by up to 6 °C (Kiper et al., 2017). As a result, these landscape proposals for Tekeli secondary school could be considered for the refurbishment. A green roof application in addition to the building self-sufficient with PV cells, which is mentioned in the previous section, would especially reduce the energy requirement by providing insulation. Hence, this intervention could reduce the amount of PV cells that would be needed, and hence reduce the initial cost of the second scenario.

For the use of sustainable material, TED Renaissance College could be an example for the renovation of Tekeli secondary school from the aspect of the use of recycled materials and certified wood products. One of the most suitable places for creating awareness about recycling is school buildings. Even though Tekeli secondary school is not completely good enough in terms of meeting the sustainability assessment criteria, has a good recycling program involving the pupils.

Also, the materials used in the refurbishment of the school should be selected in compliance with both human health and nature. In particular, fire resistance, acoustic, and thermal features are essential. Furthermore, the materials whose lifetime is completed should be returned to nature, according to waste management protocols, after the refurbishment. Principally, the lifetime of materials at the existing school building should be extended by repairing and maintaining them. In addition, new materials to be applied for the renovation of interiors should be local and natural. Durable and recyclable materials should be preferred in the design of the learning environments of the case study school.

As an example, Sidwell Friends School, shown in the section ' Precedent Studies of Sustainable School Buildings', utilised recycled materials while renewing the building. Also, Howe Dell Primary School could be a model for adapting renewable energy resources such as wind turbines. In this context, we investigated whether wind energy as an alternative to solar energy can be used in the case study school. Due to its low wind potential, being surrounded by buildings and located in the centre of a dense residential area, it is not appropriate to put wind turbines at Tekeli secondary school. However, they could be recommended for other existing school buildings in Turkey that provide appropriate conditions. The non-simulated interventions are shown in the table below.

Other Sustainable Interventions			
Water	Rainwater harvesting can save 13% of the annual water requirement	Water-efficient dual flush toilets can offer nearly 50% water savings in a year	607,500 litres water can be saved through sensor-equipped armatures
Landscape	Vegetable gardens can be designed for ecological learning Roof garden can be applied to reduce the building temperature and improve thermal performance	As a ground covering, grass can be preferred to reduce the outside temperature and increase the green spaces	According to climatic conditions, plants can be chosen for shading in the garden and traffic noise screening
Material	Materials can be recycleable and recycled after use	Durable and local materials can be preferred for schools	The refurbishment materials can be selected in compliance with both human health and nature

Table 4.6 The non-simulated interventions

Refurbishing Tekeli secondary school sustainably plays a vital role in both protecting natural resources and raising students' environmental awareness. During the refurbishment process, from planning to operation phase, there are many opportunities in terms of developing awareness and observation about sustainability. Students should actively participate in this process. In this regard, active participation of both students and teachers in the design stage of refurbishment work of Marin Country Day School should also be recommended for pupils and educators in Tekeli secondary school. After the refurbishment process, evaluating the opinion of students, teachers, staff and all users involved in the design process and implementing the sustainable criteria through the active participation of them will contribute to planning and organising the curriculum.

4.2.4 Evaluating the Interventions in the Light of Pedagogic Purposes

The active systems used in the intervention scenarios for the refurbishment of Tekeli secondary school building could contribute to environmental education of the students, since the school building as a third teacher or a 3D textbook can raise environmental literacy among young generations for a sustainable future. Some interventions for the school building can strengthen these kinds of environmental activities. For example, rainwater harvesting systems like in Sidwell Friends School and Marin Country Day School could be an integral part of the environmental curriculum so the students are offered an opportunity to learn about the importance of saving water. Furthermore, solar shading not only saves energy but it is also visible for the students because they can see the sun coming in winter and warming the floor. In this regard, the school building as a 3D textbook for environmental education becomes much more accepted.

Additionally, passive ventilation is also visible. When the window is opened, it lets the air through and there is no need to turn on the air conditioner. However, changing the building envelope and windows as major contributors to energy use in buildings generates energy savings and provides a more comfortable learning environment; however, this will be quite invisible as an intervention for the pupils, so it is probably not something that gets built into environmental education. Therefore, the things that make buildings sustainable are often really invisible to the building users, such as insulation in a wall or having a triple glazed window as opposed to double glazed windows. So, these changes themselves cannot serve as a third teacher. In the building as a 3D textbook, the teacher could point at triple glazed glass and feel that it is not cold as double-glazed ones.

In this section of the chapter, building performance simulations have been used to guide energy-efficient refurbishment suggestions for Tekeli secondary school. The advisable model has been recommended for the sustainable refurbishment of Tekeli secondary school. In terms of proposals for water, landscape, and material-efficient interventions, sustainable systems used by the precedent schools have been examined, and suggestions made for their implementation. Finally, the chapter has dealt with the pedagogic aspects of the sustainable interventions for the case study school. The following section offers a proposal about sustainable refurbishment for other existing school buildings in Turkey.

4.3 Sustainable Refurbishment Suggestions for Existing School Buildings in Turkey

Sustainable refurbishment opportunities should be evaluated for existing schools in light of certification systems. The renovation of the building envelope and windows, in addition to changes of in terms of water, landscape, and material efficiency have been presented above as a refurbishment proposal, in accordance with sustainable building certification systems. This section presents suggestions for sustainable refurbishment of existing school buildings in Turkey more generally.

The case study, and the energy performance simulations significantly influence the suggestions presented below to refurbish existing school buildings across the whole region in a sustainable way. Testing proposals using simulation software should be considered for the other schools in terms of improving their energy performance.

There are a lot of K-12 school buildings in Turkey in which a large proportion of the population receive their education. However, most of these buildings are not sustainably designed and therefore consume more energy than necessary. Also, their contribution to the environmental literacy of their students is limited. Refurbishing these buildings sustainably would address these issues and so contribute to Turkey's attempts to reduce carbon emissions and improve the environmental behaviours of the population. However, there are not major developments underway in sustainable school building and school building renovation projects in Turkey, although sustainable architectural studies have received considerable attention, especially for new office buildings and homes.

In this context, sustainable architecture of educational buildings should be given priority over other public buildings, since the foundations of environmental education are based upon them. Therefore, this research is expected to make contributions to fill this gap. Accordingly, even though the country has some sustainable development targets, such as decreasing consumption of fossil fuels and reducing greenhouse emissions by up to 21 percent (Ulucak, 2017), a comprehensive program for sustainable refurbishment of school buildings has not yet been developed in government policy.

The most important reason for not putting any item on the agenda is that the initial costs of sustainable renovation of existing school buildings are high, and the government budget cannot cover this. In addition, policy makers adopt standardised projects as a fast and cost-effective way to build educational buildings for the growing number of K-12 students every year. For example, the Ministry of Education in Turkey built 1740 new schools as a standard project between 2019 and 2020 (National Education Statistics, 2019/20, p. 54). Therefore, there is a requirement for refurbishing K-12 school buildings in line with the principles of sustainable architecture in order to fully achieve sustainable development goals. To meet this requirement, initial costs and payback periods of the scenarios proposed for Tekeli secondary school have been calculated.

Depending on the budget and conditions of the building, these scenarios would be expected to shed light on studies related to sustainable refurbishment of other school buildings in Turkey. Also, the first two proposed scenarios for Tekeli could help decision makers alter their ideas in a positive way, since the work in these scenarios will pay for themselves in less than three years. Gradual refurbishment of the existing school buildings could be considered.

Through this research it has been established that only six K-12 school buildings in Turkey were built according to sustainable building standards, whereas there are more than 68,500 K-12 school buildings designed as standard projects in 2021 (National Education Statistics, 2019/20, p. 54). The refurbishment of the existing educational buildings based on sustainable certification systems such as LEED and BREEAM has great importance on behalf of both environmental literacy, (as shown in Section 2.2.1), and conservation of natural resources. The school building refurbishment proposals stated in the scenarios above employ sustainability principles to increase the building's service life by providing resource efficiency and reducing energy consumption. Additionally, these intervention opportunities could be used in environmental education since the role of school buildings as an education tool is to promote environmental literacy amongst young generations for a sustainable future. The focus of refurbishment proposals is to be able to use all sustainable interventions as an educational tool and integrate the gains obtained from the improvements into the curriculum. For this purpose, the suggestions presented to promote energy efficiency in the Tekeli school building could be a useful model for the refurbishment of other existing unsustainable K-12 educational buildings in the regions which share similar climate conditions with Tekeli secondary school.

4.3.1 Key Suggestions for The Existing School Buildings Having Similar Climatic Conditions with Tekeli Secondary School

This section presents sustainable refurbishment proposals for existing K-12 school buildings in hot and humid climates. The limited government budget for the Ministry of Education[9] is allocated for meeting the education expenditures of existing schools and building new standardised project schools. Therefore, careful step by step planning of the school building renovation work, starting with those buildings which require low-cost sustainable renovation works, and raising awareness of these projects, will increase the possibility of realising a large-scale refurbishment program. As each scenario is realised, existing schools are expected to be improved more sustainably. At the same time, these improvements will contribute to raising environmental awareness among pupils, educators and staff as they actively participate in some activities and follow the renovation steps.

According to different climate conditions in Turkey, appropriate materials for the insulation and window interventions should be selected. Therefore, these principles are applicable across the different climate regions. In terms of building envelope refurbishment, heat loss could be reduced by changing the thickness of insulation materials and types for the schools in different climate regions. By improving K-12 school buildings with insulation compatible with the climatic conditions, building energy requirements should be reduced.

Concerning windows, appropriate solar control elements should be considered in hot climate regions, such as sun blinds, curtains, sunshades, adjustable louvres or light shelves. Also, light shelves for windows may allow classrooms to be illuminated with more natural light. While light shelves get light deep into buildings, they also prevent glare from windows. Thus, natural light is utilised efficiently. Studies on refurbishing existing schools in a sustainable way should be explained with a relation of cause and effect and at a level that students can understand, and they should be informed about this subject. For example, the curriculum could include how much energy can be saved in a year if a school building conserves natural resources and uses renewable energy. Thus, that school building would produce less greenhouse gases through this improvement, and the importance of conserving the environment by combating global warming should be highlighted by posters, information screens, and billboards.

[9] According to 2018 MEB (Ministry of National Education) statistical data, the allocated budget for K-12 education is 92.5 billion. Just 8.36% of this (approximately 7.7 billion) is used for education investments (building new schools, improving existing ones, incentives for adoption of new technologies, etc.) (National Education Statistics, 2018/19).

While the use of renewable energy sources reduces the energy load of the school buildings in Turkey, it is also very important to prevent the problems caused by fossil fuels. More energy could be saved by adapting renewable energy systems such as solar energy, and energy-efficient design strategies. Even if these environmentally friendly energy sources have high initial costs, they provide more energy gains and favourable outcomes in the future in terms of sustainability. In order to refurbish unsustainable K-12 school buildings, both electricity and heat energy could be provided with solar panels located on the south facing roof of the school buildings in order to reduce energy needs by up to 100% (see school building examples from the world). In terms of climate conditions, it is especially expected in hot climatic regions that plenty of sunny days provide a great opportunity and increases the energy gain. In this context, OIB Technical and Vocational High School in Turkey, which is analysed in the Section 2.3.5 and detailed in Appendix J, could be a useful example for refurbishing existing school buildings. Although the sunny days are less in Bursa, 30% energy savings have been achieved by means of solar panels. Also, integrating solar panels achieved 53.27% energy savings at Tekeli secondary school. Moreover, an awareness of the financial gains to be achieved in the first two scenarios proposed for Tekeli secondary school could increase the applicability of the third scenario for the refurbishment of other unsustainable schools in Turkey. In addition, students who monitor the solar panel system through informative screens might learn from the building and gain awareness of environmental protection. Moreover, Manassas Park Elementary School could be a useful model for existing school buildings in Turkey regarding the ventilation system. As a proposal, the curriculum on energy saving might be supported by automated lighting sensors referring to mechanical systems. Also, when pupils get the signal by means of a green light system referred to in Section 2.3.5, the windows are opened by them for natural ventilation. So, they could become aware of the movement of the sun during the day and seasons through daylighting systems.

Water resources existing on Earth are limited. Due to the negative behaviours of human beings, water resources are polluted and our world is facing the danger of desertification. Although the measures to be taken in order to use water resources properly are reflected in the existing science curriculum, the necessary awareness has not been provided yet in the existing K-12 school buildings in Turkey. Environmental education is very important in forming this consciousness. In addition to the materials to be used for this education, the roles of sustainable school buildings as 3D textbook and third teacher offer many opportunities. It is essential to consider these roles when refurbishing existing K-12 school buildings.

When sustainable school examples across the world were examined in the literature review, the methods of using water effectively in a structure could be listed as follows: rainwater harvesting, recycling and reuse, reduction of consumption, and resource conservation. It is an advantage to harvest rainwater in hot climate regions with a high precipitation rate. Rainwater harvesting units should be provided in places where students studying in the existing K-12 school buildings in Turkey can observe rainwater recovery and storage. In this way, the collected water in the tank could be recycled and used for garden irrigation or toilet flushing. Thus, our freshwater resources will be consumed less and natural resources will be protected. Furthermore, maintenance of the existing water and electrical installation should be done. Then, improvement projects should be started by using photocell luminaires, energy-efficient LED lighting equipment, water efficient armatures, vacuum-assisted toilets and pressurized or double-stage flush reservoirs, as suggested for Tekeli secondary school, with the purpose of using water and electricity efficiently. Energy and water savings as a result of these regulations should be shared with students in the school.

The importance of savings should be emphasised for conserving natural resources. The role of the school building as a 3D textbook will thus be started. In addition, irrigating plants in the garden of K-12 school buildings in Turkey with harvested rainwater and learning by experience will be effective in making students environmentally literate and improve their environmental awareness. Therefore, sustainable refurbishment of the existing school buildings gains prominence.

In the investigations of precedent sustainable school buildings, it was observed that these schools provide enough green areas for students' playgrounds and activities. Therefore, cast concrete should not be preferred as the flooring material in the school yards while renovating the existing K-12 schools. This is because the lack of green areas does not allow students to grow food and also it makes the space hotter in summer as it retains heat.

