THERMAL COMFORT INVESTIGATION AND RETROFITTING STRATEGIES OF AN EDUCATIONAL BUILDING

THE GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCES
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SANARYA GHAZI

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Approval of the Graduate School of Natural and Applied Sciences, Atilim University.

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ABSTRACT

THERMAL COMFORT INVESTIGATION AND RETROFITTING STRATEGIES OF AN EDUCATIONAL BUILDING

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In terms of global sustainable development, buildings are one of the largest energy consumers. Although technology advancements actively assist in constructing environmentally friendly buildings, current structures still consume a large amount of energy. Thus, we shall investigate educational facilities, one of the essential architectural types. It is vital to establish high-quality school structures to give a high-quality education to future generations. While numerous factors influence the building, thermal comfort significantly impacts the pupils. The pleasure a person feels in their thermal environment is thermal comfort. A suitable temperature environment aids physical and mental well-being. This study considers these aspects and attempts to evaluate the possibility of improving thermal comfort in educational buildings by making minor changes to the architecture rather than reconstructing them. At Atilim University in Ankara, Turkey, Design-Builder Software assessed an existing building model. The simulation was then run on the building's adjusted cases, totally seven retrofitting cases. Changing the window and frame types, as well as installing a Trombe wall, are some of the retrofitting options. In addition, the insulation material was replaced with three different materials in each case. A solar collector was added, the set temperature and airtightness were changed, and the light systems were changed to the led type. The Design-Builder ran the model for annual energy usage and recorded the result considering the building's modification. We conducted a comparative examination of the cases. The most compelling case for student thermal comfort was the use of Rockwool insulating material, which reduced student discomfort hours by 17% and was also the most effective for lowering CO_2 emissions and energy consumption, none of the instances affected airtightness. Furthermore, using a solar collector was the most expensive choice.

Keywords: retrofitting, educational building, thermal comfort, design builder.

ÖZ

BİR EĞİTİM BİNASININ TERMAL KONFOR İNCELENMESİ VE GÜÇLENDİRİLMESİ STRATEJİLERİ

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Binaların, küresel sürdürülebilir kalkınma açısından en büyük enerji tüketicilerinden biri olduğu bilinmektedir. Teknolojik gelişmeler çevre dostu binaların inşasına aktif olarak yardımcı olsa da, mevcut binalar da önemli miktarda enerji tüketiyor. En önemli yapı türlerinden biri de inceleyeceğimiz eğitimdir. Gelecek nesillere kaliteli bir eğitim verebilmek için kaliteli okul yapılarına sahip olunması gerekmektedir. Binayı birçok faktör etkilerken, ısıl konfor öğrencileri etkileyen en etkili faktördür. Termal konfor, bir insanın termal çevresi ile olan zevkini ifade eder. Hoş bir termal ortam, fiziksel ve zihinsel sağlığı destekler. Bu çalışma, bu faktörü dikkate almakta ve tasarımı yeniden inşa etmeden farklı iyileştirmeler ekleyerek eğitim binalarında ısıl konforu iyileştirme potansiyelini incelemeye çalışmaktadır. Halihazırda mevcut bir binanın analiz modeli Atılım Üniversitesi, Ankara Design Builder yazılımı kullanılarak yapılmıştır. İlk olarak orijinal kasa binası üzerinde simülasyon yapılmıştır. Daha sonra binanın modifiye edilmiş kasaları üzerinde, toplamda yedi kasa simülasyonu yapılmıştır. pencere ve çerçeve tiplerini değiştirmeyi, bir Trombe duvarı eklemeyi içerir. Yalıtım malzemesinin her seferinde üç farklı malzeme ile değiştirilmesi, güneş kollektörü eklenmesi, ayarlanan sıcaklık ve hava sızdırmazlığının değiştirilmesi ve ışık sistemlerinin led tipine dönüştürülmesi. Model, yıllık enerji tüketimi için simüle edilmiş ve sonuçlar kaydedilmiştir Bu, ilk güçlendirme senaryosu seçeneğiydi. Bina yöneliminin revizyonunu dikkate alan teorik bir yeniden tasarım senaryosu da oluşturuldu. Vakalar arasında karşılaştırmalı bir analiz yapılmış ve çalışma, hava sızdırmazlığının hiçbir vakadan etkilenmediğini, öğrenci ısıl konforu için en etkili durumun ise öğrenci rahatsızlık saatlerini %17 azaltan Taşyünü yalıtım malzemesi uygulaması olduğunu göstermiştir. CO_2 emisyonlarını azaltmak ve enerji tüketimini azaltmak için en etkili olurken, hava sızdırmazlığı hiçbir durumdan etkilenmedi. ve güneş kollektörü uygulamak en pahalı durumdu.

Anahtar Kelimeler: eğitim binası, güçlendirme, termal rahatlık, Design Builder

To my family, friends and my loved one.

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CHAPTER 1

INTRODUCTION

It is necessary to have high-quality school structures to provide a high-quality education to future generations. Additionally, these buildings should provide thermal comfort and enough fresh air [1] since the students spend almost 30% of their understudy life in interior schools, which 70% of the time are interior classrooms. Hence, instructive spaces should be inside to satisfy the comfortable indoor environment quality (IEQ) limits, moreover, since instructive buildings display a much higher inhabitancy than other buildings (1.8–2.4 m^2/individual) compared to workplaces (10 m^2 /individual). Moreover, the students spend nearly 25–30% of their time in interior classrooms [2].

The length of instruction anticipation of the students over the age of five has expanded from 10.1 in 1999 to 11.0 in 2007. Therefore, analysts and architects have paid more attention to the IEQ in instructive [2]. To this aim, existing and future buildings will place an increasing emphasis on energy efficiency and IEQ. IEQ refers to the acceptable levels of thermal, visual and acoustic comfort in addition to Indoor Air Quality (IAQ). Thermal comfort and IAQ variables (e.g., carbon dioxide (CO2) and volatile organic compounds (VOCs) concentrations) are two examples of the IEQ variables that are affected by a variety of physical, physiological, and psychological factors such as Airborne contaminants (gases and particles) from; office equipment, cleaning products, construction activities, furnishings and carpets, water-damaged building materials, microbial growth (fungal, bacterial and mold), outdoor pollutants, and so on [3].

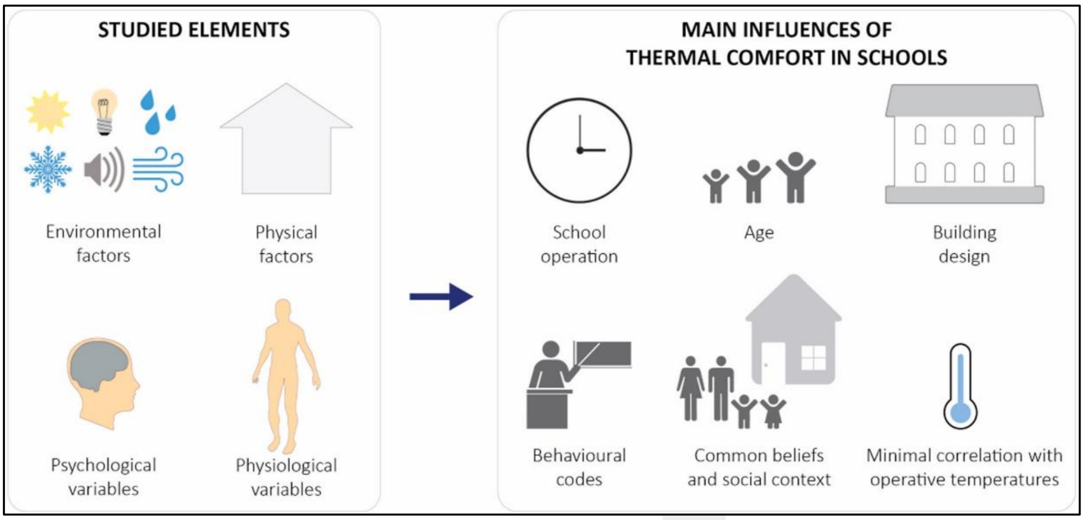


Figure 1.1 Main influences of thermal comfort [4].

The environmental factors that the IEQ depends on as mentioned above will be explained briefly:

Visual comfort is a subjective concept that takes into account things like lighting, brightness, luminosity, and the risk of glare. Having a good visual environment can help people feel better and be more productive in their places of work [5].

Acoustic comfort is the inclusion of a pleasant acoustic environment that doesn't make you feel bad. It is an important part of a non-domestic building's IEQ. People who work in offices and classrooms tend to give it a lot of thought. Speech privacy and comfortable sound levels can make people happy at work [5].

IAQ is known to have both short-term and long-term effects on the health of the people who live there. Ventilation rates and levels of pollutants are directly linked to Sick Building Syndrome, which in turn is linked to Sick Building Syndrome itself (SBS). In closed environments, IAQ is related to both chemical and physical causes such as carbon oxides, CO and CO2, environmental tobacco smoke, formaldehyde, volatile organic compounds (VOCs), ventilation rate, temperature, dampness, ionizing and non-ionizing radiation.Great IEQ interior instructional spaces can directly impact students' outcomes, such as their level of satisfaction, efficiency, execution, concentration, stress, and learning [6].

On the other hand, a lack of the IEQ in educational buildings could harm academic performance and achievement and cause many illnesses [7]. So, an excellent indoor environmental quality in a classroom should have enough and good quality of fresh air, good lighting, and a suitable temperature [1].

As the name implies, thermal comfort simply refers as humans' pleasure with their thermal surroundings. A pleasant thermal environment promotes physical and mental wellness. Conversely, people's productivity might be affected by an environment that makes them feel chilly or excessively hot [8]. Indoor air temperature (T_i), mean radiant temperature assessed from globe temperature (T_r), relative humidity (RH_i), air velocity (v_a), and the two characteristics of clothing insulation (clo) and metabolic activity rate (met) create the thermal comfort parameters. Overall thermal comfort (Predicted Mean Vote (PMV) - Predicted Percentage of Dissatisfied (PPD) index or in sometimes operative temperature (OT), air velocity, and relative humidity) are stated as parameters for an appropriate thermal climate [1].

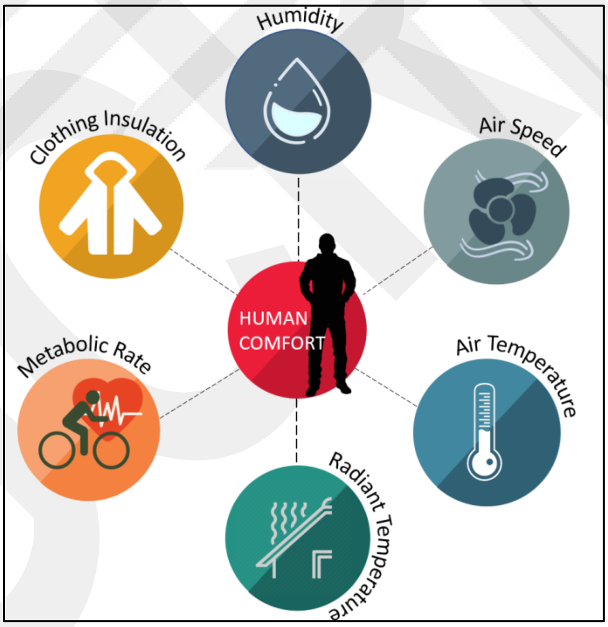


Figure 1.2 Environmental and personal factors that influence thermal comfort [1].

It is worth to remind that the value of thermal comfort in the interior environment cannot be overstated, particularly in the educational facilities. For these reasons, researchers in many areas of the globe are conducting studies on the thermal comfort of academic buildings. Predicted Mean Vote (PMV) and Percentage of Dissatisfied

(PPD) are the most often used method for estimating human thermal comfort. PMV is a weighted average of the votes cast by a group of occupants on a seven-point thermal sensation scale. Thermal equilibrium is being achieved when the amount of heat produced by an occupant equals the amount of heat lost. Individuals' heat balances can be influenced by their level of physical activity, the insulation of their clothing, and the parameters of their thermal environment. Once the PMV is calculated, the PPD, or index that establishes a quantitative prediction of the percentage of thermally dissatisfied occupants (i.e., too warm or too cold), can be determined. PPD essentially gives the percentage of people predicted to experience local discomfort. The main factors causing local discomfort are unwanted cooling or heating of an occupant's body. Common contributing factors are drafts, abnormally high vertical temperature differences between the ankles and head, and floor temperature. These indices are based on Fanger's work and consider environmental parameters including dry bulb temperature, relative humidity, air velocity, mean temperature (Fig.3), and human characteristics like thermal resistance and metabolic rate [1].