A landscape and choice of plants suited to the local climatic conditions should be recommended. Planting works for the school garden should be organised with the participation of students. In this context, precedent school buildings in Chapter 2 could be followed as a model for refurbishing the other K-12 school buildings in Turkey. As in the example of Assisi St. Francis Secondary School in Liverpool, each classroom could have a separate garden to grow regional plants, and they might be utilised by the students and their families. Also, the school imparts the love of nature to students by allowing them to consume their own vegetables. In terms of proposed efficient landscape design interventions for the existing schools, local plant species that require less water should be preferred according to climatic conditions and local soil conditions. The green area to be designed should address the age groups of children and be ergonomic and creative. By means of planting trees on the north side of the school gardens, the impact of wind from this direction could be reduced. Furthermore, adapting vertical gardens with evergreen plants to the north facing wall of the school building and creating roof gardens provide thermal insulation. In terms of sustainability, the ecological contribution of roof gardens is huge. They could absorb the heat of the summer sun while providing insulation in the winter. Also, they might collect rainwater which can then be cleansed to be used.

According to the analysis of the precedent schools in this research, they have theoretically incorporated environmental education into the curriculum. In addition to the curriculum, the sustainable schools offer the opportunity of practical experience through their designs as well. In this regard, Manassas Park Elementary School and St Francis of Assisi Academy are very useful examples in terms of the sustainability curriculum and might be a key lesson to support the proposals for the existing schools in Turkey. Sustainable schools not only take an important step towards environmental protection by means of an integrated system to convert organic waste but also help students learn through experience. In order to recycle organic waste, a waste recycling unit should be prepared. Collecting areas in the existing K-12 school buildings in Turkey should be created for materials such as paper, glass, plastic, metal, batteries, domestic wastes etc. and artistic activities should be arranged to reutilise waste by recycling. Students can recycle both paper and plastic materials and use recycled products in art workshops. Using recycled materials in creative activities both broaden student horizons and minimise waste. This saves energy and reduces carbon emissions.

Reuse of waste products encourages students' creativity and imagination. This recycling activity is crucial for educating children as environmentally responsible and conscious individuals who react to, think about, discuss, and question environmental problems. Also, seminars should be organized in order to raise awareness of waste management and recycling for the building users (teachers, students, staff, parents). Thus, the school building itself will undertake the role of third teacher about environmental education, in addition to the curriculum.

Also, the school building as a 3D textbook communicates with pupils by conveying messages in regard to its sustainability features. Thus, students could learn that great numbers of trees will not be cut down due to recycled paper and the clean energy used, and that the habitat of living creatures will not be disturbed. Also, they could achieve an awareness that greenhouse gases leading to global warming will be less emitted. The consciousness about environmental protection acquired at an early age will be carried to families and society through students. Pupils should benefit from the built environment for environmental education in terms of considering the 'teaching role' of their educational buildings.

Student-centred planning, in other words, including their projects and ideas, will contribute to their understanding of the purpose of sustainable refurbishment of existing K-12 school buildings. Students who are involved in all processes of school building refurbishment beginning from planning could gain more active learning opportunities beside theoretical information about environmental education and sustainability. While refurbishing existing school buildings sustainably, the school syllabus should be prepared in strong collaboration with pedagogues, psychologists, architects, teachers, education departments, and school communities. The school building itself could serve as a 3D textbook to raise environmentally literate individuals from early ages in order to protect natural resources and prevent environmental problems.

4.4 Chapter Summary

In terms of determining strategies for sustainable interventions aimed at achieving energy-efficient design, the basic level improvement offered building envelope modification, a different glazing type, and LED lighting for the case study school building. Besides, photovoltaic panels were suggested as a next-level improvement. As a final scenario, mechanical heating, cooling, and ventilation were included for Tekeli secondary school. In addition to energy-efficient intervention proposals for Tekeli school building, other suggestions about water, recycling, waste management, efficient landscape design and sustainable materials were offered. Then, the pedagogic aspects of the sustainable interventions for the case study school were presented in the first section of this chapter. The next section dealt with the guiding proposals to improve existing school buildings.

Considering the hot and humid climatic conditions, five insulation materials for the building envelope, which reduce the heating load, provide the best energy savings and performance, and require low cost, were selected to be tested in DesignBuilder. A list of insulation materials examined in the simulation program is attached in Appendix F. Then, an insulation material that reduces the heating load of the building and does not require large budgets to apply was determined by simulating each one separately. Depending on the geographical location and the climate conditions of the school, five different glazing types for the windows of the school building, which minimise the cooling load and harmful effects of the solar rays, were likewise selected to be tested in the DesignBuilder simulation program. Several different options regarding glazing types examined in the simulation program are included in Appendix G. Then, a glazing type that best reduces the cooling load was chosen after simulating each one separately. Simulations of energy efficiency led to the sustainable intervention model of Scenario 1. When the simulation was performed again with the selected insulation used in the envelope, window glazing type, and LED lighting interventions, these improvements provide 49.66% savings in the energy consumption of the case study building. Thus, the use of insulation materials and window components has a significant importance in providing better thermal performance and energy efficiency. In addition to the improvements in Scenario 1, the energy generated by 140 m^2 of solar panels placed on the south-facing roof provides 103.7% savings in Scenario 2. So, the school building would be able to pay for its energy consumption with Scenario 2 and achieve the goal of being a net-zero energy building. In addition to Scenario 1 and 2, the energy consumption would decrease by 30.3% in Scenario 3 when the simulations are revised to include HVAC systems. The government budget allocated to educational buildings available for the refurbishment of K-12 schools in Turkey is limited. Therefore, the third scenario is not recommended as a sustainable refurbishment proposal for these schools. Although sustainable buildings have been constructed in recent years, the practices of sustainable school architecture are not sufficient. Therefore, the proposal presented as three separate scenarios will be essential for refurbishing existing educational structures in terms of cost in the long term.

The research study evaluated how much energy might be saved through the interventions without using high-cost and energy-efficient systems. In this context, this thesis made the recommendations for the interventions having minimum energy consumption. Accordingly, the expenses would be recompensed quickly. Scenario 1 amortises its expenses in 2.9 years, while Scenario 2 pays for its initial costs in 6.6 years. However, the payback time of Scenario 3 takes many years. Therefore, Scenario 1 and 2 are more likely to be implemented since a quicker payback period is a crucial factor in the decision to undertake the refurbishments.

In addition to energy performance improvements, harvesting rainwater and using greywater recovery are recommended for sustainable refurbishment in terms of water-efficient interventions. In this context, approximately 13% of savings were provided by harvesting rainwater in the case study school. It has been emphasised that this proposal could be used for the renovation of all existing K-12 schools, particularly in areas with a lot of rainfall. Also, it has been proposed to improve the case study school and similar schools' faucets and reservoir systems to use water efficiently.

Regarding material-efficient interventions, using natural, recyclable, non-toxic and local materials would be a sustainable approach for the refurbishment of Tekeli secondary school and the existing K-12 schools in similar climates. Also, special storage areas should be designed for recycling waste. Then, the use of recycled paper and plastic materials in artistic activities will enable students to understand the significance of recycling while increasing their creative skills.

Moreover, it has been highlighted in terms of landscape efficient interventions that pergolas and shadow areas should be arranged for hot climatic conditions in the open areas where students spend their spare time and more green playgrounds should be created to allow them to interact with nature.

Furthermore, sustainable refurbishment of existing K-12 school buildings should be considered in terms of environmental literacy as mentioned in Section 2.2.1. Improving playgrounds sustainably or providing more green areas stimulate productivity and creativity in students. By considering these suggestions, the sustainable school playground will act as a 3D textbook. The sustainable school building itself contributing to learning about environmental issues will serve as a teacher with practical applications in the environment. Preparing birdhouses in trees for birds and providing opportunities for students to grow vegetables and fruits with harvested water can be given as examples.

While students are gaining environmental consciousness by observing sustainable school architecture, environmental activity opportunities offered by the building contribute to their environmental literacy. In addition, each student-centred and environment-friendly refurbishment practice should be added to the curriculum to be explained in classrooms and learning environments and thus, raising awareness should be ensured among students by indicating cause and effect relationship between the necessity of refurbishment and the benefits to be obtained as a result of it. Although students develop their knowledge about the environment and ecology through books and the curriculum, learning through environmental observation is important in terms of being environmentally literate individuals. Children's environmental consciousness is conveyed to their parents, and so society is informed about the environment.

In conclusion, this chapter dealt with the proposals for sustainable refurbishment of Tekeli school and other existing schools in Turkey. The Ministry of National Education should refurbish old schools instead of building new ones, due to the limited budget allocated to the public-school buildings. Also, they should consider the role of school buildings as teaching tools in environmental education through refurbishment. In this context, the three-scenario proposal and the other suggestions on the sustainable landscape, water, and material presented in this chapter has provided a prototype for refurbishing the existing case study school building and could be adapted to other K-12 school buildings in Turkey which have similar climatic conditions. Considering the cost of renovation, the decision-makers should prefer implementing the most convenient of the three scenarios. Accordingly, the first two scenarios have been proposed for the case study in this thesis concerning the cost of refurbishment. Work schedules for refurbishment projects should be arranged without interrupting education or educational activities and programs in the school term. So, it would be possible to do the refurbishments proposed for Tekeli and other K-12 school buildings in the summer break, but the planning period of the improvements should be undertaken before the closing of schools in order to obtain students' ideas about efficient space usage.

The next chapter will conclude the thesis. Chapter 5 summarises the findings and contribution to knowledge and covers the potential directions of this research in the future.

CHAPTER 5

CONCLUSION AND DISCUSSION

This final chapter presents a conclusion after the suggestions about the sustainable refurbishment of existing school buildings in Turkey. Then, it includes a discussion on the contribution of this research project to the literature and knowledge. It ends with key recommendations for future research.

As Abdiraimov (2016) stated in the literature, humans believed that nature automatically renews itself and ignored the preservation of the environment (Abdiraimov, 2016, pp. 30-31). However, the reports and research on the environment showed that environmental problems have increased and this renewal will not happen by itself. The increase in the level of environmental awareness of people throughout the world (Kaya, Cobanoglu and Artvinli, 2011) could be a solution of this problem. To prevent environmental problems encountered today, creating environmental awareness in society is essential. The urgency of the current climate emergency suggests a many stranded approach needs to be adopted. One of these strands is environmental awareness, but educating people takes some time. So, it may be too late to take action to reduce the impacts of climate change. From this point of view, this thesis aimed to look at implementing two interconnected things—raising environmental awareness and making buildings sustainable. The best place to gain this awareness is the learning environment.

Adopting the concept of sustainability in schools all over the world is significant in terms of the future of the environment and the world. Educational buildings can act as a catalyst by aiming to ensure sustainability through the powerful sphere of influence they have. In the literature review of this research study, the precedent school designs from different countries and climatic zones that have high scores according to the certification systems, their sustainability criteria, and adaptable features have been investigated. The certification systems do not have a category about environmental education for buildings' users. While creating a sustainable building evaluation system for educational buildings, the use of the school building as a pedagogical tool or the integration of the school building into the environmental education curriculum should also be considered as a category. Architects should consider this category to promote environmental literacy of users of buildings while applying their projects. Moreover, it was determined during the literature review that developments regarding sustainable architecture in Turkey mainly deal with offices and homes, but have not focussed on educational structures yet. In this context, the research study investigated the sustainable refurbishment possibilities for existing K-12 school buildings. It is important to emphasise this approach of the thesis that investigates the energy-efficient refurbishment of Tekeli secondary school was investigated through a simulation study. The refurbishments in this study were suggested for a single school, Tekeli Secondary School, as a representative standard school building in Turkey. However, sustainable refurbishment proposals can be developed to improve schools in different climate zones. Also, this study explored the role of school design as a 3D textbook or third teacher and determined its effectiveness to improve the environmental awareness, behaviour, attitude, and observation among K-12 school students. The reviewed literature and the analyses of the precedent schools indicate that sustainable school buildings can have the role of teaching as a 3D textbook. According to Tasci (2015), Shapiro (2016), Taylor and Enggass (2009), the physical environment and its elements could be used as a teaching and learning tool (Tasci, 2015; Shapiro, 2016; Taylor and Enggass, 2009). Sustainable schools foster continuous learning for the users of the school building. The authors such as Boca and Saracli (2019), Timur et al. (2013), and Collado et al. (2020) provided substantial evidence; assertions based on them support that schools should integrate environmental education with the curriculum. As the literature review indicates, schools should benefit from their sustainable feature when teaching the curriculum. For instance, the roof gardens in the precedent sustainable schools can be used as a teaching tool. Also, the students studying in these schools are aware of environmental issues since their schools have informed them about solar panels. Hence, students studying in these schools could be educated as environmentally literate individuals from a very early age.

The research has been completed and successfully found the answers to all the research questions. To clarify, the existing literature in the field of sustainable school architecture and about precedent school buildings from around the world was reviewed to answer the first research question “Which features of sustainable schools in the world could be adapted to the existing school buildings in Turkey in order to improve their energy performances?”. So, the refurbishment proposals suggested for Tekeli secondary school in the light of sustainable design principles of the precedent school buildings have enabled the wider application to other schools in Turkey. Then, the second research question “How can existing K-12 school buildings in Turkey be refurbished sustainably considering the criteria of sustainable building certification?” gave this thesis a clear focus. As a result of this, the sustainable principles of refurbished schools which can be adapted to existing schools were determined by taking the criteria of sustainable building certification systems into consideration. The energy-efficient refurbishment of Tekeli secondary school was evaluated through building energy performance simulations. Sustainable renovation suggestions were offered for other K-12 school buildings in Turkey. The third research question “How can the sustainable refurbishment of school buildings in Turkey contribute to their students’ environmental literacy?” was answered with an extensive literature review. The studies testing the effects of the building itself on the environmental literacy of its students have been investigated. Also, it has been determined through the precedent school analyses that sustainable schools include environmental education in their curricula and give importance to environmental literacy.