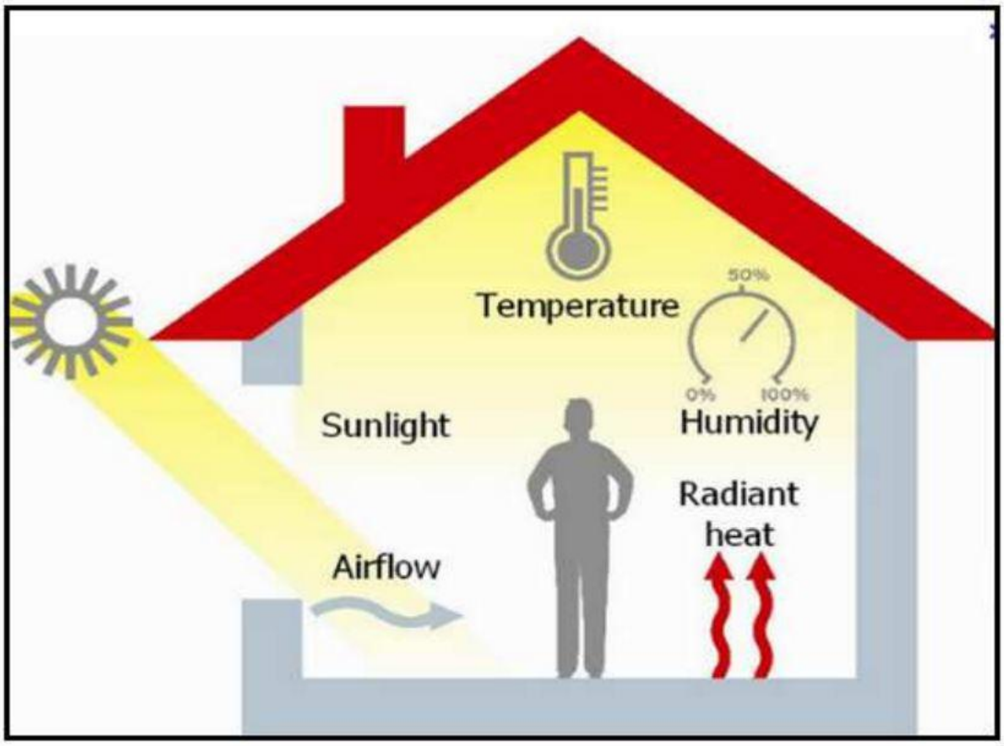


Figure 1.3 Aspects affecting the assumption of thermal comfort in the two indices (PMV and PPD) [1].

Guidelines and standard references to define a standard measurement method Worldwide, there are many guidelines and standards references for IEQ and IAQ. For example, EN 15251 specifies the standards for evaluating and designing building energy performances to meet IEQ, taking thermal, visual, and acoustic comfort into account [9]. ASHRAE Standard 55 specifies the interactions of thermal environmental variables and personal characteristics to give general guidance on thermal environmental conditions for human habitation. These criteria state that if 80% of the respondents are pleased with the existing environmental circumstances, the environment is pleasant and acceptable [10].

EN ISO 7730 is another well-known international standard that allows forecasting people's thermal feelings and thermal discontent. The computation of the PMV andindices in conjunction with other environmental factors allows for the analytical examination and interpretation of thermal comfort [11]. he questioning requirements for evaluating the PMV and PPD indices are defined in the standard EN ISO 10551. Using subjective evaluation scales tries to measure the thermal environment's effect [12]. Simultaneously, P.O. Fanger offered a statistical method to clarify comfort experiences, to establish an index that might create a connection between metabolic activity, clothing, and physical environmental factors [13]. ASHRAE Standard 62.1 and 62.2 and European Standard CEN CR 1752 specify minimum acceptable ventilation rates and IAQ for human occupants in buildings. REHVA Guidebook 13 for indoor environment and energy efficiency in schools. However, many outcomes went against them, yet they still make a solid contribution to being the most widely used techniques for thermal comfort arithmetic; as Jang et al. pointed out, they are an appropriate method that can represent the user's reaction to their comfort [14].

For a PMV, the definition may be made as stated: 'PMV is an index which forecasts, on a 7-point thermal sensor level, the average value of votes for a large group of individuals [11], with the following measurement size: +3 is too hot, +2 means warm, +1 means somewhat warm, 0 means neutral, -1 means slightly cool, -2 means chilly, and -3 means frigid. Furthermore, the PMV model employs heat balancing methods to integrate the six elements to assess thermal comfort for the users [15]. The PPD can range between 5% and 100%, depending on the calculated PMV. These comfort qualities will differ according to the occupant's location within the building.

To maintain compliance with standards, no occupied point in space should exceed 20% PPD.

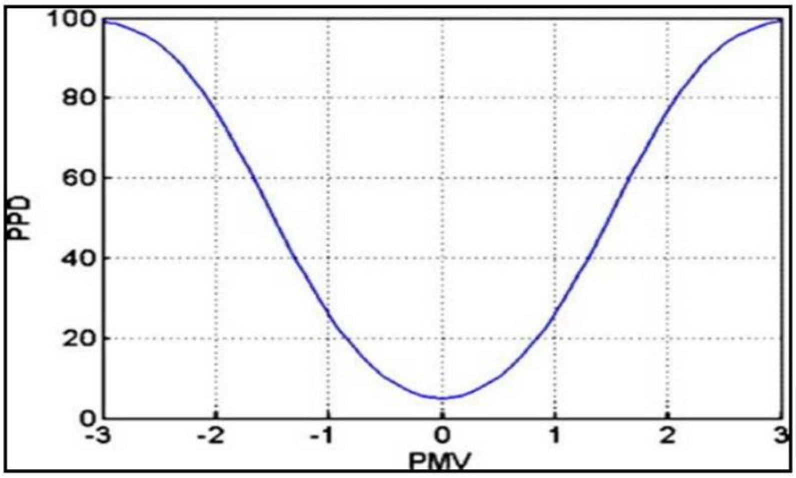


Figure 1.4 Relationship PMV versus PPD [1].

The buildings sector accounts for 30% of the final energy input and approximately 40% of direct and indirect CO_2 emissions worldwide. Population expansion and growing affluence in structures increase the energy consumption of the buildings. Global energy usage in buildings has increased by 1% each year, while global CO_2 emissions from buildings have increased by almost 1%. While the education sector worldwide consumes large amounts of energy for heating and electricity: an average of 13% of total energy consumed in the USA, 4% in Spain, and 10% in the UK area utilized by schools. According to Power, A., "*new structures add to the stock of buildings at most 1% each year, but the other 99 % of existing buildings are already built, and emit 27 % of carbon emissions across the world*." [16].

The rising energy consumption and severe environmental consequences push the researchers toward sustainable construction. Governments throughout the globe have made considerable efforts to improve the energy performance of existing buildings. However, in the twenty-first century, sustainable development in construction can only be realized if policymakers are convinced that retrofitting existing structures can provide the built environment with long-term sustainability [17]. Retrofitting is described as installing, fitting, or adapting something older with something newer. Recently, retrofitting has been defined as adding new technologies or functionality to existing systems for various reasons. Retrofitting might be done for multiple reasons, including improving power plant efficiency, reinforcing older structures to make them earthquake-resistant, or upgrading existing buildings with energy-efficient technology. Energy-efficient building retrofitting (EEBR) is the most frequent method in sustainable retrofitting. The EEBR, according to Kolaitis et al., focuses on implementing retrofitting techniques in an existing building to lower overall energy consumption while preserving or perhaps enhancing occupant thermal comfort levels [18]. To improve energy efficiency, a large number of retrofitting options are available. In energy effectiveness, it has a crucial role in the construction sector to use renewable energy and on-site technology such as Combined Cooling, Heat, and power (CCHP) and Combined Heat and Power (CHP). First, however, it was essential to pick and implement optimum retrofit combinations in a given project. Some key elements in the choice process include the nature of various forms of energy generating technologies at the site, dynamic energy costs, forms of energy demand profiles of buildings, and the variations in the use of solar and wind resources. This choice represents a multifunctional issue of optimization exposed to a variety of con conditions. Previous energy optimization studies use a range of cost reduction, maximization of thermal convenience, and pollution reduction to pick the optimum building retrofitting methods [19].

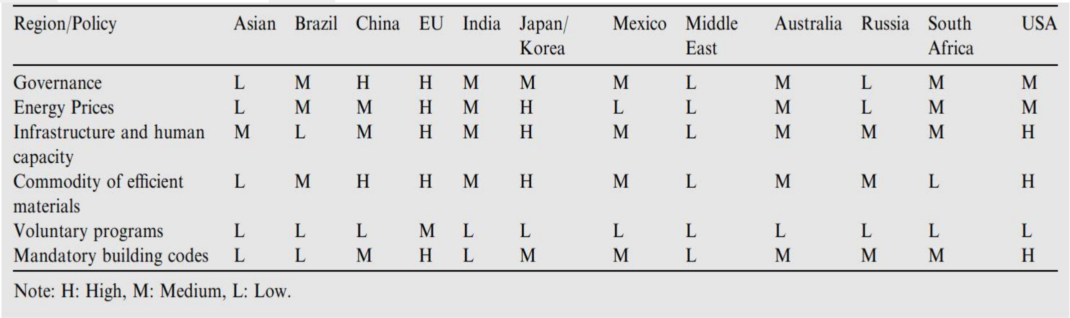
The retrofit cost is an issue for holders planning to retrofit a specific structure, especially as the performance of a building and its systems before and after upgrading lacks typically technical knowledge and standards. Therefore, Entrop et al. recommended that before building retrofitting, a technical assessment of the thermal efficiency of the building envelope, its current active cooling and heating systems, and the climatic characteristics of the outside and inside surroundings be carried out. Following the technical review, the resultant retrofitting solutions must be assessed economically by comparing the original expenditure with the projected cost savings due to energy conservation using conventional engineering economics methodologies [20]. In addition, retrofitting solutions can minimize the environmental effect of the building's operations to the benefit of severe environmental impacts in any part of the building's life cycle.

However, certain studies evaluate the ecological effects of retrofitting methods during construction and operation, such as distributed production and renewable energy technologies. Thus, the integrated emissions from the building should not contribute to the choice of new energy-efficient equipment [17].

Most projects do not implement energy efficiency retrofit methods because the cost required and the effectiveness of the prospective energy efficiency solutions are unknown. For many, the flexibility of retrofitting and funding is the obstacle to inter-rehabilitation and adoption. The enhancement of the building envelope's energy performance is based on the most appropriate retrofit approach. Examining the characteristics of existing buildings' features is necessary to comprehend thermal performance. The majority of public facilities, primarily educational in warm and dry areas, require much energy. Therefore, thermal comfort is the emphasis on energy utilization. Practical and straightforward retrofit can offer thermal convenience and hence minimize this energy. Kamel and Memari divided energy retrofitting methods spatially into three major categories depending on different types of building advances: energy retrofitting and building envelope improvement, mechanical system upgrading, and electrical system retrofitting [19].

It is predicted that by 2035, 75 % of buildings in the United States will be new or refurbished. Structure energy rules guarantee that energy is used efficiently throughout the life of the building. Table 1 provides a basic overview of building envelope policy assessment for critical areas. Some high-rated locations have material testing, rating, and labeling assessments for building envelopes [9].

Table1.1 Building envelope policy assessment of major regions [20].



Region/Policy	Asian	Brazil	China	EU	India	Japan/ Korea	Mexico	Middle East	Australia	Russia	South Africa	USA
Governance	L	M	H	H	M	M	M	L	M	L	M	M
Energy Prices	L	M	M	H	M	H	L	L	M	L	M	M
Infrastructure and human capacity	M	L	M	H	M	H	M	L	M	M	M	H
Commodity of efficient materials	L	M	H	H	M	H	M	L	M	M	L	H
Voluntary programs	L	L	L	M	L	L	L	L	L	L	L	L
Mandatory building codes	L	L	M	H	L	M	M	L	M	M	M	H

Note: H: High, M: Medium, L: Low.

Building envelopes generally comprise air, water, heat, light, and noise resistant transmission. In addition, the roof, foundations, windows, and doors are included as regards thermal walls. The thermal envelope creates a home or building as energy-efficient as possible which will lead to save money on energy costs in the long run. It will also reduce the heat loss from the building for example, in educational areas, the windows should be on the sides, and if the solar gain is to have a "low E" tint, this will decrease heat transfer which will also be achieved if the window shape, size and material are considered. Construction and environmental conditions from the outside outdoors, whose variation can influence the interconnected variables, are the temperature of external air, solar radiation in ecological conditions; refrigeration by radiation/heating and type of ventilation in HVAC systems; Internal heat profits and occupation calendar and operating conditions; Wall, roof, floor, and view of construction envelope properties. The floor area and the height of the ceiling of the construction sizes can determine completed thermal airflow behaviours, while individual characteristics can have a distinctive influence [21].

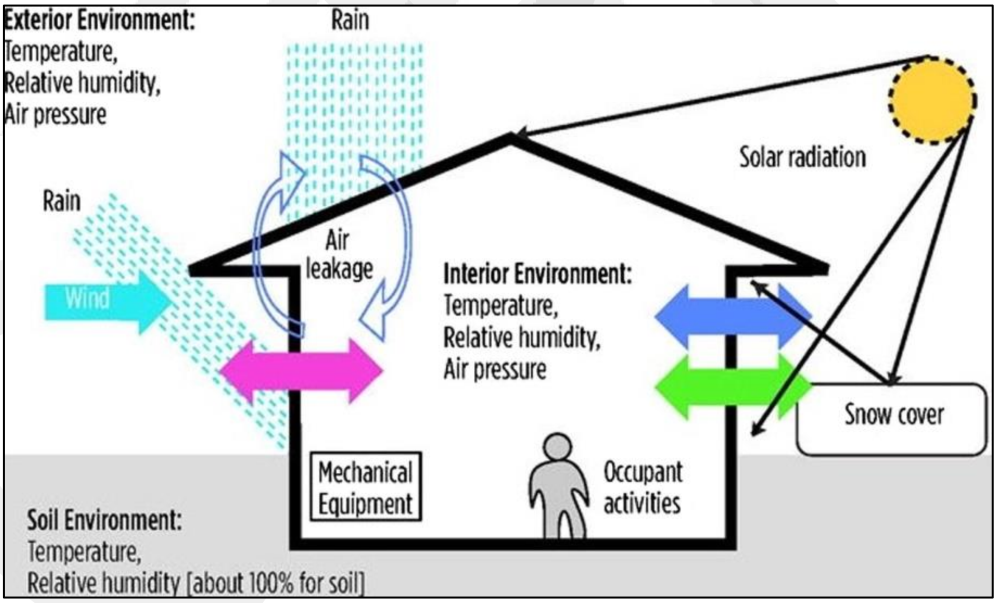


Figure 1.5 Building and Environmental Variables that can affect the Interior of Buildings [1].

CHAPTER 2

LITERATURE REVIEW

This chapter summarizes some of the studies on thermal comfort and energy consumption of educational buildings. Outcomes and findings of the research conducted in the 8 UK schools by Clements-Croome et al. [22] showed that the students and instructors have generally been subjected to unacceptable circumstances of poor air quality with CO_2 concentration levels up to 5000 ppm significantly greater than the suggested average 1500 ppm and 1000 ppm favored. The outcome of computerization of more than 200 students revealed substantially faster and more correct answers to the choice of reaction (by 2.1%), the color Word surveillance (by 2.7%), the picture memory (by 8%), and the word recognition (by 15%) of the low ventilation rates. The current study shows strongly that low ventilation rates in schools considerably impair the attention and attentiveness of children and have a detrimental impact on memory and focus. Therefore, the physical environment impacts education and learning.

In cabins of 250, 1000, and 1500 ton boats, human aspects, activities, and clothes have been surveyed by Jang et al. [14]. The human elements in the cabins of Korean marine patrol boats were examined after he appropriately changed the inland indoor goods and standards of clothing and activities. Different crew members in other places engage in various activities and dress differently. As a result of these factors, the ideal temperature for each cabin varies. As a result, it is more cost-effective and pleasant to ventilate and air condition based on the thermal environment. The findings of this preliminary research in the wheelhouse and accommodations demonstrate that demand-controlled air conditioning with PMV/PPD can save 61% of energy. The results of a study on thermal comfort evaluation and analysis in kindergartens for children aged 4 and 5 are presented by Fabbri [3]. The main goal was to compare (1) indoor microclimate characteristics, monitored using a

Datalogger by EN ISO 7730. and (2) children's subjective evaluation obtained via a survey following EN ISO 10551. an alter made to the questionnairesurvey on a psycho-pedagogical approach because pre-scholar youngsters were being interviewed .work was done with school instructors to adapt the questionnaire to the kindergarten's educational process ("Loris Malaguzzi" pedagogical model). He found that the children's responses were correct, reasonable, and truthful. Children showed that they understood inquiries and conversations about comfort and fundamental concepts like temperature and heating, but they didn't seem to know the difference between the two. Educators and pedagogues were extremely collaborative because of Loris Malaguzzi's educational technique features and the rigorous link between comfort and children's psycho-pedagogical growth.

The goal of Rodríguez et al. [4] study aims to improve our understanding of thermal comfort in educational buildings by including social and cultural factors in the analytical phase. Thermal comfort tests in two free-running schools in Bogota, Colombia, with students aged 7 to 16, were utilized as case studies. Environmental measures, polls, focus groups, and observation paper records were used to collect information from the schools and inhabitants using the Classroom Comfort-Data technique. According to the study, physical and environmental elements and psychological characteristics all impact the thermal comfort in school buildings. The mean interior operational temperatures in the classrooms were slightly associated with the thermal feeling and thermal comfort ratings. However, behavioural rules, school operations, and building design significantly impacted thermal comfort and children's steps to adjust to their surroundings. It was also discovered that as people became older, their awareness of the temperature environment and its impact on cognition grew. The adaptable model is considered an inappropriate measure for studying thermal comfort in educational facilities in a local setting.

Relationships between primary and secondary school air quality classrooms and learning outcomes have been developed by Wargocki [7]. The concentration of CO_2 and the ventilation rate were examined in terms of air quality. The reports anticipate how changing air quality in the classroom, using several measures, has influenced the school's performance and national learning assessments. For example, relationships have shown that decreasing CO_2 levels in classrooms by 2.100 to 900 ppm will enhance performance by 12% and precision by 2%. . Reduce CO_2 concentrations from 2,400 ppm to 900 ppm would raise the efficiency of national assessments and school leaving tests by 5%, and reduce CO_2 from 4200 ppm to 1000 ppm by 2, 5%. As far as the ventilation rate is concerned, these data indicate that increased air ventilation levels in L/s per individual from 2 to 7.5 increase the performance of students in national exams by 5 % and the daily presence of kids by 1.5%.

The research objectives were made by Choi et al. [23] to understand the relation between indoor environmental quality (IEQ) and student outcomes, namely IEQ satisfaction, observed learning, and course fulfillment in a series of university classrooms. Data gathered from University of Minnesota (N=631) students were examined To evaluate a predicted conceptual model with route analysis. Findings indicated that the students' good outcomes related to IEQ in schools, such as temperature, air quality, acoustic conditions, lighting conditions, furniture, aesthetics, technology, and visual requirements. The results of this study can be utilized to support IEQ designers in higher education contexts. This allows educational institutions to employ classroom design to improve desirable student outcomes. However, to comprehend how individual factors impact student outcomes, particularly those within designers' control, designers must grasp the massive number of variables that affect student satisfaction and learning.

El Asmar et al. [6] have examined the IEQ level of satisfaction of two sets of higher schools in Arizona, the United States, and Beirut, Lebanon. Dedication to sustainable and ecologically responsible design and building ages might be factors that explain the variation in performance across both campuses. To evaluate their fulfillment of the space layout, the furniture of space and comfort, the air quality indoors, the lighting levels, sound waves quality, water efficiency, cleanliness, and maintenance of the building, 320 occupiers took part in IEQ studies on the fulfillment of the occupants divided equally between both campuses. The IEQ differential between the two campuses stood at around 17 %, which sets the groundwork for future research to examine why this significant variance arises. Moreover, building age appears to correlate with the happiness of IEQ users. The findings of the surveys show that indoor environmental conditions must be continually monitored and improved.

The improvement of IAQ in current classrooms at the Jordan University of Science and Technology in a hot desert environment was presented by Ma'bdeh with several approaches for natural ventilation retrofitting. Computer simulations were utilized in the base case classroom and after applying the suggested retrofitting procedures to analyse the ventilation rate, the indoor operational temperature, relative moisture, and CO_2 concentration. Compared with the simulation findings, the natural ventilation retrofitting approach was determined in the baseline situation. A solar chimney was used to aid a wind turbine, which resulted in increased hours of comfort during work, an improved average monthly ventilation rate, a drop in the concentration of CO_2, and an improvement in relatively high humidity ratios.The energy efficiency of 39% relative to split-unit air conditioning would be obtained.

The technological research process that was done by Fregonara et al. [24] the retrofitting project defined that incorporating new technologies and new features in a group of public homes will require further in-depth research into the definition of costs of production, which are not only economical but also ecological and social. For that reason, it is essential to implement circular economic policies that aim to reduce pollution and environmental expenses and the reintegration of unwanted materials in the production cycle.

Figure 2.1 Structural reinforcement techniques and layout of exterior spaces [2]

Heschong [25] provided a statistical relationship between day lighting and student achievement and retail and sky lighting sales. The study analysed 21,000 records for schools in 3 school districts in 3 states and daylight levels in more than 2,000 classrooms using multivariate linear regression analysis. The data show that children with the most excellent daylight at the school advanced 20% more in mathematical exams and 26% in a year reading tests than the least. Likewise, children with the greatest windows progressed 15% more rapidly in mathematics and 23% more quickly than students with the smallest. Furthermore, where windows could be opened, educational development in classrooms was 7 to 18 % faster than with fixed windows, without considering air conditioning. These results have been constant irrespective of curriculums or ways of instruction.

Heschong [26] also reported on a statistical analysis of the effects on the functional performance of officers, mainly sunshine and visibility, and secondly ventilation and thermal comfort. Two distinct studies were undertaken in the same institution, the Sacramento Municipal Utility District. The initial research examined 100 employees at a reception center whose performance has been monitored constantly by a computer system and quantified in time for each call. The second research, "Desktop," assessed the performance of 200 more office employees on the desk computer in a set of brief cognitive tests. Extensive data was gathered at each office worker's cubicle on the physical surroundings. A poll on employees' comfort conditions and health problems was also included in the Desktop research. improved access to views reliably indicated better performance. In several statistical models evaluated, daylight levels and ventilation rates are essential. The studies have proven that changes in employee performance may measure indoor-related conditions, and a range of potential impact dimensions can be created to improve the needs of future investigations by other researchers.

Hathaway [27] provided a 2-year analysis of the impacts on primary school pupils' oral health, attendance, growth and development, vision, and academic achievements by various lighting schemes. The four lighting kinds utilized included: (1) fluorescent full spectrum; (2) fluorescent full-spectrum with ultraviolet light supplements; (3) cool and fluorescent white; and (4) sodium vapour high pressure. One of the four lighting models was available in each school; two schools were similar. Before and after the research, the data for students was collected. The results showed that for two years, kids receiving UV supplements had less dental caries, better attendance, higher height and weight increases, and improved academic performance than those who did not get supplements. It was determined that the lighting schemes had significant non-visual impacts for pupils under long-term exposure.

Seppanen et al. discovered a quantifiable link between job performance and temperatures within, below, and above the comfort zone. This connection is fraught with ambiguity; nonetheless, using it may be better than current practice, disregarding production. The quantifiable link between temperature and productivity may vary based on other building elements and the characteristics of the building inhabitants, and the sort of work they do. In general, remedial interventions will be more cost-effective in buildings with lower baseline IEQ or more current adverse health impacts. Data from industrial work performance studies were removed. We computed the percentage of performance change per degree rise in temperature from all experiments, and we statistically evaluated observed job performance with temperature. The data reveal that performance improves as the temperature rises to 21-22 degrees Celsius and declines as the temperature rises over 23 degrees Celsius. At temperatures about 22 o C, production is at its peak. For example, at 30 C, performance is only 91.1% of maximum, implying an 8.9 % drop in performance [28].

Pawel showed that School environments affect the students' performance by the fact that the thermal and air quality conditions in school classrooms are now almost universally worse than the relevant standards and building codes stipulate that they should be. Because financial resources for the maintenance and upgrade of school buildings are inadequate and because schools are increasingly allowing classrooms. Temperatures drift above the recommended range of 20-22C in warm weather and allow outdoor air supply rates to remain so low that carbon dioxide (CO_2) levels during school hours exceed 1000 ppm for long periods to conserve energy. He also showed that the impact of any of these investment-free but improper energy-saving measures on the indoor environment could reduce a child's academic performance by as much as 30%, so we need a more sophisticated approach to maintaining the quality of the indoor environment of the classroom [29].

Haverinen [30] assessed the impact on classroom ventilation and temperature academic performance. The study is based on measured data for socio-economic factors and state test results from 70 primary school districts (140 fifth grade classrooms) in the southwest of the United States and student level (N = 3109). There was a quantitatively important link between ventilation rates and mathematical rates, and this was stronger when six high ventilation classes were filtered (> 7.1l/s per person) and showed high ventilation rates. The relationship remained substantial when the previous year's test results were included in the analysis and had less apparent variability. The average mathematical score for students (average score of 2286 points) rose by up to 11 points per liter per second per person to an increase of a ventilation rate of 0.9–7.1 l/s per individual per person (estimated effect size 74 points). An extra 12–13 points rise was seen in the observed range of 20–25°C for each 1°C reduction (estimated effect size 67 points). For reading and scientific results, effects of comparable size were found to Greater variability. Finally, proper ventilation and thermal comfort in classrooms can considerably increase students' academic performance.

Machairas [31] show optimization approaches mainly utilized for constructing a new building and the early design stage. Most investigations used evolutionary algorithms and straight selection techniques as an optimization strategy. Earlier studies in building design and retrofitting are classified as load optimization, supply-side optimization, and integrated approach.

To obtain the best feasible option to maximize the power efficiency that simultaneously meets the end-user/occupant/owner demands of the construction, Diakaki has to offset environmental, energy, economic and social considerations. This document explores the viability of using the multi-target optimization approaches to the problem of energy efficiency improvement in buildings to allow for a review of the enormous feasible variety of various options and energy efficiency measures. It also proves that there is no optimal solution for this problem due to the competitiveness of the choice criteria involved [32].

To increase the heat comfort of a typical two-story Moroccan existing building in three distinct climates of Marrakech, Casablanca, and Oujda Sghiouri et al., provided an approach that combines objective evaluation and simulation of building energy. The optimization was done with the non-dominated genetic trial method (NSGA-II). The proportion of yearly discomfort, cooling, and heating consumption is compared with optimal and benchmark instances. The results demonstrate enhanced thermal comfort and improved overhangs lower demand for cooling in the Mediterranean climate of Casablanca by 4.1 %. This does not reflect a conflict in thermal comfort and efficiency gains [33].

Kian Wee Chen et al. included cooling systems as a variable to optimize building shape and envelope design in the early design phase's multi-objective. Integration may be done by 1) using a more straightforward computation requiring minimum form, envelope, and system data to calculate the cooling systems' energy use, and 2) by automatically choosing the most efficient system to optimize cooling energy usage. In a case study, daylight as a second and perhaps competing aim is proven the advantage of the integration. The statistic indicates that adopting an effective cooling system can lead to improved trade-offs between the two contradictory goals. These compromises are vital data for the early design phases for constructing the construction form and surplus [34].

A systematic approach for the ideal retrofitting of buildings is presented by Antipova et al. [35], taking into account numerous economic and environmental factors at the design stage. The method is founded on the rigorous mixed integer linear program (MILP), which systematically finds the best solutions to reduce the impacts of buildings on the environment. This includes the use of various sand windows and the installation of solar panels for insulating material. The LIFE Cycle Assessment (LCA) method is used to look at the environmental effects of everything that happens during the life cycle of a commercial product, process, or service. LCA also address environmental issues in this MILP, allowing for evaluating each alternative throughout its life cycle. We show how our method is based on a case study that examines Central Portuguese meteorological data.