The foundations of this research study consist of the contribution of the built environment to pedagogy through sustainable refurbishments. The two-stranded approach of the study covers energy intervention. Due to its user-interface that is used most commonly and reduces potentially incorrect inputs and the convenience it provided in the modelling process, of several alternative building energy simulation software tools, DesignBuilder simulation software program was used to evaluate the energy performance of Tekeli Secondary School before and after the proposed interventions. First of all, the existing energy consumption of Tekeli secondary school was calculated through a simulation study. Then, it was compared with the annual energy bills. As a result of this, the case study school was calculated to consume 75,251.14 kWh energy in a year. As a result of surveys, research, and simulations, energy intervention proposals were offered as three scenarios for the refurbishment of existing school buildings under sustainability criteria, and the payback periods were calculated. In the first scenario (S1), 49.66% of the total energy consumption of the building was recovered in the simulation. The scenario included improving the performance of the window glazing and building envelope and integrating LED lighting. These intervention steps were chosen due to the ease of application and lower cost. According to the energy performance analyses for Scenario 1, **Insulation 4** (stone wool) and **Opening 2 (**double glazing with louvres) were offered as appropriate intervention types for hot and humid climatic conditions.

In the second scenario (S1 + S2), the school building would be able to pay for its total energy consumption with Scenario 2 and achieve the goal of being a net-zero energy building. The combined improvements cover both building envelope and adding solar panels. The installation cost and energy savings of using photovoltaic panels are determined after the total surface area of the case study building's roof was calculated. Thanks to a large number of sunny days in Antalya, the second scenario focuses on photovoltaic solar panels in addition to Scenario 1 to benefit from daylight and reduce energy consumption. Solar panels were located on the south-facing roof of the school building in order to make the best use of solar radiation and prevent overshadowing. According to the energy requirements, the appropriate surface area of the solar panel was determined to be 140 m^2. So, the energy generated by the solar panels provided 103.7% savings in energy performance simulations of Scenario 2.

Then, the last scenario (S1 + S2 + S3) incorporated HVAC systems to improve thermal comfort and energy efficiency. In addition to Scenario 1 and 2, the requirement for the energy consumption of the school building decreased by 30.3%, when the simulations were performed with mechanical heating, cooling and ventilation systems. Then, the initial costs and the payback periods of the scenarios were calculated. Accordingly, scenario 1 amortises its expenses in 2.01 years, while Scenario 2 pays for its initial costs in 4.24 years. However, the payback time of Scenario 3 is very long. A quicker payback period would be a crucial factor in the decision to undertake the refurbishments. Therefore, the first two scenarios are appropriate but the third scenario is not suggested as a sustainable refurbishment proposal for other K-12 schools in Turkey due to both requiring a higher budget and providing lower energy gain.

The DesignBuilder simulations of the case study school in this thesis suggested that sustainable refurbishment of existing K-12 school buildings provides a decrease in the amount of energy consumption (kWh) and savings in total energy consumed. So, CO_2 released to the atmosphere is reduced.

In terms of convenience and cost, this research mainly focuses on energy-efficient interventions but in general, suggestions have been offered about other intervention titles such as material, water and landscape. In addition to the energy intervention, the amount of rainwater that can be harvested within a year has been calculated by determining the surface area of the roof and using meteorological data for Antalya. As a water-efficient improvement proposal, it has been suggested that a rainwater collection tank with a capacity of 10,000 litres for a ten-day period of collection can be embedded under the ground on the north-west side of Tekeli secondary school building due to its location close to the toilets where it can easily be retrofitted to an existing toilet plumbing system. In this context, approximately 13% of savings would have been provided by harvesting rainwater in the case study school. Therefore, savings would be achieved on the water bills of Tekeli secondary school, located in a city with lots of rainfall. Then, general sustainable design principles of precedent school buildings were offered to improve existing buildings in terms of material and landscape.

Considering the existing situation regarding school buildings in Turkey, it is clear that the new K-12 school buildings have not been constructed according to sustainable criteria and certification systems, except for just six sustainable K-12 school buildings as mentioned in Chapter 3. Duplicating standardised schools without meeting sustainable school building criteria has negative effects on the performance of learning environments and their users. Besides, environmentally friendly designed schools are necessary to educate students in a more comfortable environment and to protect natural resources. The proposals made for Tekeli Secondary School are also applicable to other K-12 educational buildings in similar climatic conditions of Turkey. Also, sustainable interventions should be integrated into the existing standard K-12 school buildings with the least change, the most rational solutions, and the minimum budget, before the end of life of the structure. Achieving more sustainable schools could give a chance for their students to develop environmental awareness and internalise the concept of sustainability. As part of the proposed Turkish, or indeed any, school refurbishment or new construction programme, there must be a consideration of potential pedagogic activities using the newly refurbished or built school buildings, otherwise the benefit of improved environmental literacy will be missed. Any improvements to the building should be accompanied by activities designed for students. This also implies that even in a school building which itself is not very sustainable, environmentally focussed activities can still be conducted with the students. Therefore, this research study contributed to the studies claiming that there is a relationship between the built environment and pedagogy.

Furthermore, this research has shown through energy performance simulations that designing sustainable school buildings by renovating existing ones and managing them sustainably is cheaper than managing schools built as standard projects. Thus, the government and national education should adopt the proposals in this study and do planning in light of them to both improve existing buildings sustainably and use sustainable school buildings as pedagogical structures. Refurbishing existing schools could bridge the gap between architecture and environmental literacy by embracing educational issues in sustainable design. Part of the conclusions of this research indicates that existing school buildings should be renovated by considering their role in pedagogy. In this regard, these two important contributions—improving energy performance and encouraging environmental education—along with a strategy for using the improvements as pedagogical tools would create an advantage in obtaining the necessary government funding for such refurbishment of a school.

One of the significant targets of this project is to link sustainable refurbishment strategies with the sustainability curriculum and educational outcomes. Thus, school buildings could act as a laboratory in terms of practical experiences in the efficient use of materials, energy, and water. The environmental education curriculum must be developed and applied during the K-12 school period. The integration of the curriculum will raise awareness of children about the built environment that they live in and use, and contribute to the protection of the environment. High-performance sustainable schools, designed as 3D textbooks, are important in shaping the youth's consciousness about sustainability as a general life concept. Today's environmentally conscious children are tomorrow's adults. Therefore, the Ministry of National Education in Turkey should develop an environmental policy to improve the existing school buildings and introduce environmental literacy by combining the curriculum with sustainability practices. Joint improvement projects, standards, regulations, and guidelines generated by architects, pedagogues, researchers, and the Ministry of National Education could increase the number of sustainable schools.

In terms of both curriculum and school architecture, environmental education is essential for a sustainable future. The suggestions presented in this research may not be a complete solution to achieve sustainable refurbishment of K-12 educational buildings, but they could be a proper action to take and emphasise the importance of integrating environmental education with sustainable architecture. The experiences of the case study schools shared in this research demonstrate that the suggested proposal could be a convenient method to refurbish existing school buildings and to acquire the necessary knowledge, behaviour, attitude, and awareness for sustainable education.

5.1 Contribution to Knowledge

While reviewing the literature, it was determined that there is a limited number of studies that examine the effects of sustainable school architecture on environmental literacy. In identifying this gap in the hybrid field of sustainable architecture and environmental education, this study emphasises the need for more field research in this area, so that future sustainable schools (both new and refurbished) can better contribute to the environmental literacy of their students. It serves as a catalyst for further academic research on sustainable architecture and education.

This research project brings together two different fields covering the refurbishment of existing school buildings sustainably and improving the environmental literacy of students through sustainable schools. The knowledge generated through the study could be beneficial for researchers in many different disciplines involving environmental literacy, environmental education, sustainable architecture, and environmental psychology.

Additionally, the reviewed literature and the precedent school analyses have indicated that sustainable approaches for the built environment contribute to improving students' environmental awareness by offering them an opportunity to experience environmentally friendly activities. Therefore, it is important to refurbish existing school buildings sustainably. Besides, the pedagogic processes that might use the sustainable school building as a 3D textbook or third teacher should be combined with the design phase of the building (new or refurbishment), rather than considering this to be a separate activity that take place once the building is finished as this will miss opportunities for teaching. Thus, this thesis study has contributed to a gap in the fields of sustainable architecture and education.

During the planning process for the sustainable improvement of the K-12 school buildings, a working group of government officials, school staff, and teachers, bringing their expertise in pedagogy should prepare some proposals for architects. Through these proposals, an increase in the contribution of educational buildings as a third teacher or 3D textbook to pedagogy could be realised. Thus, the architects and design team should also provide visible techniques for sustainable refurbishment projects in order to increase the opportunity to learn by experience. This research serves as an indicator of the contribution of architectural elements to pedagogy. In this regard, this thesis provides a very useful piece of knowledge that careful thought must be given to how the school building can be used for environmental pedagogy. Therefore, the proposal is always to link the building construction and design to the pedagogy. So, a proposal coming out of this thesis is that Turkey should adopt legislation on a "sustainable schools programme" that must consider pedagogy as much as it does building performance, and implement it gradually. This is not something that is limited to Turkey but could be applicable everywhere.

In the case study work, the notion of who/what is “active” in the learning opportunities presented by the sustainable school building is particularly important. The current literature suggesting that there is some causal connection between the sustainability of the school building and the environmental literacy and behaviour of its students is only borne out if either the building or teacher is actively "teaching" the lessons of the sustainable building features. In this context, sustainable refurbishment works of existing schools can enhance students’ behaviour and provide consciousness about the efficient use of water, energy, and resources. Thus, pupils are able to communicate with their friends and families, having the potential to drive sustainable development through social behaviour.

Since the presented proposal does not require high cost, this essential research is a guiding light for developing countries with high populations to sustainably refurbish K-12 school buildings. Also, this thesis makes a great contribution to the difficulty and complexity of sustainable renovation for K-12 educational buildings.

5.2 Recommendations for Future Studies

For further studies, some practices could be recommended in light of the findings of the present research. Principally, the results of the thesis are valid only for the schools which took part and could be generalised for similar K-12 schools in the same climates. To understand the potential link between sustainable school building and environmental literacy, i.e. the role of school buildings as a third teacher or 3D textbook, more fieldwork could be done. More case study schools in different climate conditions could be investigated. Replicating this research with more K-12 school buildings from different regions would be attractive. It is possible to carry out such a study on an international scale by seeking variations and similarities. The next stage of this research could be to determine environmental literacy of students by applying a questionnaire before and after refurbishment of a specific school and to compare the impact of the teaching role of school buildings on their environmental literacy, so that the impact of this single change could be evaluated. This way, the success of a project could be measured not only in the energy, water, etc. savings after refurbishment, but also the impact on the education (environmental and otherwise) of its pupils. Further studies investigating the refurbishment of existing school buildings and the role of sustainable buildings as a tool for environmental education are essential to develop the knowledge of this field. Moreover, the findings of this research will shed light on improving existing school buildings and designing sustainable schools in the future. For further research, the interventions could be expanded to include alternative renewable energy sources.

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APPENDICES

This section includes a number of supportive information relevant for this thesis. The contents of appendices are as follows:

APPENDIX A: THE AIMS AND WEIGHTINGS OF BREEAM

BREEAM's Aims

The aims of BREEAM are (BREEAM, 2008):

- 'To mitigate the impacts of buildings on the environment,
- To enable buildings to be recognised according to their environmental benefits,
- To provide a credible, environmental label for buildings,
- To stimulate demand for sustainable buildings' (BREEAM, 2008, p. 9).

- **The BREEAM Credit Weightings**

- BREEAM assesses the performance of buildings in the following key areas:

- 'Management: Overall management policy, commissioning site management and procedural issues.
- Health and Wellbeing: Indoor or external health and wellbeing.
- Energy: Operational energy and carbon dioxide issues.
- Transport: Transport related carbon dioxide and located – related factors.
- Water: Consumption and water efficiency.
- Materials: Environmental implication of building materials, including life – cycle impacts.
- Land Use and Ecology: Green fields and brown fields sites and ecological value conservation and enhancement of the site.
- Pollution: Air and water pollution issues' (BREEAM, 2008, p. 9).

APPENDIX B: THE AIMS OF LEED

- **LEED’s Goals**

- The aim of LEED rating systems is to promote a transformation of the construction industry through strategies designed to achieve seven goals:

- 'To reverse contribution to global **climate change,**
- To enhance individual **human health** and well-being,
- To protect and restore **water resources,**
- To protect, enhance, and restore **biodiversity** and ecosystem services,
- To promote sustainable and regenerative **material resources** cycles,
- To build a **greener economy,**
- To enhance social equity, environmental justice, **community** health, and quality of life,
- These goals are the basis for LEED's prerequisites and credits' (LEED, 2019a).

APPENDIX C: COMPARISON OF LEED AND BREEAM

	LEED	**BREEAM**
General	√	√
Energy-saving		√
Preparation of building user manual	√	√

Reuse of land and rehabilitated land	√	√
Separation of waste recycling areas in operation	√	
Green area maximization	√	
Reduction of heat islands	√	
Electro-mechanical systems		
Systematic commissioning	√	√
Minimum lightening levels		√
Lightening comfort items	√	√
Fresh air levels	√	√
Thermal comfort items	√	√
Observation of energy consumption	√	√
Reduction of light pollution	√	√
Encouraging the use of off-site renewable energy	√	
Use of renewable energies in the field	√	√
Saving on water		
Water-saving vitrification	√	√
Leak sensors		√
Water-saving landscape use	√	
Observation of water consumption	√	√
Environmental pollution		
CO_2 emission reduction calculations		√
Prevention of pollution during construction	√	√
Calculation of ecological value of land		√
(continues on next page)		
Reduction the effect of heat-transfer fluids on the ozone layer	√	√
Reduction of NOx emissions		√
Reduction of the impact of insulation materials on global warming		√
Reduction of flood risk	√	√
Material		

Selection of sustainable materials	√	√
Selection of recycled materials	√	√
Reuse of building skeleton and shell	√	√
Supply of local materials	√	
Human health and welfare		
Acoustic performance		√
Use of low volatile organic compound material	√	
Daylight applications and glare prevention applications	√	√
High frequency lighting		√
Prevention of indoor air pollution	√	√

Table A1. Comparison of LEED and BREEAM

Compared with the LEED building assessment system, BREEAM is the oldest example among the other building assessment systems. Although LEED has separate versions for primary building types like new construction, interiors, shell, the variety in the version of BREEAM is more than the LEED system has – in number. This is an advantage of BREEAM on LEED, as it covers a broader view in this sense. However, BREEAM concentrates on many different building types. But this complexity of BREEAM makes LEED the most user-friendly and simple building assessment system among other systems. In comparison to the assessment categories of LEED system, BREEAM has more categories that concentrate both on the social and technical aspects of sustainable design. But this creates some disadvantages as more categories mean more data to collect and could create a complexity for the design team.

APPENDIX D: INFORMAL LISTS OF BREEAM AND LEED BASED ON THE OBSERVATION

	Credit Description	Possible Points	Achieved
Management	Commissioning	**2**	0
	Considerate Constructors	**2**	0
	Construction Site Impacts	**4**	0

	Building User Guide	**1**	0
	Site Investigation	**1**	0
	Consultation	**1**	0
	Shared facilities	**1**	0
	Security	**1**	0
Health & Wellbeing	**Credit Description**	**Point**	**Achieved**
	Daylighting	1	0
	View Out	1	0
	Glare Control	1	0
	High frequency lighting	1	0
	Internal and external lighting levels	1	0
	Lighting zones and controls	1	0
	Potential for Natural Ventilation	1	0
	Indoor Air Quality	1	0
	Volatile Organic Compounds	1	0
	Thermal Comfort	1	0
	Thermal Zoning	1	0
	Microbial Contamination	1	0
	Acoustic Performance	1	0
Energy	**Credit Description**	**Point**	**Achieved**
	Reduction of CO2 Emissions	15	0
	Sub-metering of Substantial Energy Uses	1	0
	Sub-metering of High Energy Load and Tenancy Areas	1	0
	External Lighting	1	x
	Low or Zero Carbon Technologies	3	0
	Building fabric performance and avoidance of air infiltration	1	0
	Cold Storage	1	0
	Lifts	2	0
	Escalators and travelling walkways	1	0
Transpor	**Credit Description**	**Point**	**Achieved**
	Provision of Public Transport	3	x
	Proximity to amenities	1	x

	Cyclist Facilities	2	0
	Pedestrian and Cyclist Safety	1	0
	Travel Plan	1	0
	Maximum Car Parking Capacity	2	0
Water	**Credit Description**	**Point**	**Achieved**
	Water Consumption	3	0
	Water Meter	1	x
	Major Leak Detection	1	0
	Sanitary Supply Shut Off	1	0
Materials	**Credit Description**	**Point**	**Achieved**
	Materials Specification (Major Building Elements)	4	0
	Hard Landscaping and Boundary Protection	1	0
	Re-Use of Facade	1	0
	Re-Use of Structure	1	0
	Responsible Sourcing of Materials	3	0
	Insulation	2	0
	Designing for Robustness	1	x
Waste	**Credit Description**	**Point**	**Achieved**
	Construction Site Waste Management	4	0
	Recycled Aggregates	1	0
	Recyclable Waste Storage	1	0
	Compactor / Baler	1	0
	Composting	1	0
	Floor Finishes	1	0
Land Use & Ecology	**Credit Description**	**Point**	**Achieved**
	Reuse of Land	1	0
	Contaminated Land	1	0
	Ecological Value of Site and Protection of Ecological Features	1	0
	Mitigating Ecological Impact	2	0
	Enhancing Site Ecology	3	0
	Long Term Impact on Biodiversity	2	0
P	**Credit Description**	**Point**	**Achieved**

	Credit Description	Point	Achieved
	Refrigerant GWP – Building Services	1	0
	Preventing Refrigerant Leaks	2	0
	Refrigerant GWP – Cold Storage	2	0
	NOx emissions from heating source	3	0
	Flood Risk	3	0
Innovation	**Credit Description**	**Point**	**Achieved**
	Innovation	10	0

Table A2. Informal evaluation of the existing school building according to BREEAM Education criteria.

	Credit Description	**Possible Points**	**Achieved**
Sustainable Sites	Site Selection	1	0
	Development Density & Community Connectivity	5	x
	Brownfield Redevelopment	1	0
	Alternative Transportation: Public Transportation Access	6	x
	Alternative Transportation: Bicycle Storage & Changing Rooms	1	0
	Alternative Transportation: Low-Emitting & Fuel-Efficient Vehicles	3	0
	Alternative Transportation: Parking Capacity	2	0
	Site Development: Protect or Restore Habitat	1	0
	Site Development: Maximize Open Space	1	0
	Storm water Design: Quantity Control	1	0
	Storm water Design: Quality Control	1	0

	Heat Island Effect: Non-Roof	1	0
	Heat Island Effect: Roof	1	0
	Light Pollution Reduction	1	0
Water Efficiency	**Credit Description**	**Point**	**Achieved**
	Water Efficient Landscaping	4	0
	Innovative Wastewater Technologies	2	0
	Water Use Reduction	4	0
Energy & Atmosphere	**Credit Description**	**Point**	**Achieved**
	Optimize Energy Performance	19	0
	On-site Renewable Energy	7	0
	Enhanced Commissioning	2	0
	Enhanced Refrigerant Management	2	0
	Measurement & Verification	3	0
	Green Power	2	0
Materials & Resources	**Credit Description**	**Point**	**Achieved**
	Building Reuse: Maintain Existing Walls, Floors, Roof	3	x
	Building Reuse: Maintain Interior Non-structural Elements	1	0
	Construction Waste Management	2	0
	Materials Reuse	2	0
	Recycled Content	2	0
	Regional Materials	2	x
	Rapidly Renewable Materials	1	0
	Certified Wood	1	0

	Credit Description	**Point**	**Achieved**
Indoor Environmental Quality	Outdoor Air Delivery Monitoring	1	0
	Increased Ventilation	1	0
	Construction Indoor Air Quality Management Plan During Construction	1	0
	Construction Indoor Air Quality Management Plan Before Occupancy	1	0
	Low-Emitting Materials: Adhesives & Sealants	1	0
	Low-Emitting Materials: Paints & Coatings	1	0
	Low-Emitting Materials: Flooring Systems	1	0
	Low-Emitting Materials: Composite Wood & Agrifiber Products	1	0

	Indoor Chemical & Pollutant Source Control	1	0
	Controllability of Systems: Lighting	1	0
	Controllability of Systems: Thermal Comfort	1	0
	Thermal Comfort: Design	1	0
	Thermal Comfort: Verification	1	0
	Daylight & Views: Daylight	1	0
	Daylight & Views: Views	1	0
Innovation in Design	**Credit Description**	**Point**	**Achieved**
	Innovation in Design	5	0
	LEED Accredited Professional	1	0
	Credit Description	**Point**	**Achieved**
Regional Priority	Regional Priority	4	x

Table A3 Evaluation of the existing school building according to LEED for Schools (2020) criteria.

APPENDIX E: ENERGY CONSUMPTIONS FOR THE HEATING AND COOLING

MEASURED IN SIMULATION PROGRAM BEFORE THE INTERVENTION

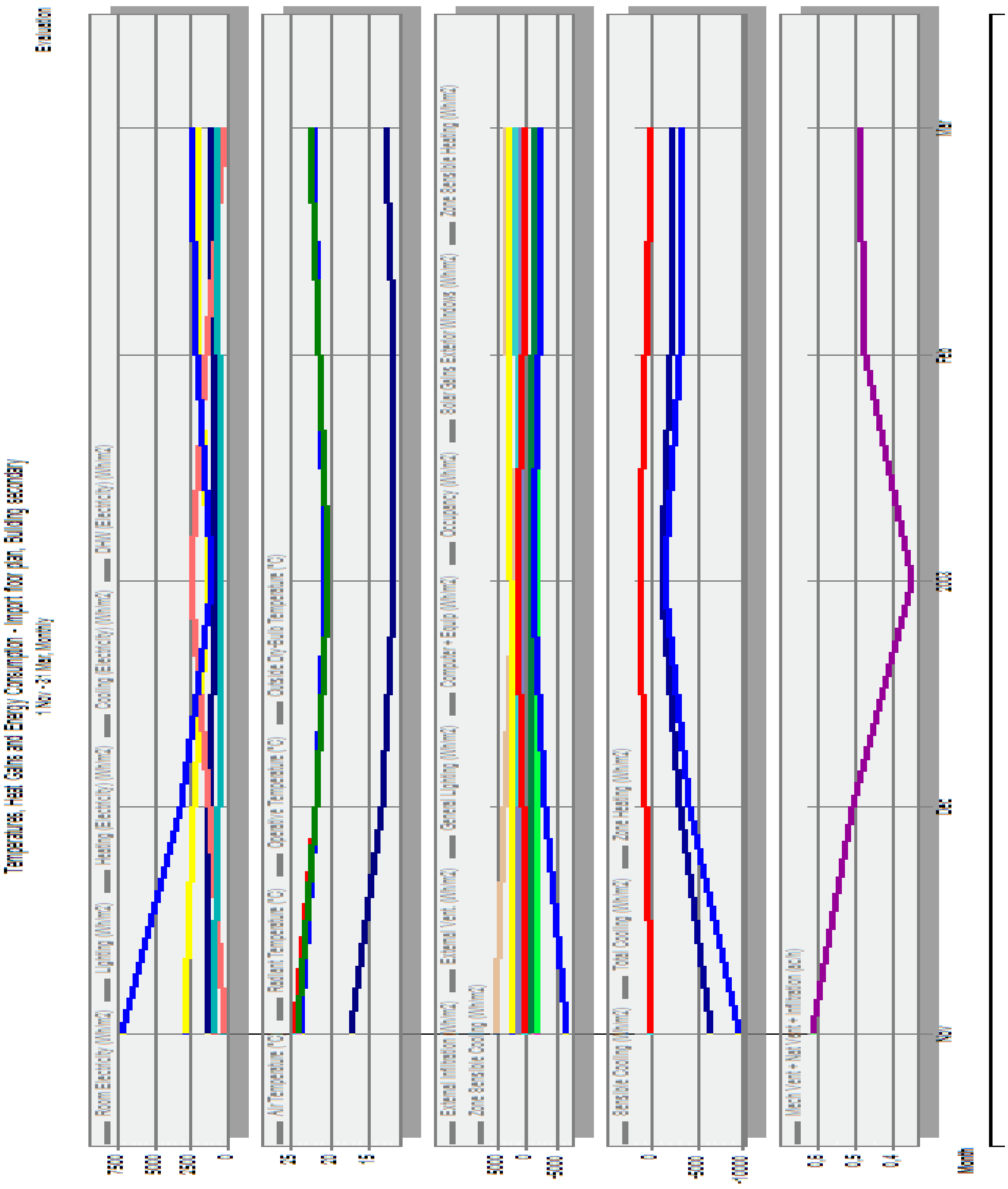


Figure A1 Energy consumption for the heating before the intervention

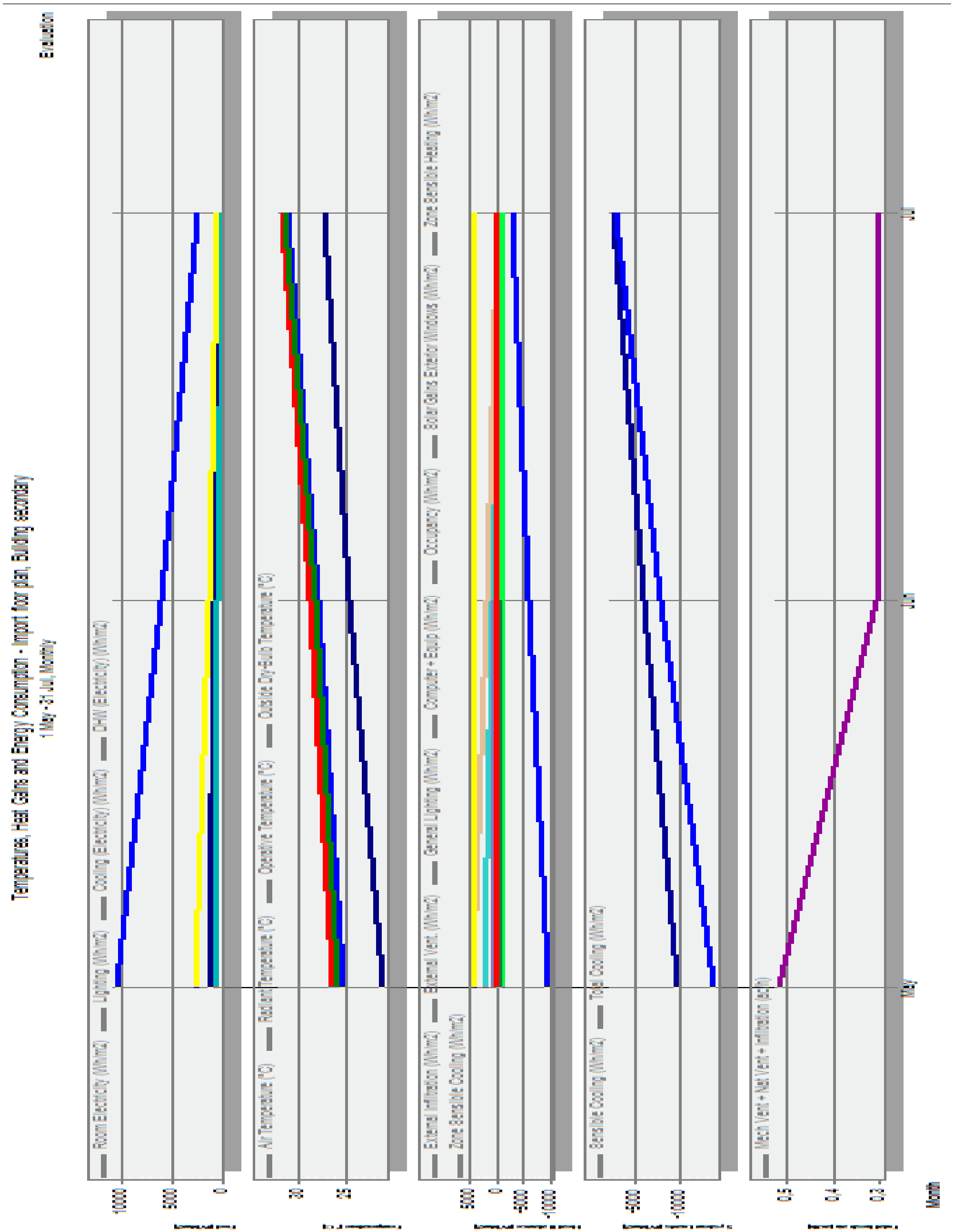
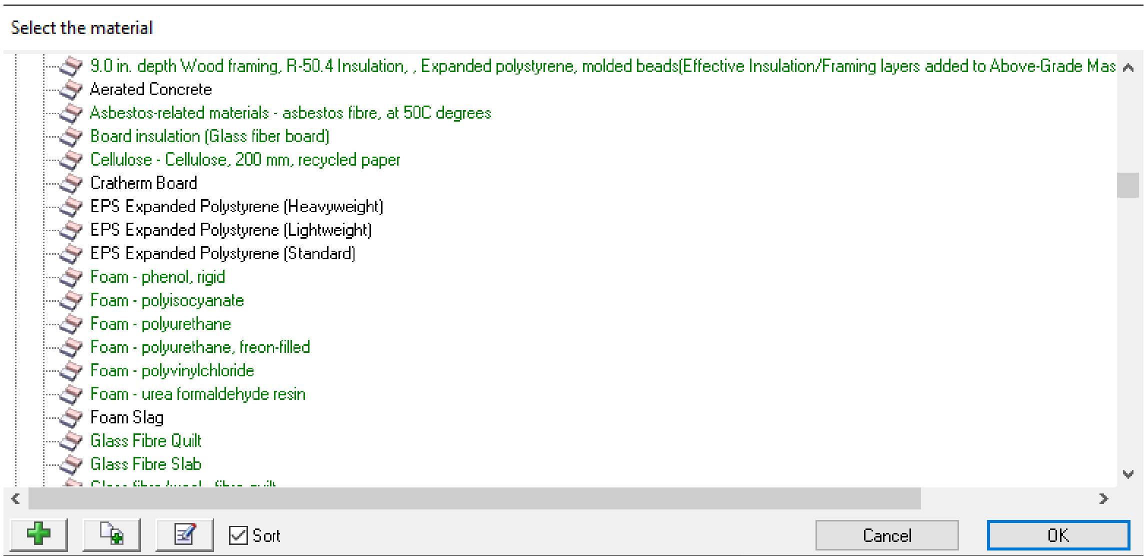