Bianco et al. revealed that an entirely defined, replicable approach enables scientists, experts, and designers to maximize the retrofit energy of existing buildings is used in many steps in an optimal way for the energy renovation of an educational facility. The critical part is to combine the usage of a mathematical code to formulate the issue of optimization with evolutionary algorithms and one of the most appropriate software for the entire energy simulation of buildings under transient heating transfer circumstances. Even while rehabilitating the building exterior might be beneficial under favourable financial conditions, it turns out that the most profitable energy efficiency methods entail the modernization of energy systems. The economic renovation lowers the demand for primary energy to 12 kWh/m^{2}a, so the building may be designated nZEB [36].

A method is given to optimize building systems for many objectives and simultaneously with Raphael Wu et al. it combines the dynamic energy demands simulation to examine each retrofit case with optimizing an energy hub designed to suit a range of existing buildings such as age, size, and usage. Conceived as a mixture linear epsilon (MILP) mix, the optimization packages are re-fitted with technology to deliver renewable and high-efficiency power, such as biofuel, heat pumps, solar thermal, and solar cells panels to reduce lifecycle costs and greenhouse gas emissions (GHGs). Due to its multi-objective, inclusive evaluation and capacity to capture specific building properties and trends in a neighbourhood, this technique provides developers, district, and city policymakers with information essential to take good decision-making. The technique is used to simulate energy needs in Energy Plus and solve the problems of optimization using CPLEX in the case study of typical residential structures in Zernez in Switzerland. While common trade-offs can be seen in selecting energy system and retrofit, optimization findings show that various buildings, ages, and size, lead to optimum repair and building systems solutions. With the above technique, GHG emissions from the whole communities may, when selected for each building type, be decreased by up to 76 % at an increased cost of 3 % as compared to present emission levels [37].

Dalia [38] studied thermal comfort using sun sail shade in school courtyards in Port Said. Due to an examination of the court coverage ratio, there is no notable change between air temperature, PMV levels, and others when the percentage in the modelled cases is increased by more than 60%. (C, D, and E). Hence, the thermal- and economic advantage of a court coverage ratio of 60 % is adequate. Furthermore, the temperature differences were around ~0.5 °C while the PMV values were reduced to 22%, and the PET values were lowered by 4 °C.

Muna et al. [39] seek to examine and evaluate the connection between the current design of the UAE school courtyards and the happiness of the pupils. A self-administered survey was applied to secondary school students in two private schools in the UAE to collect the data. The relationship was established using six hypotheses; the SSS software used many tests such as regression models to investigate the hypotheses developed. The SSP (Statistical Package for Science Software) tool was used to study the relation.

Students at school buildings in the temperate climate zone of Nepal have examined the existing state of thermal comfort. During fall 2017, a survey was carried out by Mishan et al. [40] on the indoor thermal spaces and the accompanying thermal perception. 818 pupils have taken part in the survey, three times voting: at the beginning, midway through, and at the end of every 45-minute class. The interior global temperature was comparable to the external air temperature under air circulation. At an average temperature of 27 °C, around three-quarters of the pupils felt quite comfortable. However, students in private schools reported a lower predicted comfort temperature due to better garment insulation. Despite the dress restriction, students dressed down to acclimatize to the outside thermal climate, which was above 30 degrees Celsius during the autumnal season.

Baharuddin et al. [41] made a study to assess the level of thermal comfort of high school pupils in Makassar's tropical metropolis. The research is based on data from 8 high schools chosen. In 48 classrooms, there were 1594 pupils. The data collected comprises private information and environmental measurement factors. The pupils were simultaneously asked to complete their thermal comfort levels surveys. Extremely high temperatures were shown in the study rooms. The air temperatures fluctuated from 28.2 livers in the morning and 33.6 livers in the morning, respectively lunchtime. The radiant temperatures were equal to the air temperature, showing a modest airflow rate. Relative humidity was the sole metric capable of meeting the Indonesian national standards. Although roughly 80% of respondents agreed to this heat, the majority wanted an air temperature reduction. Only approximately 23 % of respondents in PMV (expected average voting) were predicted to be a bit warm (+1). The regression analyses showed that neutral warming of 29.0 µ/aC and 28.5 /aC respectively for TSV and TCV.

Richard de Dear [42] performed in nine schools in three different subtropical climates in the summer of 2013 in a combination of air-conditioned, evaporated, cooled, and naturally ventilated classrooms. A total of 2850 surveys from both elementary and high schools were gathered. As a result, the balanced and desired temperature of the students, which is often colder than predicted for grownups in a similar thermal environment, was determined to be an indoor operation temperature of around 22.58C. The analysis presented a suitable summer variety of Australian students from 19.5 to 26.68C under the sector assumption that a reasonable range of indoor operating temperatures relates to the group mean thermal sensations between 20.85 to 10.85C. The analysis indicated that the variations between schools in thermal responses are more significant than those in more equitable weather regions, where kids are more subjected to more comprehensive weather changes.

The findings of the research field on thermal comfort at the Italian classes in Turin (North-West Italy) were investigated by Corgnati et al. [43]. During the hot and middle of the season, investigations were carried out under free operation circumstances (especially examined in previous research). The ambient factors that influence thermal comfort were evaluated while simultaneously expressing subjective assessments of the thermal environment. Significant trends and correlations have been identified. The results demonstrate that the thermal preference from heating to the mid and warm months is changing gradually. The findings show a trend. The results reveal that surroundings are somewhat warm or heated during the heating period and that a neutral environment is preferable in the middle of the season.

Teli et al.'s study included thermal comfort evaluations and internal environmental factors assessments in natural aired schools in Hampshire, England. In repeated surveys outside the summer period, students aged 7–11 years were questioned, with a total of around 1300 replies reporting their thermal sensations. The results were compared with the two common techniques in existing comfort standards, the thermal balance, and the adaptable models. For the uncovering patterns, the thermal model variables PMV (predicted mean vote) and PPD (predicted percentage of dissatisfaction) were computed using the recorded physical parameters, expected values for garment insulation, and four alternative metabolic rate methods.

By evaluating the comfortable temperature formula generated from the study with the formula used in the European Standard EN 15251, the validity of the human comfort model was explored. The findings suggest that children are much more sensitive to extreme temperatures than grownups, with pleasant temperatures around 4 and 2 degrees Celsius more minor than the PMV and EN 15251 human comfort model projections, respectively [44].

Through a long-term field study, Hwang et al. [45] conducted in central Taiwan between local kids attending 14 elementary and high schools from September to January, the ASHRAE 55 adaptable concept of thermal comfort was evaluated for its application warm and humid weather. Thermal neutrality, adaptive behaviour, and thermal comfort zones are investigated. In the location of the standard linear regression of thermal sensation voting against operating temperature, probity analysis was conducted of thermal acceptance reactions from students in order to examine comforts zone boundaries for 90% and 90% acceptance, the relevant comfort areas were identified at 20.1–28.4°C and 17.6–30.0°C, respectively. Compared to the annual comfort zones indicated in the ASHRAE Standards 55, the bottom limit for tolerance of 80 % differs from those reported in this study, and the foundation level is 1.7° C lower than the ASHRAE suggested.

Examining the effect of building type on the outcomes, Jentsch offered a comparison of the findings from a moderate school building study involving questionnaires on thermal comfort and measurements of ambient interior factors. There were a total of 2990 replies. In the study period (June and July 2012), the buildings had an average air temperature differential of 2,7 °C over occupied hours. The medium-weight building was colder than the light-weight structure [46].

In the peak of summer in 2017, 24 field surveys were performed by Talukdar [47], and 579 data sets were gathered and evaluated to concentrate on the evaluation in the NV classrooms in the tropical-wet climate zone in Bangladesh of the student's thermal senses and behavioural adaptations. Mean indoor air, relative moisture, and wind speed was measured at 30.9°C, 78.4%, and 0.8 m/s. Talukdar utilized a linear regression model for estimating the new temperatures, although it is more appropriate for the classroom setting and sample size to forecast Griffiths' average comfort temperature (27.8 °C). In the ASHRAE Thermal Sense scale of 27.5 – 33.8 °C, around 43.7 % of the students responded in two center comfort bands of 0 and +1. Talukdar evaluated Griffiths' technique to the current thermal comfort models using the student's comfort temperatures (Tcomf). Tcomf was found within 80 % and 90 % of ASHRAE 55 acceptable zone at about 87.7 % and 81% of pupils. In addition, about 89.3% and 95.9% of the students' comfort bands of CEN (EN 15251) were discovered in both categories II and III. Results show that throughout the summer, children adjust comfortably to severe conditions.

To ensure a comfortable and studying student performance, providing adequate thermal conditions in university classrooms throughout the year is vital. In Xi'an, China, Wang [48] has carried out year-long university-level field research in classrooms. A total of 1973 data sets were gathered across all four seasons. the results essentially imply that particular consideration must be devoted to preventing overheating in summer and increasing the ventilation rate for all seasons in naturally ventilated university classrooms in Xi'an city.

Guevara et al, [49] study is based on a reaction to thermal comfort from 429 surveys gathered in three geographical locations in Ecuador from December 2017 to January 2018. The study contrasts true thermal feeling with forecast models. Quito (Cfb), Guayaquil (Aw), and Tena are the cities with their respective Köppen climatic classifications (Af). In this study, many classrooms, free-running and air-conditioned, were included. Regardless of weather changes, the designs and characteristics of the structure are pretty comparable in materials. The Predicted Mean Vote (PMV) was utilized using simple linear regression analysis.

Jing et al,[50] research aims to examine university students' general and local thermal commodities by a field survey carried out in a classroom in Taiyuan, China, during the hot season. The results show that PMV exaggerated the temperature sensation of students. The TAV (Thermal Acceptance Voting) specified the broadest permissible range of temperatures and may be 19°C in Taiyuan at the bottom limit of 80% acceptability. Students chose a colder atmosphere than a neutral one.

The research seeks to identify the thermally inconvenient locations, their physical and architectural features while discussing the situations in which campus users might improve their comforts. Envi-met and IES-VE simulations are utilized with traditional thermal indexes to examine the current outdoor temperature environment. In most areas investigated, findings reveal significant degrees of heat discomfort. Consequently, recommendations are made to improve the design quality of outdoor places to optimize their thermal comfort conditions. The study suggests that efficient redevelopment of outdoor space in the tropics can lead to a high frequency of usage and increased comfort via appropriate attention to the crucial effects of shade and vegetation [51].

The objective of the current study is to review information on relationships among high-intensity exercise and heat disease, including WBGT (Wet Bulb Globe Temperature), PET (Physiological Equivalent Temperature), and Universal Thermal Climate Temperature (UTCI) and environmental factors. In the research, new students were encouraged to reply with microclimate measurements to the survey regarding their thermal perception when they relaxed during an outdoor training session. Some pupils had a heat syncope, and over 30% had "profuse sweating" due to the results. Air temperature has the most critical influence on thermal comfort. In order to prevent over-exposure in a hot outside setting, the stress classifications WBGT, PET, and UTCI need to be adjusted for new outdoor training [52].

Ning [53] seek to investigate the impact on university students in the extreme cold area of China of climate adapting and Thermal indoor history. Measurement of the indoor physics was carried out through online questions on heat sensations and comfort, adaptable techniques.

The findings reveal that the average MTS votes were consistently higher than the forecasts for PMV. Moreover, there were apparent discrepancies between MTS and PMV throughout various seasons. Meanwhile, in various seasons, thermal-neutral temperatures have changed. The thermal adaptation of volunteers to the cold climate was gradually degraded as long-term thermal exposure to the artificially heating environment. In addition, after adapting to indoor heating conditions, the participants were sensitive to interior variations in temperatures, notably the decrease in indoor temperatures. The consequences for energy and human health have been postulated during space heating.

CHAPTER 3

METHODOLOGY

This chapter mainly investigates the work conducted during this thesis, which was focused on elaborating an educational building efficiency by an energy audit that has been performed to identify energy-saving opportunities and assess economic and environmental benefits. This study is conducted at Faculty of Law in Atilim University, located in Ankara, Turkey. The 13572 m^2 one-of-a-kind building was constructed in 2009, which 1389 active students attended according to the 2020 data. Not only does the School of Law feature classes and workplaces, but also has a conference hall, a library with studio space, student clubs with conferences, and a cafeteria with a food court with occupant schedules that appear to be irregular. In addition, this work considers the weather and location of both the city and the university.

A dynamic simulation calculation program, DesignBuilder with EnergyPlus [54] as the analysis engine was utilized to evaluate building energy performance and the development of energy profiles, DesignBuilder is an EnergyPlus-based software program for measuring and controlling energy, carbon, lighting, and comfort as a simulation. DesignBuilder was created to make the process of developing simulations easier. Quickly and cost-effectively, DesignBuilder compares alternative building designs utilizing function and performance-based comparison results from numerous analyses [55]. The actual performances of the buildings were determined using audit data on user profiles, building envelopes, and plant systems. By adjusting the model using real-world performance data, it was possible to develop numerous retrofitting methods and then choose the best one, considering economic and environmental benefits, comfort, architectural quality, legal requirements, and the actions' coherence with the surrounding environment. Because the purpose of this study is to demonstrate and define the Preferred Approach to Enhance Energy Efficiency in Educational Buildings and the best scenario retrofit, the primary goal of the calculation and modeling procedure is to calculate the thermal comfort hours, installation costs, maintenance costs, CO_2 consumption, and energy consumption. Later on, this zone definition, heat transfer estimate, heat loss can be made using less time-consuming approaches.