Figure A2 Energy consumption for the cooling before the intervention

APPENDIX F: A LIST OF INSULATION MATERIALS EXAMINED IN THE SIMULATION PROGRAM



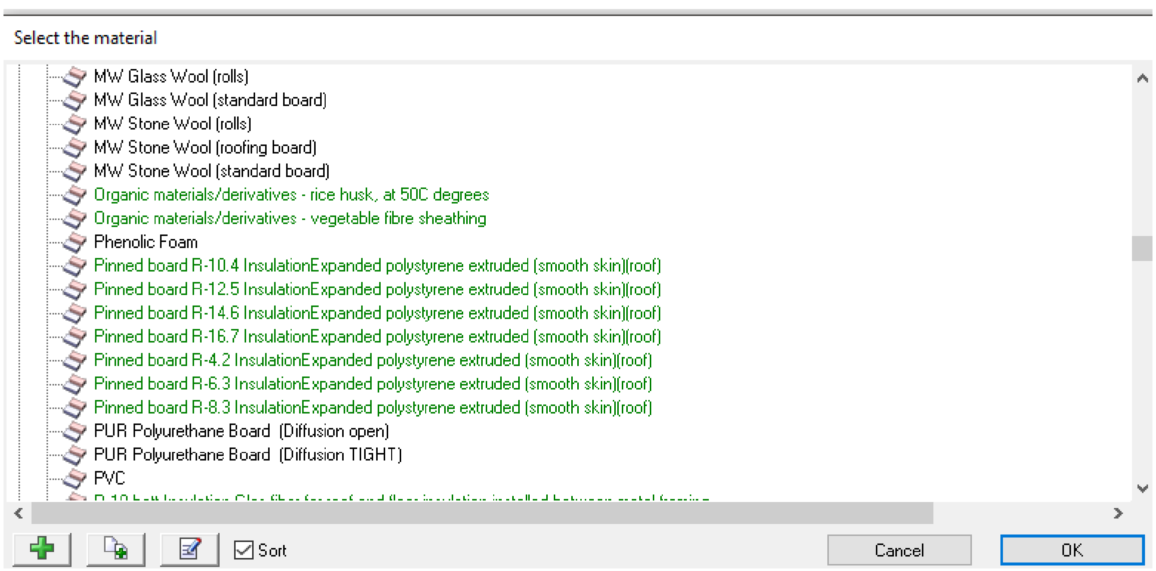
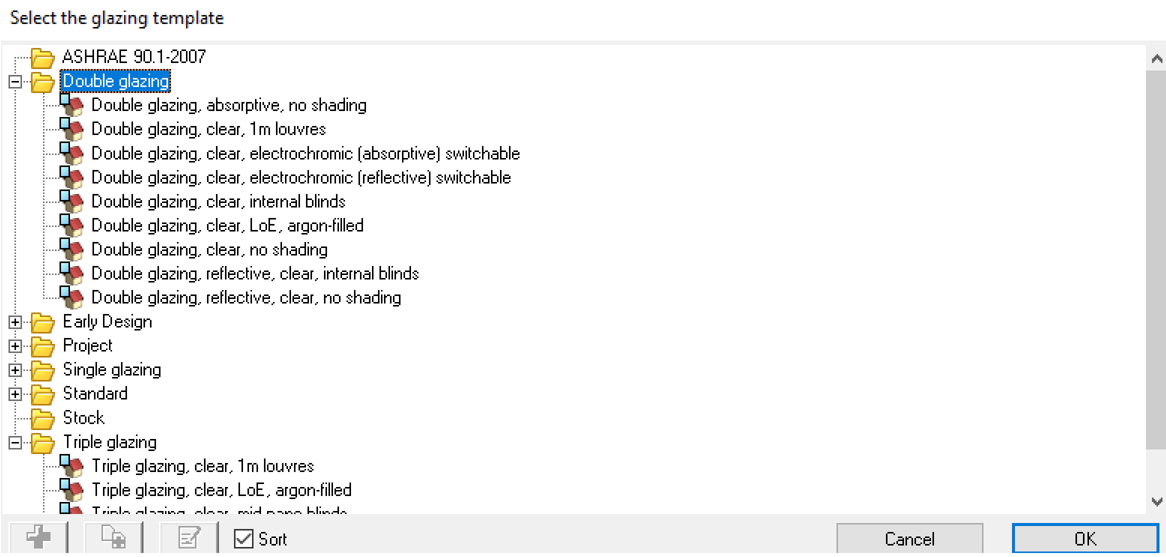


Figure A3 A Number of Insulation Materials in the Simulation Program

APPENDIX G: A NUMBER OF DIFFERENT OPTIONS REGARDING GLAZING TYPES EXAMINED IN THE SIMULATION PROGRAM



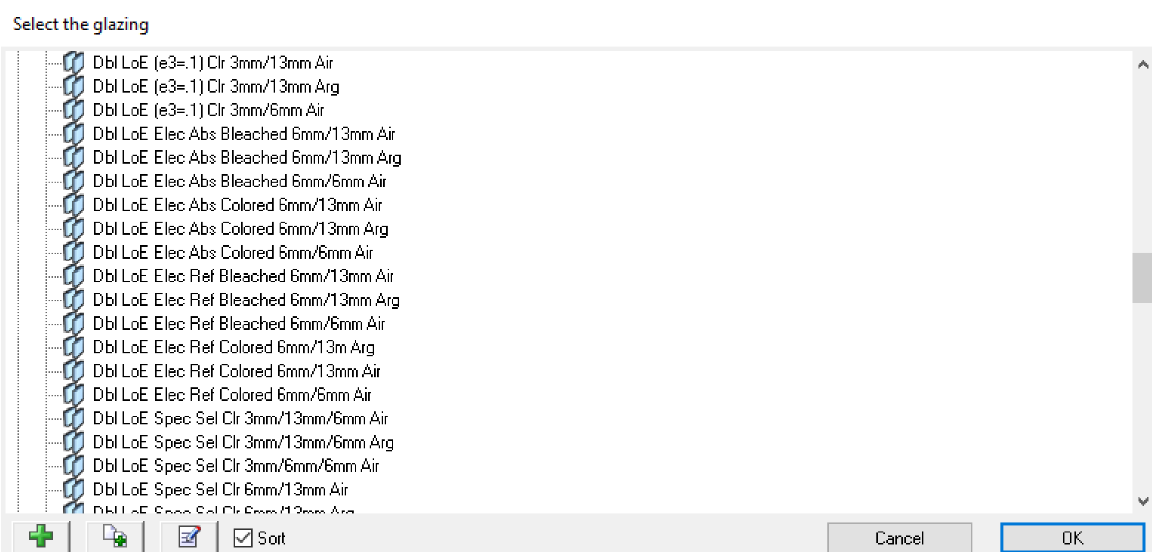


Figure A4 A Number of Glazing Types in the Simulation Program

APPENDIX H: BREEAM CERTIFICATION of OIB TECHNICAL and VOCATIONAL HIGH SCHOOL

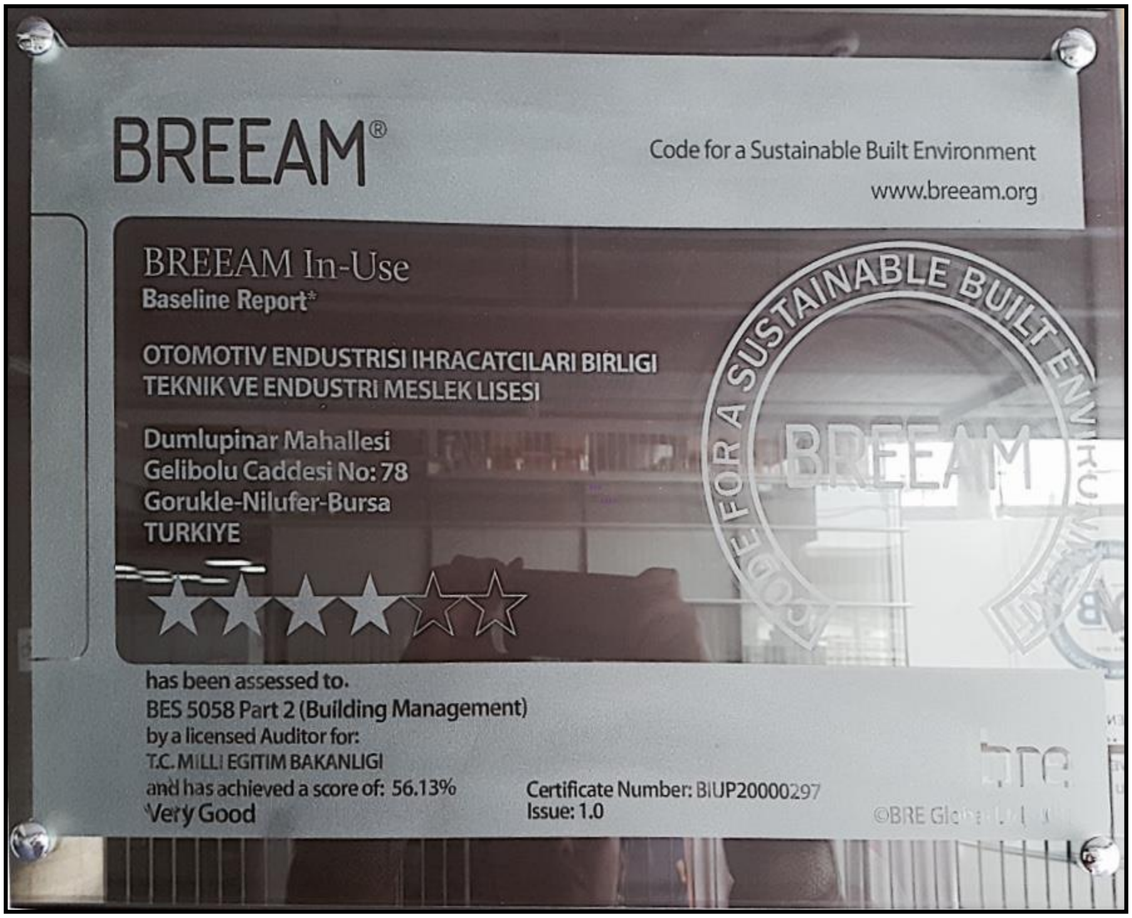


Figure A5 The photograph of the BREEAM certification taken by the author

Source: Author

APPENDIX I: LEED CERTIFICATION SCORES OF TED RENAISSANCE COLLEGE

1000031093, Istanbul, Istanbul

TED RONESANS KOLEJI

LEED BD+C: Schools (v2009) — **GOLD, AWARDED MAY 2014**

SUSTAINABLE SITES		AWARDED: 18 / 24
SSp1	Construction activity pollution prevention	REQUIRED
SSp2	Environmental site assessment	REQUIRED
SSc1	Site selection	1 / 1
SSc10	Joint use of facilities	1 / 1
SSc2	Development density and community connectivity	4 / 4
SSc3	Brownfield redevelopment	0 / 1
SSc4.1	Alternative transportation - public transportation access	4 / 4
SSc4.2	Alternative transportation - bicycle storage and changing rooms	1 / 1
SSc4.3	Alternative transportation - low-emitting and fuel-efficient vehicles	2 / 2
SSc4.4	Alternative transportation - parking capacity	2 / 2
SSc5.1	Site development - protect or restore habitat	0 / 1
SSc5.2	Site development - maximize open space	1 / 1
SSc6.1	Stormwater design - quantity control	0 / 1
SSc6.2	Stormwater design - quality control	0 / 1
SSc7.1	Heat island effect - nonroof	1 / 1
SSc7.2	Heat island effect - roof	1 / 1
SSc8	Light pollution reduction	0 / 1
SSc9	Site master plan	0 / 1

WATER EFFICIENCY		AWARDED: 8 / 11
WEp1	Water use reduction	REQUIRED
WEc1	Water efficient landscaping	2 / 4
WEc2	Innovative wastewater technologies	2 / 2
WEc3	Water use reduction	4 / 4
WEc4	Process water use reduction	0 / 1

ENERGY & ATMOSPHERE		AWARDED: 11 / 33
EAp1	Fundamental commissioning of building energy systems	REQUIRED
EAp2	Minimum energy performance	REQUIRED
EAp3	Fundamental refrigerant Mgmt	REQUIRED
EAc1	Optimize energy performance	6 / 19
EAc2	On-site renewable energy	0 / 7
EAc3	Enhanced commissioning	2 / 2
EAc4	Enhanced refrigerant Mgmt	1 / 1
EAc5	Measurement and verification	2 / 2
EAc6	Green power	0 / 2

MATERIAL & RESOURCES		AWARDED: 6 / 13
MRp1	Storage and collection of recyclables	REQUIRED
MRc1.1	Building reuse - maintain existing walls, floors and roof	0 / 2
MRc1.2	Building reuse - maintain interior nonstructural elements	0 / 1
MRc2	Construction waste Mgmt	2 / 2
MRc3	Materials reuse	0 / 2
MRc4	Recycled content	2 / 2
MRc5	Regional materials	2 / 2
MRc6	Rapidly renewable materials	0 / 1
MRc7	Certified wood	0 / 1

INDOOR ENVIRONMENTAL QUALITY		AWARDED: 10 / 27
EQp1	Minimum IAQ performance	REQUIRED
EQp2	Environmental Tobacco Smoke (ETS) control	REQUIRED
EQp3	Minimum acoustical performance	REQUIRED
EQc1	Outdoor air delivery monitoring	0 / 1
EQc10	Mold prevention	1 / 1
EQc2	Increased ventilation	1 / 1
EQc3.1	Construction IAQ Mgmt plan - during construction	1 / 1
EQc3.2	Construction IAQ Mgmt plan - before occupancy	1 / 1
EQc4	Low-emitting materials	0 / 4
EQc5	Indoor chemical and pollutant source control	1 / 1
EQc6.1	Controllability of systems - lighting	1 / 1
EQc6.2	Controllability of systems - thermal comfort	1 / 1
EQc7.1	Thermal comfort - design	1 / 1
EQc7.2	Thermal comfort - verification	1 / 1
EQc8.1	Daylight and views - daylight	0 / 3
EQc8.2	Daylight and views - views	1 / 1
EQc9	Enhanced acoustical performance	0 / 1
EQpc123	Designing with Nature, Biophilic Design for the Indoor Environment	REQUIRED
EQpc124	Performance-based IAQ design and assessment	REQUIRED

INNOVATION		AWARDED: 5 / 6
IDc1	Innovation in design	4 / 4
IDc2	LEED Accredited Professional	1 / 1
IDc3	The school as a teaching tool	0 / 1

REGIONAL PRIORITY		AWARDED: 4 / 4
EAc1	Optimize energy performance	1 / 1
EAc3	Enhanced commissioning	0 / 1
EAc5	Measurement and verification	0 / 1
WEc1	Water efficient landscaping	1 / 1
WEc2	Innovative wastewater technologies	1 / 1
WEc3	Water use reduction	1 / 1

TOTAL 62 / 110

40-49 Points	50-59 Points	60-79 Points	80+ Points
CERTIFIED	SILVER	GOLD	PLATINUM

Figure A6 LEED scores of Ted Renaissance College

Source: http://www.cevredostu.com/yesilbina/ted-ronesans-koleji/

APPENDIX J: THE DETAILED PRECEDENT STUDIES of SUSTAINABLE SCHOOL BUILDINGS

This section presents seven sustainable school building samples from around the world, which have high scores in either LEED or BREEAM certification systems. It first introduces five sustainably built schools. Two of them have been chosen from Turkey as they have similar building materials, techniques and technologies, and climatic conditions to the main case study school (Tekeli Secondary School) and the existing knowledge and skills of the people in the construction industry are relevant. Then, two important examples of sustainable renovation of an existing school building is examined at the end of this section. When the sustainable school examples were examined, it was seen that it is possible to find more information about new school buildings. But data on sustainable refurbishment of school buildings are limited and only for reduction of energy costs in general. So, this section also investigates two examples which have sustainable adaptations including both sustainable practices and energy reduction in detail.

In this study, educational buildings are identified for detailed research into the key drivers which contribute to delivering sustainable design and energy efficiency features which can be adapted to existing school buildings are investigated. At the same time, instances where these precedents use the buildings for pedagogic purposes will be highlighted. Therefore, the overall reason for doing precedent studies is to learn lessons from existing buildings that might be useful for improving the existing school in Turkey. Things learned from these precedent school buildings are also about how they might be used as a pedagogic tool. Accordingly, this section combines aspects of the preceding two sections – environmental education and sustainable design – to examine how both have been deployed at a series of precedent study projects.

So, successful sustainable school building examples around the world will shed light on this project in terms of adaptable architectural features and act as key precedents to inform the direction of the proposed changes that are tested in the thesis. These precedent studies will focus on the aspects of the projects most relevant to the thesis, and will be drawn upon when making proposals for improvement to the main case study school (Tekeli Secondary School).

This section presents the most relevant features to be adapted in each of these precedent studies, and then summarises other sustainability features. Finally, the use of each school building as an educational tool is pointed out.

1- St Francis of Assisi Academy

The first of these five schools is St Francis of Assisi Academy in Liverpool, UK, designed by Capital Percy Thomas and completed in 2006. It is a secondary school with a capacity of approximately 900 students and 100 staff. It has an excellent rating in BREEAM assessment.

This school was mainly chosen for its rainwater harvesting system because it can be a useful model to adapt for the case study school, which has the potential to collect rainwater in terms of climatic conditions. An area of roof in the concrete building was planted with sedum as shown in Figure A7 (left). Rainwater is harvested from the roof. In this way, a 5,000-litre tank within the building supplies the toilets. Digital monitors display the amount of water collected (Wilkinson, 2008). Both a green roof and rainwater use for toilets are applicable for Turkish climatic conditions because the average amount of annual precipitation in the area where the school is located is over 1000 mm (MGM, 2021) and relatively similar to the average amount of annual precipitation in Liverpool (The Met Office, 2020). As the area in Turkey receives a lot of rainfall during winter months, harvested rainwater could be stored and used for toilet flushing in dry months. Also, the roof of the main case study school can carry approximately a 5,000-litre tank. So, the way in which this school uses rainwater can help to integrate such a system into the refurbishment proposal.

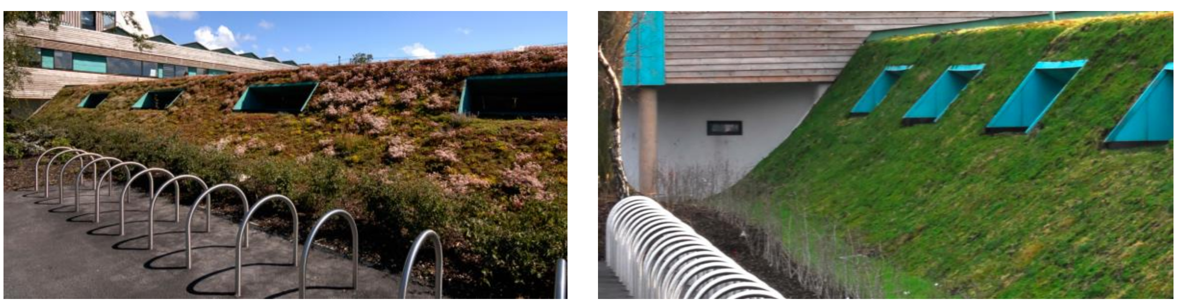


Figure A7 Green roofs (Fira Landscape Architecture, 2017).

Additionally, the school employs a range of different sustainable building design systems (SEED, n. d.). For example, it has photovoltaic panels on the roof that provides 5% of the electricity demand in winter and 10% in summer. In addition, the natural light of the building is provided through a north-facing atrium (see Figure A8), which allows north facing daylight into the classrooms. Since north light does not bring about solar gain and glare, it is better for even lighting and for studying. This would be also relevant for the main case study project to avoid direct sunlight in a hotter climate. Natural ventilation and movable shading are also used to prevent overheating, i.e., tinted or reflective glass or fixed shading devices for summer period.

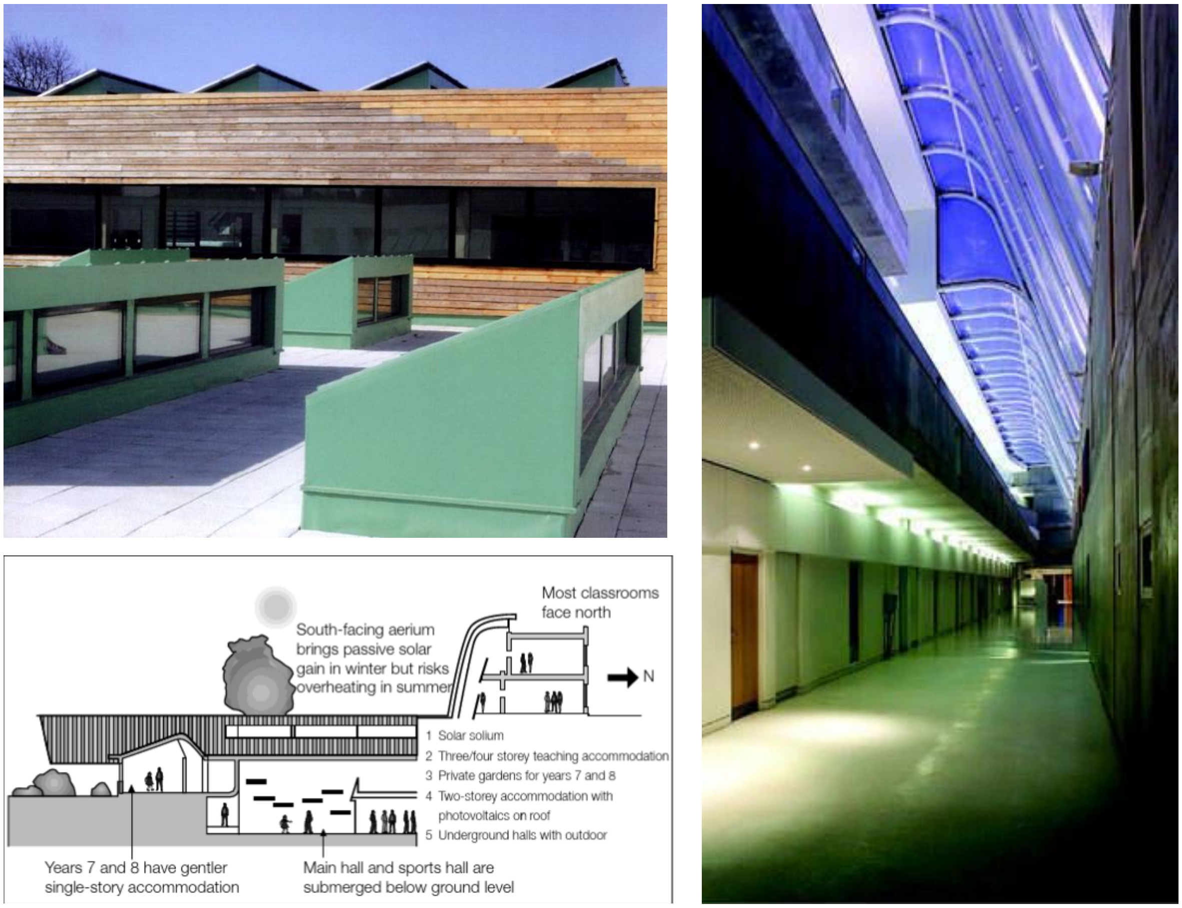


Figure A8 North facing atria (Smith, 2016) (above left); North-south section of the school (DfES, 2006; Smith, 2016: 113) (below left); Translucent roof (Design Build Network, 2007) (right)

Finally, the academy has a particular emphasis on environmental issues and is very proactive in engaging students with sustainable issues and encouraging positive behaviours. Teachers guide students to comprehend the reason why sustainable development is important and older students share their knowledge with younger ones. Also, the curriculum in the precedent schools encourage a software interface enabling students to understand the environmental systems and observe generating energy by solar panels. Students studying in these schools can be informed about the energy consumption and generation by the monitor. In this way, the school building as a teaching tool is used within the curriculum, meanwhile students could see how much saving in water and energy consumption they provide through the monitors in the building actively teaching. Also, students have been encouraged to design a sustainable travel plan as part of the curriculum. Moreover, year 7 students grow food and plants in the school garden and this activity is integrated into their lessons (Dauncey, 2009). The school incorporates environmental issues into the curriculum and its pedagogic focus is environmental. So, it is a useful example on behalf of the integration of sustainability and school architecture.

2- Howe Dell Primary School

Howe Dell Primary School located in Hatfield, UK was designed by Capita Ruddle Wilkinson and built in 2007. The primary school has nearly 450 students. When it was built, it was one of the most sustainable educational building in the United Kingdom (Smith, 2016). Therefore, the school building has been awarded as BREEAM "Excellent"- rated school.