3.1 Data collecting

The data collection strategy focused on examining architectural designs and procuring dimensions data collected on the law school building drawings to comprehend the architectural configuration and heating qualities. As a result, the study materials were received from the Directorate of Construction and Technical Works, including architectural and mechanical drawings. An archival search was used to examine project papers, construction permits, and technical reports about each structure's architectural and mechanical features. Relevant quantitative and verbal data were entered on different pages for each selected building. The building permits provided the address, construction year, and professional standing of the designer. Architecture drawings were used to determine floor counts, zoning status, building width and height, total floor area, net-usable floor area, the total area of shared areas, total volume, front, window area, and wall area. At the same time, the heating system, heating demand, and material U-values were determined from mechanical drawings. Due to proximity and similar sites attributes such as altitude, cross-linked areas, and other factors affecting weather data nearby, the weather service collected by energy plus weather (EPW) template data such as wind speed, wind gust speed, wind direction, dry bulb temperature, relative humidity, dew point, and solar radiation in hourly time steps and compared with our measurements and so on. For the indoor areas thermal computation, honest observer by onset (HOBO) sensor gathered data together with scheduled occupancies, calculating the number of people, electrical devices, and luminance independently for each zone. The data used during this work which we will be explaining in detail through each section of the mythology was obtained from a group of energy engineering students in Atilim University under the supervision of Asst. Prof. Dr. Cihan Turhan [56].

3.2 Building selection

The case study was chosen in Ankara, situated in the middle of Turkey (latitude 40°12 N, longitude 32°98 E), 5A ASHRAE climate zone, which has a typical Koppen climate is classified as Csb type.

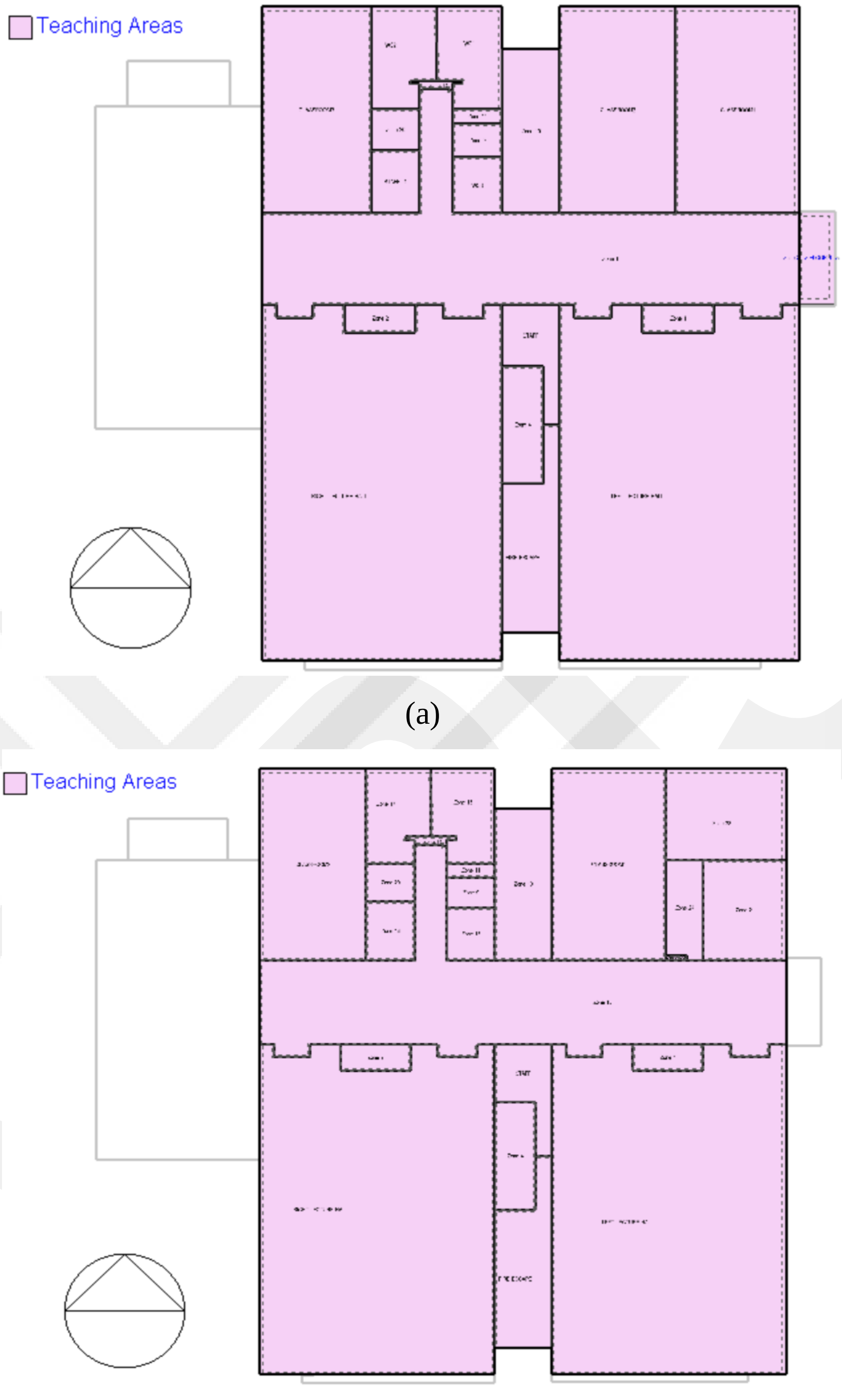
The weather of the case building can be summarized that Ankara Stream is created by the confluence of Çubuk and Hatip Flows in Etlik site. Before emptying into the Sakarya River, it flows through Ankara, one of Turkey's most populous and modern cities. The studied region is dominated by a step climate, with annual precipitation ranging between 300 and 500 mm. Everywhere, rain is seasonal, with the highest annual rainfall happening in the spring and the lowest annual rainfall happening in the summer. As a result, the research area's temperature ranges between around 20°C- 30°C in summer and between nearly 0°C - 5 °C in winter, with noticeable changes between winter and summer, and day and night [58].

Figure 3.1 Turkey and Ankara map in details

The building comprises two sections featuring gallery space, an educational component, and academic offices. There are two floors in the east half, and the third roof floor usually has two basement levels with no educational zones. The building involves classrooms and offices, a conference hall, a library with studio space, student clubs with workshops, and a cafeteria with a dining hall with seemingly erratic occupant schedules. In addition, our model assumes a level floor in lecture halls rather than a sloped surface employed or students' comfort in following classes with higher seating height. Architectural drawings provided the floor counts in a building, zoning status, building width and height, total floor area, net-usable floor area, total floor area of shared spaces, total volume, the total area of the facade, window area, and wall area.

Figure 3.2 Case-building external views

Architectural drawings indicated the number of floors in a structure, the zoning classification, the length and width of the structure, the total floor area, the net-usable floor area, the total floor area of common spaces, the total volume, and the total area of the exterior, window area, and wall area.



(a)

(b)

Figure 3.3 Architectural Floor Plan for the building (a) first floor (b) second floor.

In the existing building, in the base model, 0.7 ac/h air leakage "hekimboard" coating, fluorescent type lighting, and aluminum frame with the addition of double windows, has already been used. The table below shows the baseline parameters used during the work [56].

Table 3.1 Base line parameters

Base Design	**Wall**	**λ thermal conductivity (W/mK)**	**l thickness of the material (m)**	**ρ density (kg/m^3)**	**Total U value (W/m^2-K)**
	hekimboard	0.180	0.012	1350.000	1.66
	Concrete Block	0.20	0.200	600.000	1.00
	XPS	0.034	0.50	35.000	0.15
	Plaster	0.57	0.020	1900.000	3.30
	Window Dbl Clr 6mm/13mm Air	0.900	0.060		2.665
	Window Frame Aluminum	160.000	0.005	2800.000	2.665
	Airtightness (ac/h)	0.7 (ac/h)			
	Lighting Fluorescent	9.8 W / m^2			
	heating temperatures	22 °C			
	heating set back	18 °C			
	cooling temperatures	23 °C			
	cooling set back	28 °C			

3.3 Modeling with DesignBuilder of baseline

The experiment was carried out using the DesignBuilder computer program and considering the building above's existing conditions. The first step was to create a three-dimensional computer model of the structure.

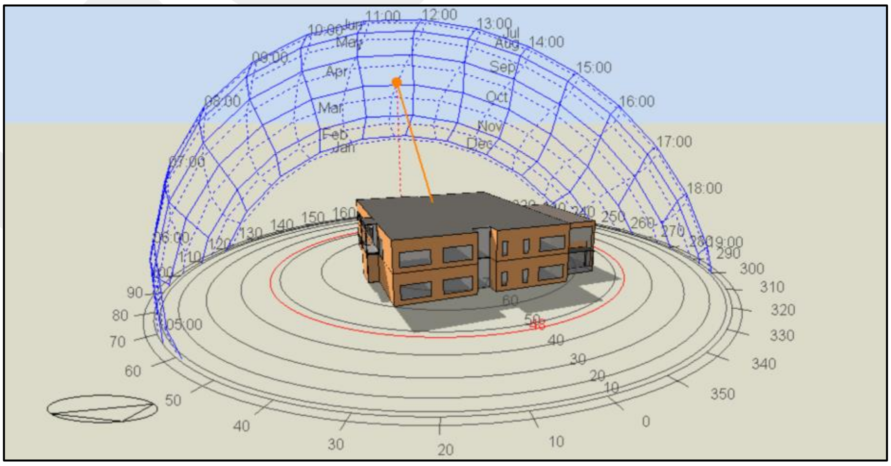


Figure 3.4 Rendered View of Base Model with Sun-Path Diagram at DesignBuilder

Information from the Esenboga International Airport in Ankara was used to obtain dry bulb temperature, dew point temperature, relative humidity, atmospheric station pressure, wind speed, and wind direction, as well as radiation data. In addition, the geography and orientation of the site are chosen. The construction material is chosen from the material library. Finally, the parameters of the building are input following the supplied standards.

Once selected, building material from the material library, the collected building parameters were entered under the given standards. Due to the restrictions of the trial version software, the building is divided into distinct zones for simulation purposes, with a maximum of 50 zones, as shown in figure 3.5 for simulation purposes, and is subject to the limitations of the trial software. Considering the programmed human activities in each region, the building visuals are created. Simulation of software for educational building a specific timetable and a calendar that includes holidays and non-working hours for each designated region was made for the year, and the output data were analyzed.

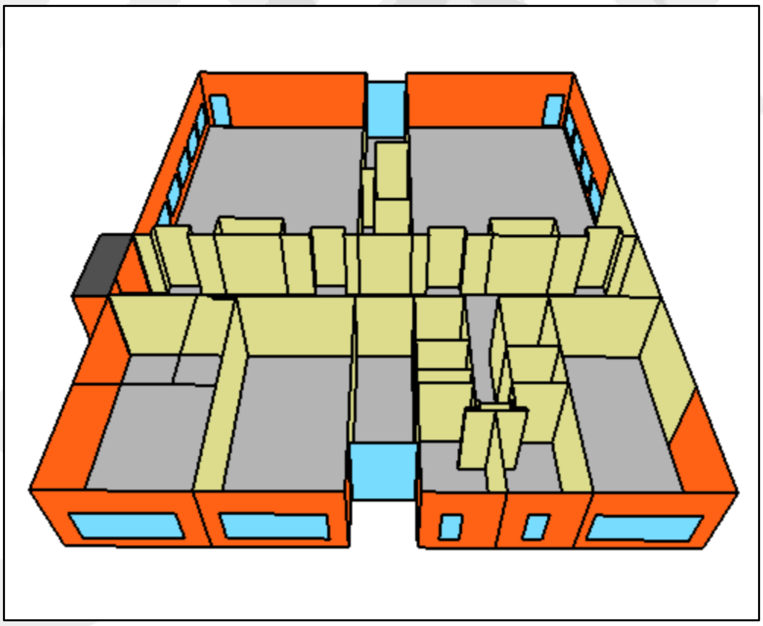


Figure 3.5 Over view of the baseline model

The research was carried using the DesignBuilder computer program and considers the existing conditions of the previously stated building. The structure's three-dimensional computer model was created as the first step. Now that we have our base case, the software simulates a calendar year with a defined schedule that considers holidays and quasi-hours for the defined educational building and analyzes the emission data. We generate several models with independently changed variables to assist in determining the most effective strategies for increasing energy efficiency. The primary benefit of using DesignBuilder is that it enables calculating the energy consumption of a hypothetical building by including renewable energy equipment such as solar panels and wind turbines. Because DesignBuilder software includes detailed data templates for a wide range of construction simulation inputs such as traditional envelope building elements, lighting systems, and occupancy schedules, it is well-suited for use in building simulations.

On base models, the modification includes adding three different materials and substituting the inner and outer surface insulation materials with XPS, Glasswool, and Rockwool. To change the system, we replace all lighting systems with LED lighting models. Our model demonstrated a reduction in air leakage up to 0.2 1/h. additionally; set points for heating systems have been changed.

Modification cases included changing the single window to a triple window and replacing the frame with PVC and a wooden frame in another. The Trombe Wall was added to the building's highest sunbathing façade. Photovoltaic (PV) panels and solar collectors were used on the roof. Each case will be discussed in greater detail in the following section.

3.4 Modified Case – Retrofitting Scenarios

The next step was to look at the impact of the modification on the current building's energy use and thermal comfort of the students—this strategy allowed for minimal retrofitting work to improve current circumstances. We create numerous models with individually modified characteristics to determine the best ways to enhance energy efficiency. Because our base model contains a fixed specification with its values, individual simulations transformed distinct instances. Insulation has already been employed in the existing building, with the addition of "hekimboard" covering 0.7 1/h air leakages, fluorescent-type lighting, and a double window with an aluminum frame.