The primary school has renewable energy technologies such as solar panels and a wind turbine to generate electricity. Also, a heating system (Interseasonal Heat Transfer), which is a form of GSHPs, is utilised in order for passive gain and heating by using lots of water pipes embedded in the asphalt surface of the school playground (Georgiou, 2016). Solar collectors transfer heat via water circulation. In case solar hot water systems on the roof generate the extra heat in hot summer times, it is conducted to the inter-seasonal heat store. Warmed water pipes by the sun in the storage heats the school in winter. This system saves nearly 50 per cent of the CO_2 emissions. Howe Dell primary school is examined as a precedent study to learn about examples of solar energy technologies for electricity via photovoltaics and heat via solar hot water, and their use. As a primary lesson learned from this school, integrating solar energy systems would be relevant to the case study school, which has a potential to generate electricity energy from the sun via photovoltaics and whose roof and climatic conditions are available for the installation of solar panels. This is also a simple and local technology that has a common use in Turkey so there are people who know how to install it and know how to maintain it. A secondary lesson learned from this precedent is to have a rainwater harvesting system. This system collects water to use for toilet flushing or irrigation. A green roof planted with sedum absorbs some of the rainwater (Aras, 2019), and the other part of the rainwater is collected through a rainwater harvesting system. Thus, harvested rainwater in the school is used for toilet flushing. Any surplus is utilised for irrigating the garden. Rainwater can be collected in the gap between paving stones. So, Howe Dell Primary School was selected to be examined as a sample school for these criteria.

Figure A9 Solar panels in the school (Bonehill, 2016).

Additionally, the primary school does not only provide a learning environment for students, but also is a good example of sustainable buildings since it incorporates robust sustainable strategies. For example, the school building has the green roof, which contributes to thermal insulation through their elements such as plants and soil (Aras, 2019). Therefore, the roof of the school provides energy efficiency both for heating in winter and for cooling in summer (Aras, 2019). A green roof system could be applicable for Turkey because the roof and climatic conditions of the case study school are available for the installation. Moreover, high performance windows reduce heat loss. The school building utilises daylight efficiently. In addition, it is constructed with sustainable, local, and low impact materials such as wood from natural sources and recyclable materials.

Finally, the school building is used as an educational tool in the curriculum. For example, students studying in this school are growing their own foods and plants. While they are picking the vegetables and fruits, they learn the growth process and have a chance to connect with nature. This is a really useful lesson to learn from this building.

Figure A10 Gardening club

(Howe Dell Primary School, n. d.)

The students can also observe the harvesting rainwater process in the open-air classroom on the roof. So, children learn about sustainability by means of bringing nature into their classroom. There is also a software interface which enables children to observe the environmental systems, how rainwater is being stored. An easy to use and access software interface allows students to monitor the environmental systems like renewable energy (Smith, 2016). These screens help students understand how energy has been generated by the sustainable systems. So, sustainable features of the school raise their awareness and provide them to comprehend the results of their actions. Moreover, the curriculum is organised according to sustainability principles. For instance, children learn how to use recycled materials such as yoghurt pots for sink tops (Bonehill, 2016), old mobile phones as a reception desk and drainpipes for the library counter. They have a chance to learn recycled and local materials that were used in the school design so the building serves as a 3D textbook. Lessons such as art, science, history and geography are integrated into sustainability issues. Also, the green roof offers students an opportunity to observe birds as part of the curriculum.

3- Manassas Park Elementary School

Manassas Park Elementary School located in Virginia, USA was designed by VMDO Architects and built in 2009. The elementary school has nearly 800 students and 60 teachers. It also has a LEED Gold certification. It is the first construction achieved the sustainable building certification in Manassas Park city with the first recycling and green cleaning program (Wordsworth, 2010). While the school was building, all existing trees were protected and some of them were transported to the surrounding of the playgrounds through tree spades. Ecological diversity was also enhanced with native species (The Centre for Green Schools, 2010).

This school was mainly chosen for its ventilation system because its “green lights” notification system could be a proposal for the main case study school. The system determines which type of ventilation is needed to according to the weather conditions. Natural ventilation is utilised for cooling in case the temperate climate conditions are convenient. Vertical ventilation ducts on the manually operable windows provide fresh air (Figure A11). “Green lights” notify favourable conditions (Figure A12). The lights are connected to a weather-predictive mode in the building automation system. Children are actively involved in energy conservation through the signal lights. This means that a green light comes on when the weather is suitable for natural ventilation, and the lights tell the students to open the windows. In case the weather is not convenient, mechanical ventilation becomes involved (Barr, 2011; AIA, 2017). This school is a good example for Tekeli Secondary School, whose natural ventilation is insufficient. It has been chosen because of having a mixed system and making this system observable especially by the students.

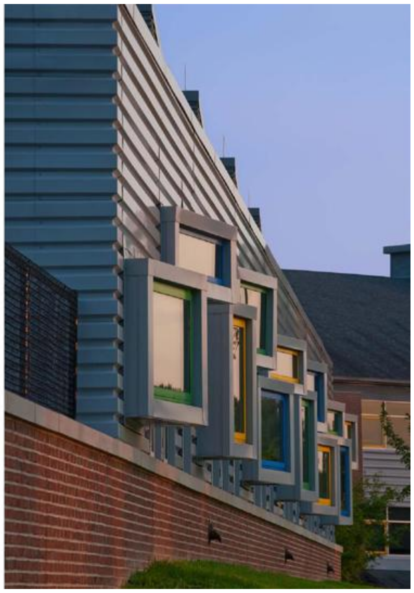


Figure A11 Operable windows (AIA, 2017)

Figure A12 The school has a signage program teaching sustainable building systems (Solaripedia, n. d.)

Additionally, the elementary school has a number of different sustainable features. For example, there is a rainwater harvesting system on the roof with a 79,000-gallon storage. The treated water is delivered to the building flushing fixtures and the rest is reassessed for irrigating the landscape (LEED, 2019b). Also, efficient fixture and lamp selections and occupancy-controlled light switching contribute to savings (ASHRAE, 2006: 3). It was tested through energy modelling when cooling, ventilation and lighting were used most intensively and this showed that the building consumed nearly 50 % less energy compared to operating in the first year (Barr, 2011). Moreover, the building envelope of the school was insulated with polyurethane foam to achieve energy efficiency. In addition, the sloped ceilings in the classrooms provide natural light entering through the light louvres. Daylighting in the learning spaces and classrooms is optimised. For this purpose, three houses including classrooms facing north and south were built. Big trees on the west shade the three-storey educational houses. “Closed” spaces such as gym, loading dock, mechanical rooms were planned on the east side in order to prevent excessive solar heat gain. Besides, a glare-free teaching wall is used (ASHRAE, 2006). Furthermore, healthy and low-emitting materials were used in the school design and flooring materials require less maintenance (LEED, 2019b). Brick in the construction is durable, has local and cultural significance in the area. There are 20% recycled materials in the project. Moreover, 75% of construction waste was diverted from the landfill (AIA, 2017).

Finally, the school as a pedagogic tool guides students to environmental stewardship. The school curriculum is supported with sustainable design features (AIA, 2013). Every detail in the school design has been considered as an educational opportunity. Educational signboard informs about the daylight harvesting strategies and promotes students to develop conservation behaviours. Real-time building performance data is able to be monitored by students through a green screen in the school's main entrance. Occupants could access all information online. The screen explains energy, water data and sustainable features of the school building. Moreover, the outdoor area serves as a learning classroom and also is an informal gathering area for teachable moments about sustainable building systems facts. For example, this sustainable school building teaches students lessons about cultivating the vegetables in the garden as shown in Figure A13 (Long, 2011). The elementary school also has a "Family Market" program providing fresh and high nutritional value foods for students and their families.

Figure A13 Manassas Park Elementary School, Virginia (AIA, 2017)

The local ecosystem was used in a didactic manner. As AIA stated, "outside environment was brought inside of the building. The school is organized into three "houses". Each house is extensively themed around a season. Each classroom is named after a species commonly found in that season and place. In this way, children correlate their classrooms with plants and animals rather than numbers" (AIA, 2017).

4- OIB Technical and Vocational High School

OIB Technical and Vocational High School located in Bursa, Turkey was designed by MartiD Architecture and built in 2010. The high school has nearly 720 students. It also has a BREEAM Very Good certificate. Arkitera stated that "OIB Technical and Vocational High School was recognised in December 2012 as the first public building in its field and the first and only educational institution to earn a Green Building Certificate" (Arkitera, 2016). BREEAM Certification of this school can be seen in Appendix H.

Figure A14
Turkey's First and only Educational and Public Building with BREEAM "very good" Certificate

In terms of adaptable sustainable architectural features to existing school buildings in Turkey, this learning environment might be a useful case study for the PhD research. For example, the school generates its own energy needed by means of solar systems on the roof. Also, unnecessary use of electricity and water is prevented by smart sensors. In order to use less water and reduce the water bills, self-closing taps and dual-flush toilets are used. According to the bills obtained from the school archive, the average savings in water and electricity consumption were reduced 30% as a result of these implementations.

Additionally, the high school building is appreciated for its harmony with green pattern, the topography, and other environmental aspects (Singhal, 2013). Also, there is a small garden behind the school to grow foods for personnel and the students staying in the dormitory.

Finally, the school has pedagogic roles. For example, students could collect their garbage and separate them as paper, plastic, organic, non-recyclable, metal and batteries by the help of the recycle bins. In order to teach the students about the sun and solar energy, students are also encouraged to be responsible for using electricity energy efficiently. Students are informed about electricity power generation from solar panels, while working principles of the system is being explained.

Figure A15 Recycle bins

Although there were lessons about the environment and the environmental activities were integrated into the curriculum in the past, but now social clubs are taking on this task according to the annual plan and social activities regulations.

Figure A16 Planting activity in the school

Also, there are recycling activities encouraging the students in the school. The school has a zero-waste project for recycling that Ministry of Education and Ministry of Environment and Urbanisation has started.

The school organised an award ceremony for the students, teachers and staff who contribute to recycling most in the context of zero-waste project. They were rewarded with cloth bags with the school logo.

Figure A17 The image indicating the ceremony

In addition, parents, teachers and staff are involved in environmental education. They could find a chance to discuss the subjects in the curriculum about raising environmental awareness.

Figure A18 An example of environmental education for teachers and parents

5- TED Renaissance College

TED Renaissance College located in Istanbul, Turkey was designed by Hatirli Architecture and built in 2013. The secondary school has approximately 1200 students. It is the first private school in Turkey to achieve LEED Gold Certificate. LEED Certification Scores of the school can be seen in Appendix I.

Figure A19 The school building and its garden

This school was mainly chosen for its solar panels because they generate electrical energy and provide the hot water to use in the school. Nearly 30 percent energy-savings are achieved. Also, **u**sing water-efficient fixtures, reservoirs, and efficient irrigation systems for the landscape designed with local plants provide 50 percent savings in water consumption (Renaissance Holding, 2018).

Additionally, the school has many environmental features. For example, the learning areas were designed to get maximum advantage of daylight (Renaissance Holding, 2018). Also, all wood products used in the school design was legally sourced from sustainably managed forests. Bamboo covering materials, which are able to renew itself in a very short time, were also preferred rather than oaken coating materials renewing itself in many years (see Figure A20). Recycled timbers as a building materials were used during the construction phase, and the wastes were sent back to recycling. Teachers often remind students in lessons that recycled materials play a part in the building construction process. Moreover, students could learn the features and environmental performance of the school building and their impacts on the environment in environment clubs.

Figure A20 The use of bamboo material in the interior design

Moreover, students grow local foods and observe the growth of the seeds planted in the school garden by gathering all the year and then collect their fruits and vegetables.

Figure A21 Growing activity from TED Renaissance College.

Finally, there are other lessons learned from the school as a teaching tool. The design of each space supports environmental consciousness. For example, students could benefit from daylight by means of big window sizes and learn to use renewable sources instead of electricity energy.

They learn that the bigger window size means the more daylight and energy saving, while their teachers emphasising the renewable energy resources and fields of usage in lessons. In addition, the environmental activities performed by the students in the curriculum strengthen their ties between the school building and the environment. The rainwater harvesting activity with buckets in the school garden teaches the issue of water cycle in the curriculum them practically. Also, they understand the importance and the function of the rainwater collection unit. Students participate in the studies and presentations planned by the committee within the framework of National Education curriculum. As the whole school, they removed the paper cups used in water dispenser and have started a project called “bring your own water bottle”. TED Renaissance School also adopts the zero-waste project. Students have different waste boxes in the corridor in order to sort their garbage as plastic, paper, glass, metal, organic, non-recyclable, and etc. Students and teachers who are the members of the Eco-School Committee share the information about awareness activities throughout the education year.

Figure A22 Art activities from the recyclable materials.

In terms of workshop activities, students exhibit their creative works that they have produced in the visual arts lessons throughout the year. The products are created from recyclable materials which they collect.

6- **Sidwell Friends Middle School**

Sidwell Friends Middle School in Washington, USA was built in 1950 and refurbished in 2006. It was designed by Kieran Timberlake Associates. The middle school has nearly 350 students. Its campus includes adding a new building (54%) and refurbishing the main building (46%) (AIA, n. d.). The refurbished middle school building is the first K-12 school in the United States to have a LEED Platinum rating and the first LEED Platinum building in the District of Columbia for its environmentally sensitive features and innovative sustainable technologies.

Figure A23 General view of the school (GreenShape, n. d.)

The original middle school was expanded and reused in the refurbishment project. This school, which has an integrated design with old and new, was mainly selected for the improvements of its windows and building envelope because it refurbished its building envelope energy efficiently and improved the windows of the original building. Renovations and additions to the windows of the existing school building increase insulation so that heating load is reduced in winter. Refurbishing the windows and adding skylights to the existing building perform well. For this reason, this school is relevant to the research and these improvements could be applied to the main case study school.

Additionally, the refurbished school building has a range of different sustainable features. For example, rainwater in the vegetated roofs is reused in the toilets and cooling towers so that the school's use of potable water is significantly reduced (AIA, n. d.). Also, a central energy plant in the school recycles building waste water on site for greywater used in the building; allows greater control of energy resources and provides a demonstration of responsible energy use to students (AIA, n. d.).