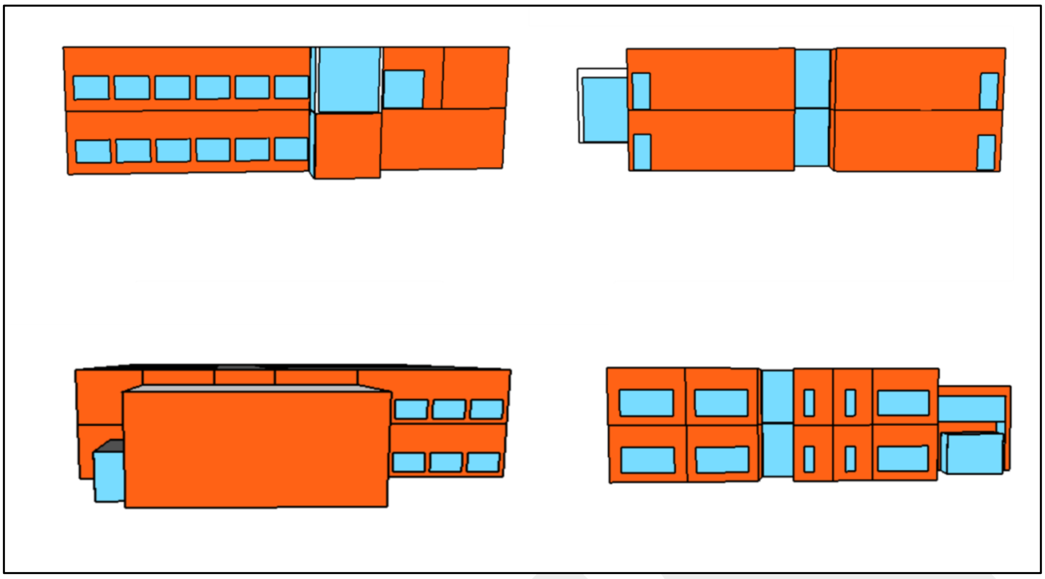


Figure 3.6 Side views of the modification of the baseline

The following changes were made to the base models:

3.4.1 Case one: Insulation Material Modification

Insulation is one of the most challenging decisions that constructors and architects face during the construction process. Although interior insulation is economical, it may limit the space available and does not provide water protection. In addition, external insulation is both expensive and insect-infested. Therefore, effectiveness, toxicity, and toughness must be considered.

Extruded polystyrene (XPS) foam is rigid insulation made from polystyrene polymer but generated using an extrusion process and it is commonly colored to distinguish the product's brand. XPS is more commonly used for waterproofing below grade and for roofing systems where insulation is placed on top of the roof membrane (IRMA, or inverted roof membrane assembly). Insulation made of XPS can be used in any building envelope because of its versatility, suitability, and high thermal efficiency [59].

Mineral fiber insulation made from Basalt and Recycled Slag, called ROCKWOOL. Slag is a direct result of the steel and copper industries, and basalt is a volcanic rock. Fibers are created by melting and spinning the mineral. It is afire-resistant fiber insulation designed to resist temperatures over 1,800 °F. Mineral wool, unlike fiberglass insulation, does not dissolve at such high temperatures [60].

Insulation made from glass fibers organized in a wool-like texture is glass wool. The small air pockets between the glass result in high thermal insulation properties due to the process. A variety of thermal and mechanical properties can be achieved through the use of different types of glass wool. Glass wool can be used to protect flat surfaces like cavity walls, ceiling tiles, curtain walls, and ducting as a loose-fill material blown into attics or sprayed on the bottom of structures, sheets, and panels with an active binder. Noise-cancelling and insulating piping are just two more applications for its [61].The base model insulation that was used is “hekimboard.” and was changed as explained above with three types o insulation materials. The U value of the wall is decreased as 1.16, 2.1 and 2.2 W/m^{2}K for the XPS, glass wool and rockwool, respectively.

3.4.2 Case two: Lightning System Modification

The diodes that produce light (LEDs) when electricity passes through a light-emitting diode (LED), the semiconductor device produces light. Electrons and holes (the particles that carry the current) merge in the semiconductor material to generate light. There are many advantages to using LED bulbs over incandescent bulbs, and they can also outdo many fluorescent lamps. LED lights use about 50 % less electricity than traditional lightning. Without filaments or glass enclosures, LEDs are breakage resistant and largely immune to vibrations and other impacts. LEDs come on at 100-percent brightness almost instantly however, and with no re-strike delay. Other luminaries, such as incandescent and compact fluorescent lighting, have a shorter lifespan than LED lamps. As a general rule, LEDs do not often go out or die. As a result, the LED's lighting slowly decreases over time, known as "lumen decay" [62]. The case building lighting was Fluorescent type and was changed to LED type in this case.

3.4.3 Case three: Decreasing air leakage (Airtightness)

Building airtightness (also referred to as envelope airtightness) can be described as the ability of a structure to resist air leakage from its envelope. Variable pressures throughout the building envelope caused by the stack, wind, and mechanical ventilators are responsible for this air leakage. The primary goal of airtightness is to eliminate all unintentional gaps and cracks within building's enclosure. Creating a healthy, comfortable, and energy-efficient home requires airtightness. Air leakage can also contribute to moisture issues, which can impact the health of inhabitants and the structure's durability. Up to half of a building's heat is lost through the exterior envelope because of this [63]. The thesis decreased the airtightness value from 0.7 1/h to 0.5 1/h by sealing method. It can be done in a variety of ways from increasing insulation to securing the perimeter of windows and doors. It will save money on heating costs this winter if you keep air from getting out through gaps and cracks.

3.4.4 Case four: setpoint temperature adjustment

The temperature during which a thermostat is referred to as the thermostat's set point. A structure can save a significant amount of energy by modifying just a few of these points. For example, when a heating setpoint is reached, the HVAC system warms the room and maintains that temperature. While for the cooling setpoint, the HVAC system would then cool the room and attempt to maintain it. If the ambient temperature is within the comfort range, the heating or cooling system will not operate (although it may continue to provide ventilation to your room) [64]. The set-temperature was decreased 1°C for heating system as a retrofitting case. Heat loss is slowed by a decreasing the building temperature in winter. For this reason, the longer it takes for the building to cool down to a lower temperature than it would have at a higher temperature, the more energy will be saved.

3.4.5 Case five: Window Type and Frame Modification

Triple-pane windows are exactly what they sound like: a window with three panes of glass instead of the standard two. A layer separates each section in triple-pane windows, just as in double-pane ones. Air or gas between its panes of glass helps stabilize the window and improves energy efficiency while also functioning as a sound barrier. In addition, the reflective layer created by the additional glass layers and the gas between each layer helps keep warm air in during the winter and out throughout the summer [65].

A window frame refers to a window between the glass and a building wall installed and fixed. Frames can be effortless in quasi windows or very complicated, with many moving sections in many working windows

The most typically used material for window frames is wood. Because of their warm appearance, insulating properties, and ease with which they can be painted, wood frames have long been used widely in window frame construction. However, in contrast to vinyl and fiberglass, wood frames require more ongoing maintenance, such as regular sealing, staining, and painting, to keep them looking their best. In addition, with their low cost and low level of insulation, they are vulnerable to cracking, which allows uncontrolled air and water to enter the building [66].

Un-plasticized polyvinyl chloride (UPVC) is a hard plastic often used in windows and doors because it does not bend. As a result, pollution, humidity, dust, and mold cannot do anything to the item. Because UPVC windows frame lasts longer than wood window frames, they are a superior option to wood windows frames. It is also impact resistant, adding to its security benefits and retaining its shape in average climatic temperatures. It is also environmentally friendly because it can be reformed at a high temperature and recycled [67].

The case building window was a double type window and was modified with triple type one while the frame was aluminium and was modified once with PVC frame and once again with wooden frame.

3.4.6 Case six: Adding Trombe wall

Trombe walls are a technology that can be used in homes to make the building heat itself. It takes less energy to warm a home with Trombe walls than with furnaces or other space heaters, which means less energy is used to warm up the home. These walls are sound because they do not require much work to set up and are suitable for places where quiet and privacy are essential. This kind of wall is made of a dark-colored material like concrete. They are built facing the Sun just so the Sun's rays fall on this wall. Outer glazing is then put on this wall. There is a small amount of air between the wall and the glazing. This glazing works like a tiny greenhouse to keep the Sun from going out [68]. Trombe Wall in the modification case was installed on the highest sunbathing face of the building as shown in the figure 3.7 below

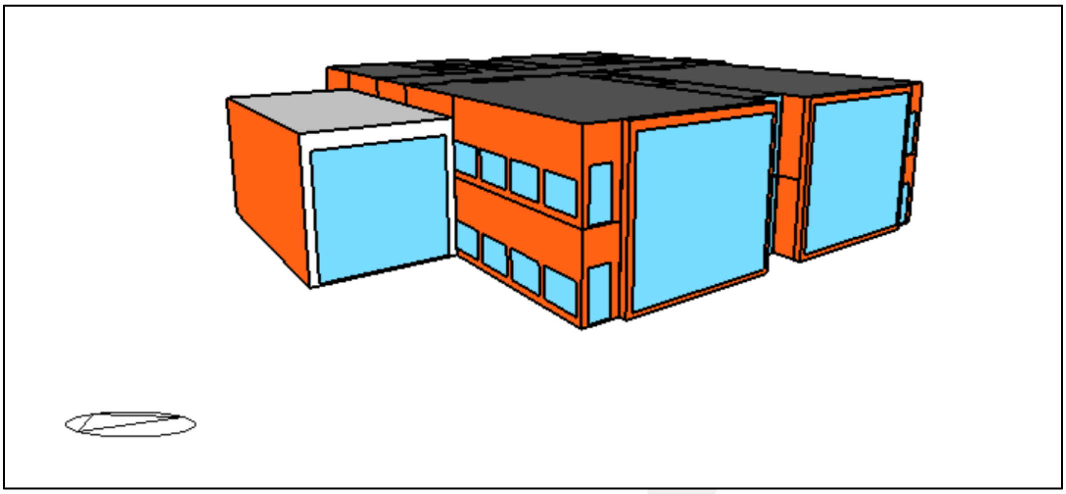


Figure 3.7 Modification of the Trombe wall

3.4.7 Case seven: Adding Photo-Voltaic (PV) Panels and Solar Collectors

Solar PV (photovoltaic) uses solar power to generate electricity (SPV). The board's core is a photovoltaic array. A larger SPV system can power both residential and commercial buildings. Solar radiation hitting the solar board generates a coordinated current. As a result, 100-320 an increase in electric energy produced per board Solar photovoltaic systems are quiet and have no moving parts. Quickly installed, they foster energy independence. Low maintenance costs are a plus. Modern solar panels generate electricity from daylight, not direct sunlight, though they produce more on sunny days. A solar PV panel is commonly placed on the roof of a building, but it can also be installed on the ground and the façade of the building. Solar PV panels only require routine cleaning [69].

Solar water heaters, also known as solar water heaters, are an excellent alternative to traditional water heating systems like tankless coil water heaters, gas water heaters, electric water heaters, or heat pump water heaters. They use the sun's energy for heating water instead (all of which use gas, oil, or electricity to power them). They have collectors, a tank to store water, a heat exchanger, a controller system, and a backup heater that are essential parts. A solar hot water system can help save money and cut back on traditional energy sources like oil, electricity, and gas [70].

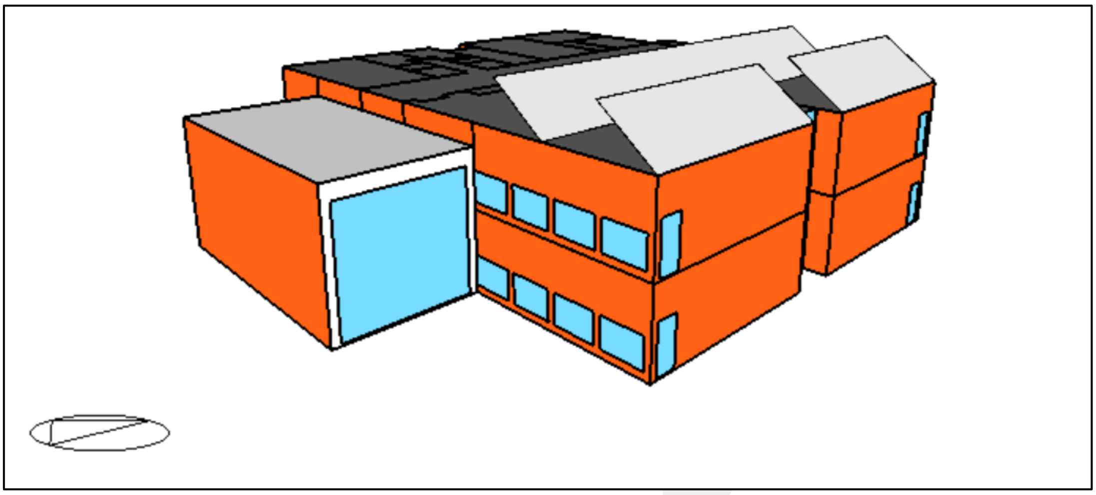


Figure 3.8 Modification of solar collector –PV panels

Three solar collectors were installed on the case building's roof. Two of them were photovoltaic solar collectors with 72.500 m^2 for each of the collectors, while the third and the most prominent collector that we used was solar hot water type with 162.498 m^{2,} as shown in figure 3.8.

Each new model has been subjected to a cost-benefit analysis, emphasizing energy savings. The outputs of thermal conductivity (W/mK), U value of the material (W/m²K), Thermal Mass (kg/m^3), Source Energy (kWh), Design Heating Capacity, End-Use Heating (kWh), Time Not Comfortable Based on Simple ASHRAE 55-2004, Equivalent CO_2 ($kgCO_2$), and Net Electricity from Utility (kWh) are especially compared before making a final decision.

Appendix A contains the modification cases and the effects they have on each parameter also contains field studies and data details about the simulation models for collection purposes.

CHAPTER 4

RESULTS AND DISCUSSIONS

The outcomes of the above experiment, which was described in Chapter 3 of the Research Method, were summed up, and a correlative analysis was conducted between the retrofit cases on the DesignBuilder outputs for various components. Each new model has been subjected to a cost-benefit analysis, emphasizing energy savings and thermal comfort. The outputs of thermal conductivity (W/mK), U value of the material (W/m^2K), thermal time constant (hour), Source Energy (kWh), Design Heating Capacity, End-Use Heating (kWh), Time Not Comfortable Based on Simple ASHRAE 55-2004, Equivalent CO_2 ($kgCO_2$), and Net Electricity from Utility (kWh) are especially compared before making a final decision.

The following table is the data collected from the anuual simulation of the baseline and the retrofit cases which the detailed simulation figures are found in appendix B. Each output result is per a year. It is worth to remind that the baseline is assumed as “0” to understand the retrofitting cases impact better. For instance, thermal insulation is considered as “0” for baseline model and after adding the XPS insulation, it retrofits 1.16 W/m^2K decrease from the baseline model.

Table 4.1 simulation result of the modification cases.

Column1	Thermal Time Constant	U-value	AirTightness	Thermal Comfort (not comfortable)	Installation Cost	Mainta. cost	Energy consumption	CO_2 emissions	Outdoor space	Indoor space
UNIT	**hour**	**W/m^2K**	**1/h**	**Hour**	**$**	**$**	**kWh/m^2**	**$kgCO_2/m^2$**	**m^3**	**m^3**
Baseline	0	0	0.7	3147	0	0	284.5	56.9	0	0
XPS (inner)	190.8	1.16	0.7	3011	13451	268	148.6	29.72	0	3450
XPS (outer)	190.8	1.16	0.5	3011	13451	268	148.6	29.72	3450	0
Airtightness(0.5)	0	0	0.7	2987	1050	100	241.7	48.34	0	0
Led Lighting	0	0	0.7	3147	2432	100	211.9	42.38	0	1210
Glasswool (Inner)	98.7	2.11	0.7	2611	15678	311	117.9	23.58	0	2481
Glasswool (Outer)	98.7	2.11	0.7	2611	15678	311	117.9	23.58	2481	0
Rockwool (Inner)	96.4	2.26	0.7	2599	17111	325	109.9	21.98	0	2481
Rockwool (Outer)	96.4	2.26	0.7	2599	17111	325	109.9	21.98	2481	0
Set Point Temperature	0	0	0.7	3129	0	0	151.7	30.34	0	0
PV Panel/Sollar Collector	0	0	0.7	3147	18140	450	161.9	27.523	2100	570
Trombe Wall	0	3.13	0.7	3048	10980	250	222.1	44.42	4500	0
Tripple Window	0	2.08	0.7	2987	5612	150	244.4	48.88	617	617
Wooden Window Frame	22.8	1.15	0.7	3055	4811	150	238.9	47.78	254	254
PVC Window Frame	24.9	1.19	0.7	3011	5480	150	222.6	44.52	287	287

4.1 Thermal Time Constant comparison

We can see from the above table results that the time constant is one of the most minor understood factors that affect a building's thermal performance, whether or not it is designed to be an Adaptive Residence. However, this parameter significantly impacts how a building responds to changes in inner and outer conditions, which is critical to the operation of its heating/cooling system. There are many situations where a high time constant is recommended, such as homes used all year round and having a constant temperature. Structures of this type are also more water-resistant. On the other hand, the situation is quite different when it comes to summer homes. Schools are no different in this regard. In this case, high-time constants can be a drawback. According to the intended use of the building, a building's comfort level can be positively or negatively affected by the time constant.

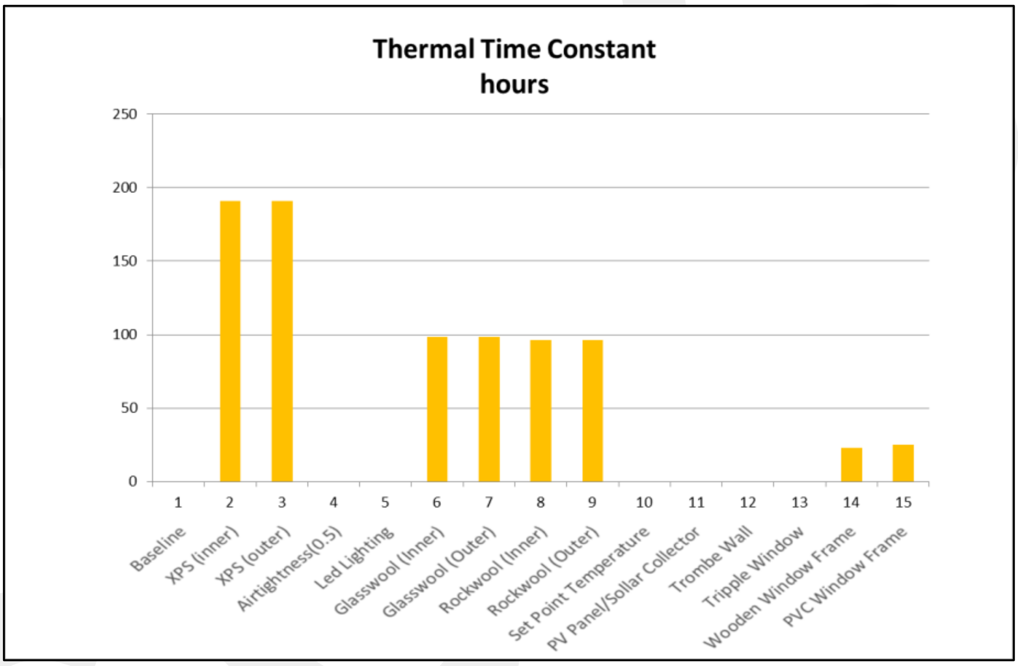


Figure 4.1 Thermal time constant test results

As mentioned previously, the lower the time constant for schools, the better the case for a building retrofit; thus, there were many cases that was neglectable such as changing the set point temperature, adding solar collectors, adding Trombe wall, changing airtightness and change the window pane. The best case for the time constant is the change in the window frame for both wooden and PVC with a two-hour difference between the two frames. Making the wooden frame the best retrofit and the time constant to 22.8 hours; the worst possible case was the change in insulation inner and outer material to XPS, increasing the time constant to 190 hours; and the worst possible case was the change in insulation.

4.2 U-values comparison

As shown in the figure below, the airtightness, led lighting, photovoltaic panel, and solar collector, and set temperature cases did not affect the u-value, also known as The thermal transmission coefficient is known as the amount of heat transferred through a structure (which may be made entirely of one or more materials) divided by the temperature difference across the framework. The unit of measurement is W / m^2K. The greater the building's insulation, the lower the U value. Thermal transmission can be significantly affected by quality and installation standards. For example, insufficient insulation with gaps and cold bridges can result in a higher than necessary heat transfer coefficient. Heat transfer is concerned with heat loss via conduction, convection, and radiation.

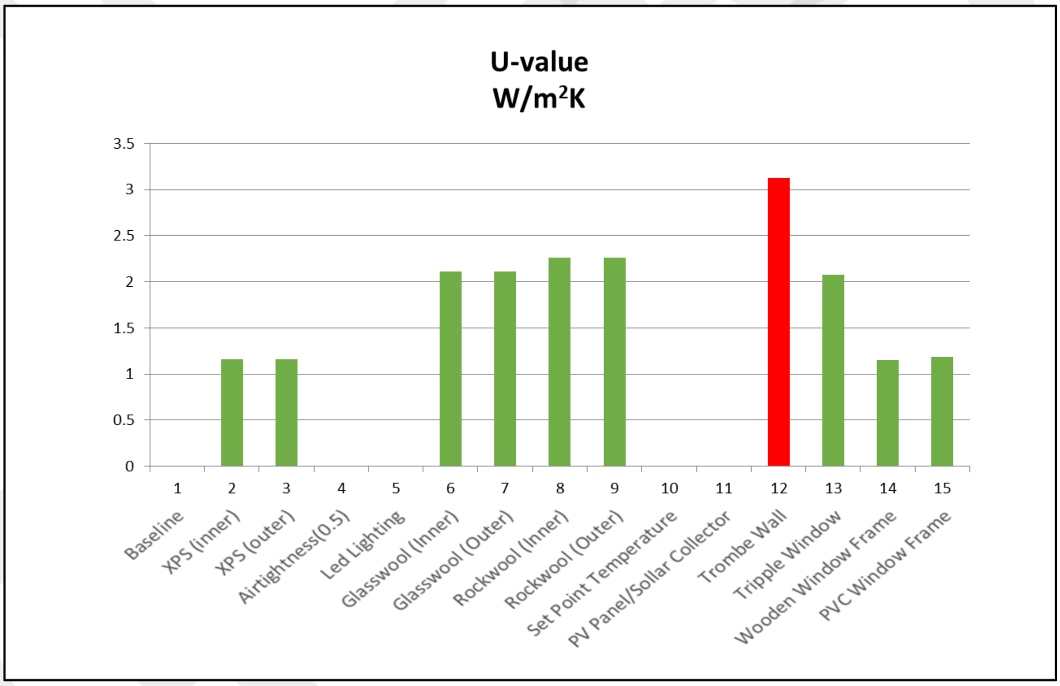


Figure 4.2 U-values test results

The worst retrofit case is changing the window frame to a wooden frame, which results in a U-value of 1.15 W/m^2K. Analysis indicates that the building's wooden frame is the worst insulation solution, followed by XPS inner and outer insulation at 1.16 W/m^2K and PVC window frame at 1.19 W/m^2K. The difference between these three retrofit cases is minimal, but when compared to the unfavourable case, adding a

Trombe wall to the case building results in a U-value of 3.3 W/m^{2}K, which is the best insulation solution.

4.3 Installation and Maintenance Cost comparison

Regardless of how important it is to get information about thermal and architectural data from research and analysis, we must also consider how much money will be spent on each modification case. The design-builder simulation is not just about engineering. We can also figure out how much it will cost to make each change.

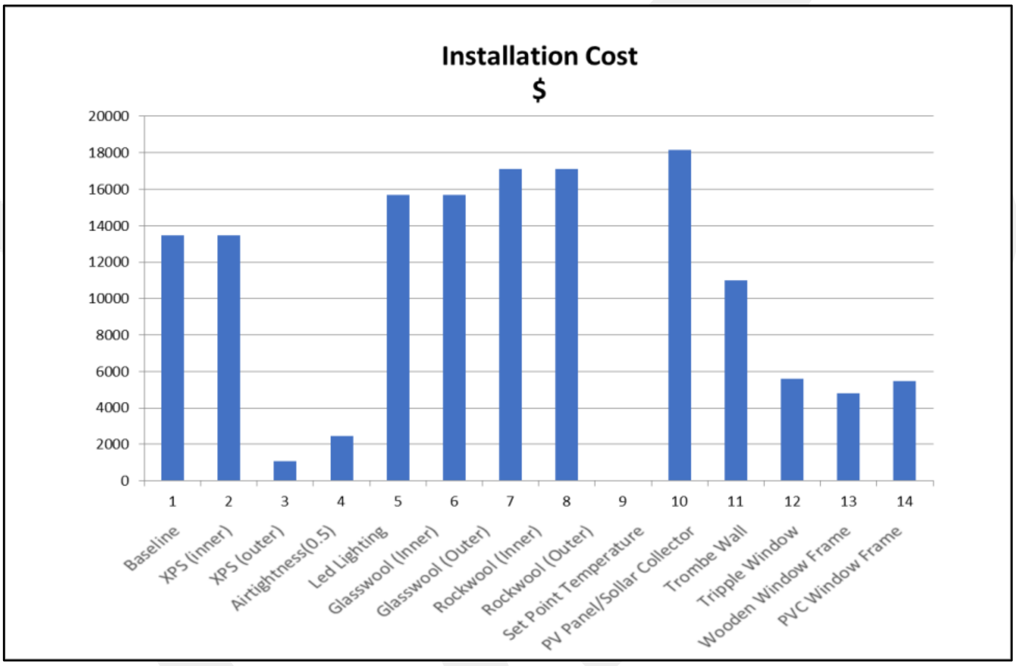


Figure 4.3 Installation cost test results

Changing the building's set temperature will cost nothing, and the following less expensive case is changing the baseline building airtightness, which will cost 1050$, followed by changing the building's led lighting, which will cost 2432$ while replacing the window frame with a wooden frame and changing the window to a triple type window will both cost between 5000 to 6000$. There is a significant cost increase for the rest of the cases, making installing PV panels the most expensive solution costing 18140$. We should also think about keeping each retrofit application up to date. The maintenance costs for the retrofitting situations are shown in the table below. This cost comprises maintaining and repairing the machinery and components used in each retrofit project. Knowing how much the machine will cost in terms of upkeep, wear, and emergency repairs will help make better judgments regarding it.