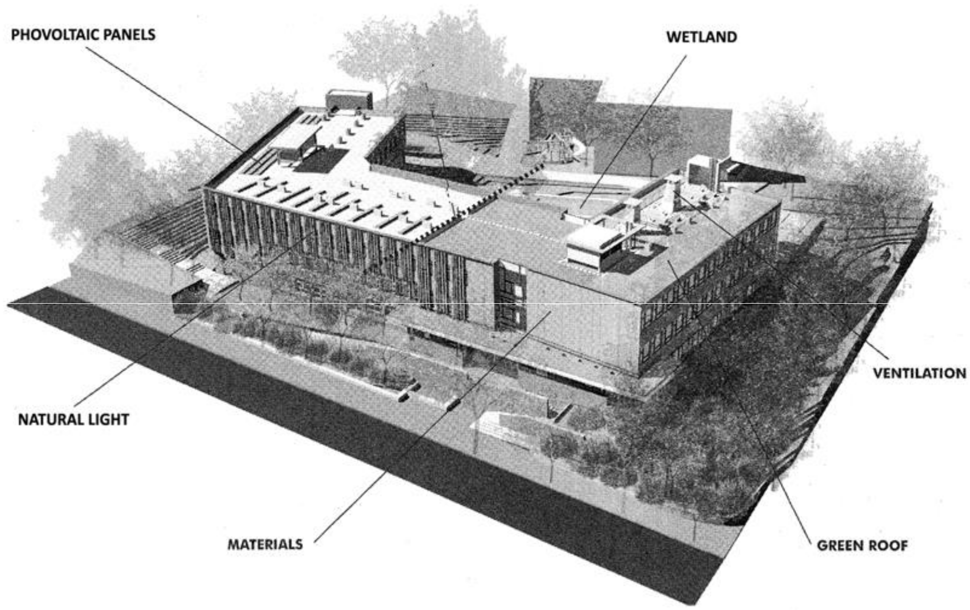


Figure A24 Sustainable adaptation of Sidwell Friends Middle School (Gelfand and Freed, 2010).

Saving energy is the fundamental principle of the building renovation. The school building uses 60% less energy by means of energy efficiency and passive solar systems by providing natural ventilation and shading and using lighting control sensors. Nearly 5% of the building's electricity is met by the solar photovoltaic panels on the roof **(**Kieran Timberlake Architects, 2010). Solar thermal technologies also provide 24% reduction in energy use in the existing school building. In addition, the green roof reduces urban heat island effect by providing insulation. Moreover, the solar chimneys serve the additional classrooms are planned to be utilised in air-conditioning and mechanical ventilation modes, which demonstrate the responsiveness of both passive and active systems to the local climate **(**Kieran Timberlake Architects, 2010). Solar chimneys as shown in Figure A25 help natural ventilation and minimise the need for artificial cooling. In order to absorb the sun's heat more effectively, solar chimneys are painted black. When the air inside the chimney is heated, it rises and pulls cold air out from under the ground via the heat exchange tubes (Chavrat et al., 2014). Therefore, the solar chimney is one of the sustainable ventilation strategies that could be used for the refurbishment projects in hot climates in terms of cost and adaptiveness. South-facing glazing at the tops of the shafts heats the air and creates a convection which draws cooler air in through north-facing open windows (Bauer et al., 2010). In the refurbished building using solar chimneys, mechanically assisted natural ventilation is used to minimise the need for artificial cooling.

Figure A25 Solar chimney ventilation (LPA, 2009)

Also, wooden slats made from recycled wood (from 100-year-old wine casks) are utilised to shade the windows from summer sun. North windows are unscreened. Screens at the east and west windows are vertical, whereas screens at south windows are horizontal (Ford, 2007). Furthermore, reclaimed wood materials include exterior cladding which is show in Figure A26 (left), decking and flooring, and the stone used for landscaping. Interior finishes were selected in order for being local and highly recycled, using bamboo doors and renewable materials, and having low chemical emissions (Leddy Maytum Stacy Architects, 2000). Moreover, healthy foods are sustainably produced and locally sourced by the school. Food wastes are composted to make fresh farmable soil. Students usually grow vegetables and herbs for the cafeteria.

Figure A26 Reclaimed wood cladding (USGBC, 2007)
Figure A27 View from southwest overlooking wetlands courtyard (Kieran Timberlake Architects, 2010)

Finally, students benefit from the building as a teaching tool. The school building allows them to analyse the relationship between the natural and the built environment to foster an ethic of social and environmental responsibility in each student. Students are a witness to human and natural created systems that work in which the building is a part of the environmental curriculum. For example, while science teachers are teaching the water cycle, they can use the rainwater harvesting unit as a teaching material to demonstrate the process of evaporation and re-intensification of water. So, students could benefit from the refurbished roof, which filters rainwater, as an educational laboratory and learn the efficient use of water. Also, students could grow vegetables and fruits in the vegetated roofs for the school kitchen.

Figure A28 View of planted roof, and solar chimneys (Sidwell Middle School, n. d.)

The landscape and the building complement each other **(**Kieran Timberlake Architects, 2010). Many of the teachers at all grade levels have designed lessons around the building system's opportunity (Bauer et al., 2010).

Figure A29 Abundant use of daylight in library (left and right); artificial illumination is controlled by sensors (right) (Kieran Timberlake Architects, 2010; AIA, 2020)

7- Marin Country Day School

Marin Country Day School in California, USA was built in 1956 and its renovations were completed in 2010 (AIA, 2013). It is designed by EHDD Architecture. The school covering primary and secondary education has nearly 600 students. The school constitutes of new buildings (68%) and renovated buildings (32%). The project includes a technology centre and new library, classrooms, art studios and student services offices in 23,094 square feet of new buildings and 10,646 square feet of renovations (AIA, 2013). Refurbishment works in the field covered creek restoration, a new playground and the courtyard (AIA, 2013). The building is recognised as the first zero-energy school building in North America. The school building earned LEED Platinum certification from the U.S. Green Building Council in April 2010 (AIA, 2013). The American Institute of Architects selected this school as one of the "Top 10 Green Projects" in 2013.

This precedent school was mainly chosen as an example of sustainable refurbishment for being a zero-energy school building and having a similar climate condition with the case study school in Turkey. The energy-efficient and sustainable features of the school could be adaptable for the case study school. For example, solar panels generate energy so energy bills are reduced. Also, solar tube skylights were added to existing renovated classrooms to supplement side-lighting with top-lighting in the centre of the classroom (AIA, 2013) and most classrooms have daylight from two or three different directions (AIA, 2013). So, the school saves electric energy for the lighting.

Additionally, there are many sustainable strategies to learn from this precedent school in order to be used in a number of different schools. For example, the school building has a green roof for insulation. Also, wooden horizontal sunshades are preferred for the west facade so that overheating could be prevented and the large windows from afternoon sun could be protected. Moreover, harvested rainwater reduce energy demand for water. The rainwater catchment system on the roof provides water conservation and efficiency. Also, the treated wastewater is purified and used for toilets and cooling systems. The recycled water enables to reduce the consumption of plenty of water and contributed to the sewerage system. There are water-efficient fixtures such as waterless urinals and dual flushing toilets in the school. Furthermore, students studying in this school are thought water cycles, natural ecosystem. They are aware of using water efficiently. Also, the materials salvaged from the refurbishing the existing building were recycled and used in the new building (AIA, 2013). Furthermore, passive design strategies include natural ventilation, thermal mass, building orientation, operable windows, daylight controls and exterior shading. (Zelenay, et al., 2011). According to Georgiou, "wooden horizontal sunshades on the west facade protect the large windows from afternoon sun"

(Georgiou, 2016). Around 95 percent of spaces are naturally ventilated and benefit from the daylight (Georgiou, 2016). Also, an efficient radiant heating system ensuring heating and cooling through water circulation in tubes under the concrete floor was preferred in the building (Hanley, 2010). In addition, the outdoor classroom is used by students to harvest their crops. Also, homemade foods made of local and organic products are available in the school's lunch program.

Finally, Marin Country Day School's Strategic Plan aims to make environmental literacy an integral part of its curriculum and strengthen the students' sense of connection with nature (AIA, 2013). Pupils become environmentally conscious through activities such as recycling, composting, planting. Students actively participated in the design stage and the building encouraged their understanding about the building's refurbishment process. The precedent school has pedagogic roles. For example, students studying in this school are taught about water cycles and natural ecosystem. They are aware of using water efficiently. Thanks to the water meters, students can oversee the rainwater collected from the roofs versus what is consumed overall (Georgiou, 2016). In order to allow students to understand building performance, energy meters were installed to monitor individual classrooms' lighting and plug loads. A web-based monitoring system lets students see how PV output varies with the weather and the season (AIA, 2013).

Figure A30 Marin Country Day School Learning Resource Centre (left) and Courtyard (right) (AIA, n. d.)

Figure A31 View from the school garden (above) and the main building (below)
(AIA, n. d.)

APPENDIX K: THE NUMBER OF STUDENTS AND EDUCATIONAL INSTITUTIONS IN TURKEY

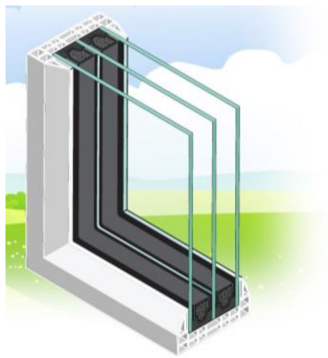
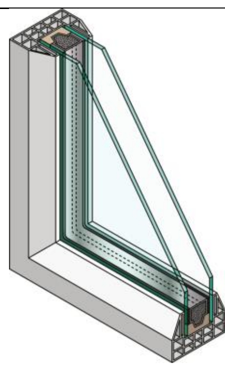
Education Year (2018-2019)		
Level of Education	**Number of School**	**Number of Student**
Pre-school Education (Public + Private)	**10 669**	**1 564 813**
Primary School (Public + Private)	**24 739**	**5 267 378**
Lower Secondary School (Public + Private)	**18 935**	**5 627 075**
Upper Secondary School (Public + Private)	**12 506**	**5 649 594**
Total (Public + Private)	**66 849**	**18 108 860**

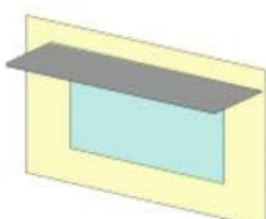
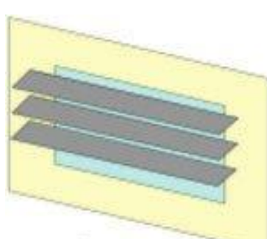
Table A4 Data related to the number of students and educational institutions in Turkey (National Education Statistics, 2018/19)

APPENDIX L: A table explaining the visible and physical features of insulation materials used in the simulations (Thermal Insulation in Buildings, 2006, p. 16-17)

	INSULATION MATERIALS				
	Thermalite high strength	Foam polyurethane	Vermiculate insulating brick	MW stone wool (standard board)	EPS expanded polystyrene (heavyweight)
Images					
Density Kg/m^3	470	36	112	50	25
Thermal Conductivity $W/m.^0C$	0.25	0.024	0.055	0.034	0.036
Thermal resistivity $m.^0C/W$	4	41.7	18.18	29.41	27.78
Maximum Working temperature ^0C	320	75	110	250	75
Compression strength N/mm^2	2.9	2-3	-	0.2	1-2
Fire resistant	Non-flammable	Flammable	Non-flammable	Non-flammable	Flammable
Water Absorption (% Volume)	High	1-4	-	High	2-3
Vapor Permeability	-	0.5	-	High	2

APPENDIX M: A table explaining the visible and physical features of openings used in the simulations (Thermal Insulation in Buildings, 2006, p. 16-17)

WINDOW GLAZING TYPES			
	Images	U-Factor W/(m^{2}k)	Solar Heat Gain Coefficient
Triple glazing		1.045	0.402
Double glazing		0.935	0.396

TYPES OF GLAZING			
Mid-pane (internal) blinds 	Local shading (Albatayneh, 2021, p. 12)		Louvres 
	Overhang 	Louvres 	

APPENDIX N: PUBLICATIONS

The following five documents based upon the work reported in the present thesis have been published prior to its submission:

Emir, H. N. S., 2015, The Evaluation of Thermal Comfort on Primary Schools in Hot-Humid Climates: A Case Study for Antalya, 3rd International Conference on Sustainable Development, Pontifical Gregorian University of Rome, Italy, June 6th, 2015, European Journal of Sustainable Development, Vol. 5 (1), pp. 53-62, ISSN: 2239-5938, *DOI: http://dx.doi.org/10.14207/ejsd.2016.v5n1p53*.
A peer-reviewed published paper and oral presentation.

Emir, H. N. S. and Dulgeroglu, C., 2015, Predicting Impacts of Climate Change on Geographic Distribution of Oriental Spruce (*Picea Orientalis*) Using MaxEnt Modelling, 1st International Conference on Environmental Science and Technology, ICOEST, Sarajevo, Bosnia and Herzegovina, September 9-13th, 2015.
A peer-reviewed published paper and oral presentation.

Emir, H. N. S. and Sever Mutlu, S., 2016, The Effects of the Application of Trinexapac-Ethyl and Giberellik Asit on Warm and Cool Seasons Grasses Species, VI. Ornamental Plants Congress, The Book of Proceedings, p. 43, Western Mediterranean Research Institute, BATEM, Wow Topkapi Palace Antalya, April 19th -22nd, 2016.

A peer-reviewed published paper and oral presentation.

Emir, H. N. S., 2018, Sustainable K-12 Schools Supporting Ecological Literacy, 2nd International Conference on Sustainability, Energy and Environmental Sciences, ICSEES, FLE Learning**,** Cambridge, United Kingdom, September 17th – 19th, 2018.
A peer-reviewed published paper and oral presentation.

Emir, H. N. S., 2018, Suggestions for Refurbishment of Existing K-12 Schools in the Light of Sustainable Criteria, Beyond All Limits: International Congress on Sustainability in Architecture, Planning and Design, Cankaya University, Ankara, October 17th – 19th, 2018.

A peer-reviewed published Extended Abstract and oral presentation.