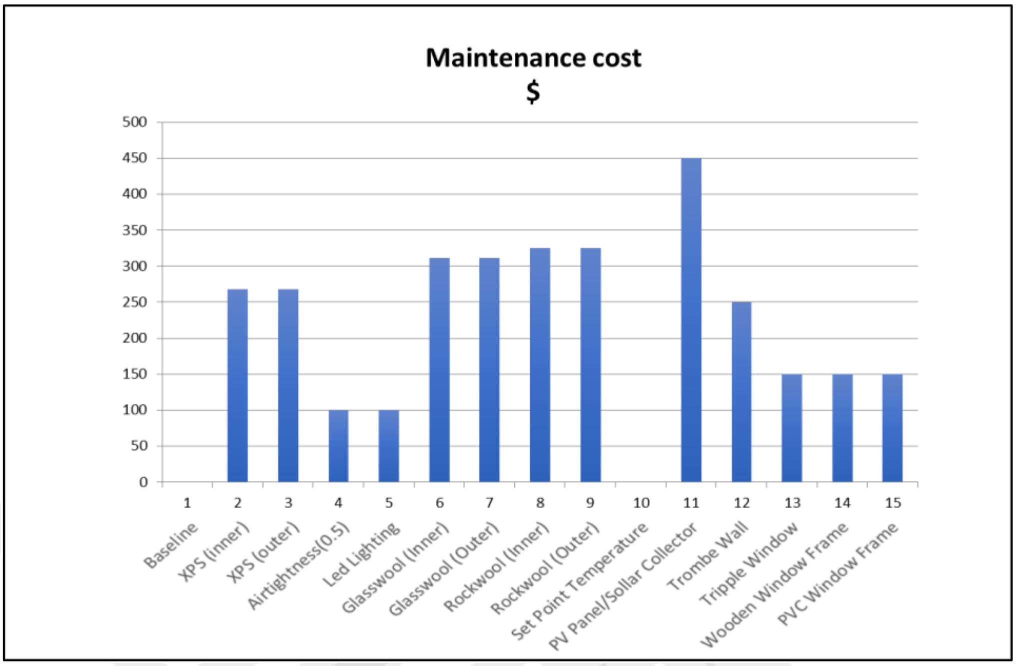


Figure 4.4 Maintenance cost test results

The maintenance cost is lowest during airtightness and the XPS insulation wall, which costs \$100, and highest during the application of PV panels and solar collectors, which costs 450 dollars. The remainder of the instances generally cost between \$200 and \$400.

4.4 CO_2 Emissions comparison

When a building uses technology that relies on combustion, carbon dioxide is released straight into the atmosphere. Such as Water heaters, like boilers and furnaces, employ fossil fuel combustion as a source of heat. If the energy source is a fossil fuel, onsite power generation also adds to emissions from the building. The yearly carbon dioxide emissions of the building are reduced from 59 $kgCO_2/m^2$ to 21 $kgCO_2/m^2$ once the insulation material is changed to Rockwool type, as shown in Table 4.1. Changing the airtightness and window type to triple window type, on the other hand, will have the most negligible impact on CO_2 emissions, resulting in 48 $kgCO_2/m^2$.

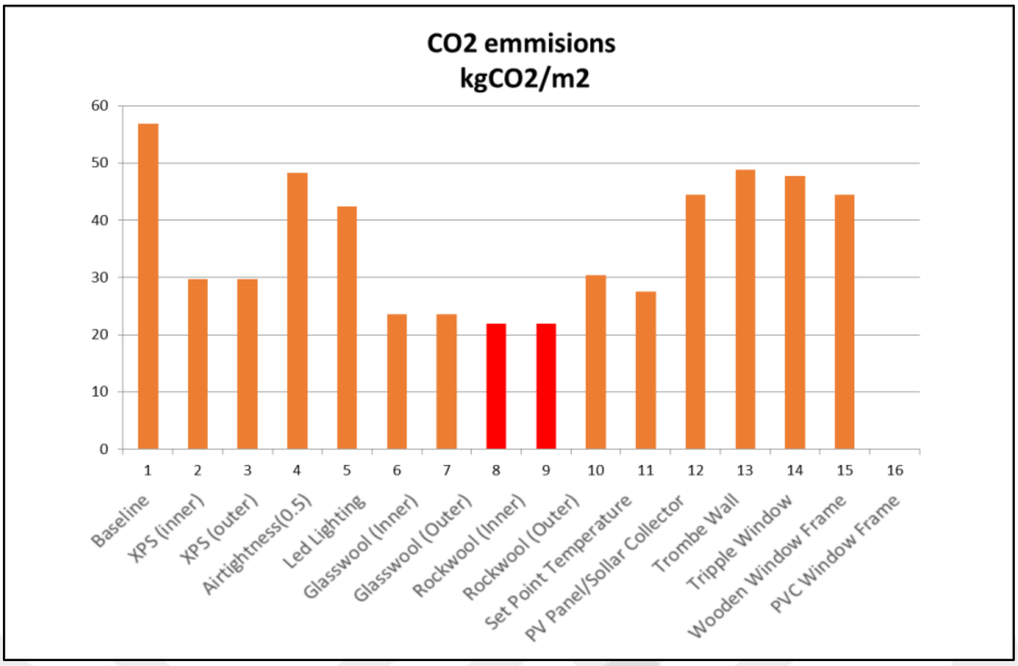


Figure 4.5 CO_2 emission test result

Applying the modification scenarios of glass wool and XPS insulation inner and outer surface, as well as installing PV panels and solar collectors on the building roof, would have a significant impact on the emission, as shown in the graph above, decreasing it to a range of 23 $kgCO_2/m^2$ to 29 $kgCO_2/m^2$.

4.5 Energy Consumption Comparison

As illustrated in the figure below, the yearly energy consumption of the original structure is 284.5 kWh/m^2. However, retrofitting the case by replacing the inner and outer rock wool insulation surfaces reduces energy consumption significantly to 109.9 kWh/m^2, while glass wool insulation reduces consumption to 117.9 kWh/m^2. In comparison, this addition of XPS insulation material reduces the consumption to 148 kWh/m^2.

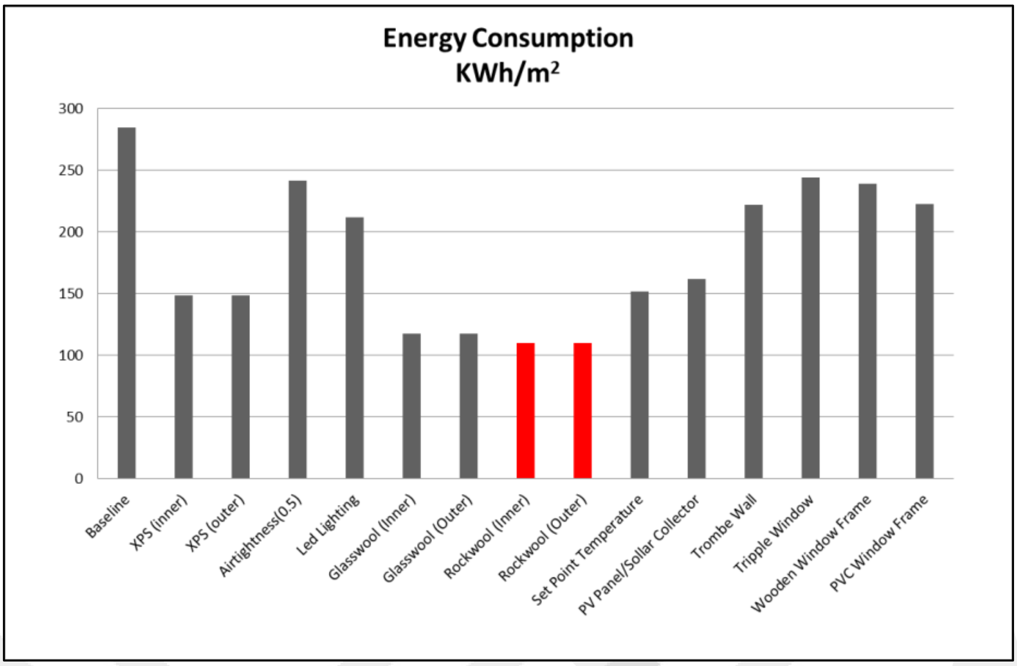


Figure 4.6 Energy consumption test result

As indicated in the figure, changes in airtightness, LED illumination, window and frame alteration all have a negligible effect on energy consumption decrease**.**

4.6 Thermal Comfort Comparison

Because this thesis was conducted on educational buildings, we must consider that the student's thermal comfort throughout the year is one of the most critical factors affecting their efficiency. As a result, selecting the best modification case that keeps them comfort most of the time is a must.

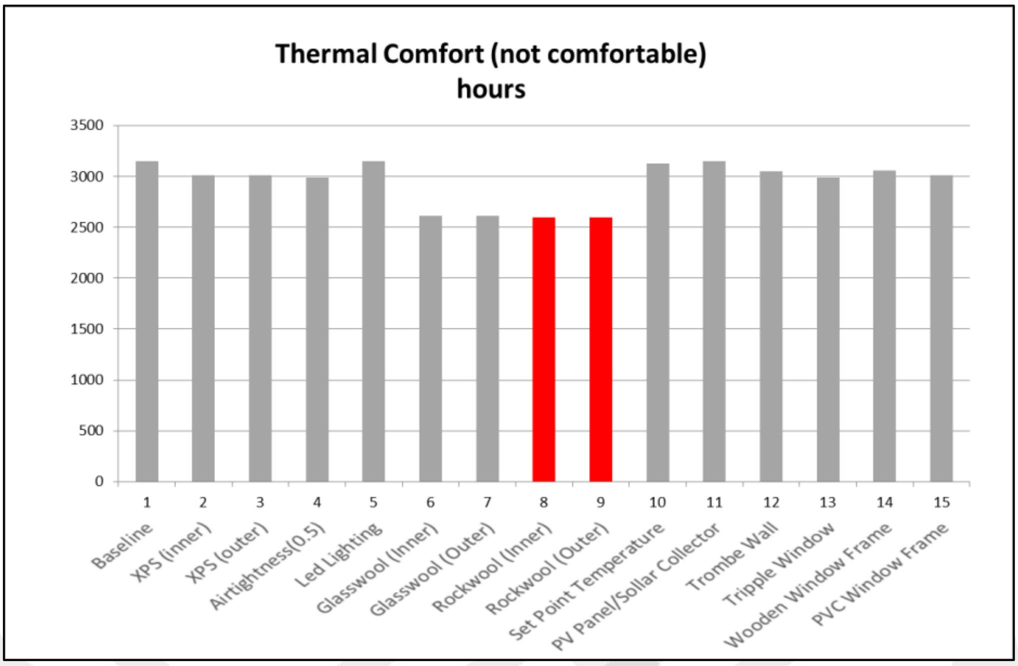


Figure 4.7 Thermal comfort test results

In the original building, students will endure 3147 hours of inclement weather. As a result, we use our retrofit cases to shorten unpleasant hours. The duration can be reduced by insulation in the inner and exterior surfaces. The uncomfortable time will be reduced to 2599 hours with rock wool insulation, while the irritating duration will be 2611 hours with glass wool insulation. The remaining adjustment situations will keep the discomfort hours around 3000 hours.

4.7 Inner and Outer Spaces Requirements

Some modification scenarios will increase the building size because their installation will consume space and change the design of the building. Some cases will stack up to the outer area of the building, while others will add up to the inner space. These two data will assist us in determining which cases impacted the region of the base structure.

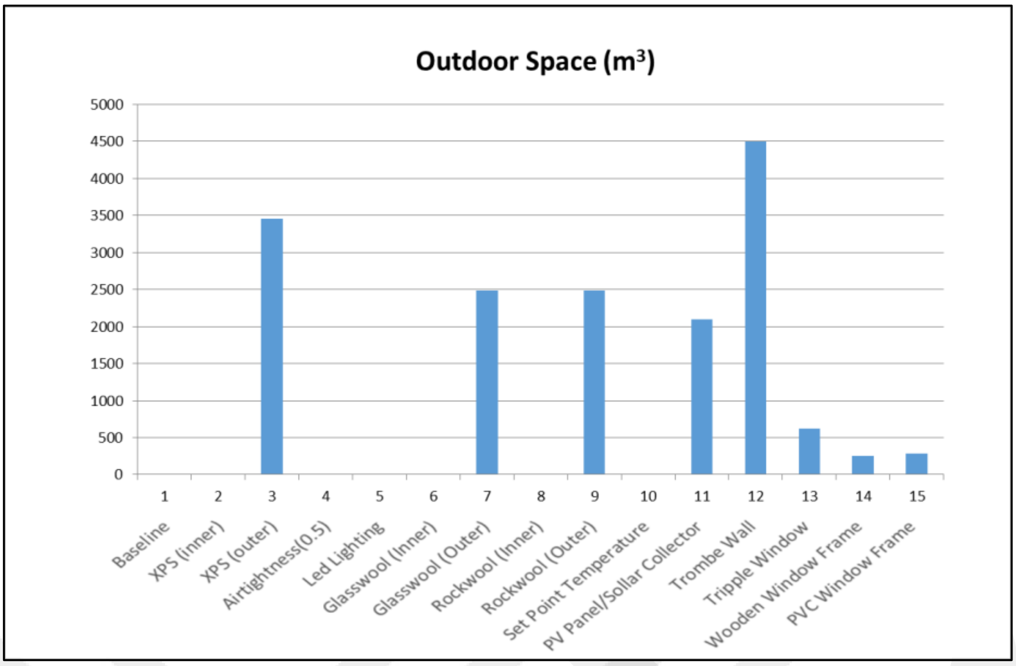


Figure 4.8 Case-building outdoor space test result

The XPS insulation inner and outer surface will add the maximum value to the space, totaling 3459 m^3. While glass wool and Rockwool insulation add the same amount of space by 2481 m^3, by 4500 m^3, the Trombe wall adds the maximum room to the outside area. The solar collector expands the outside space by 2199 m^3 and 570 m^3.

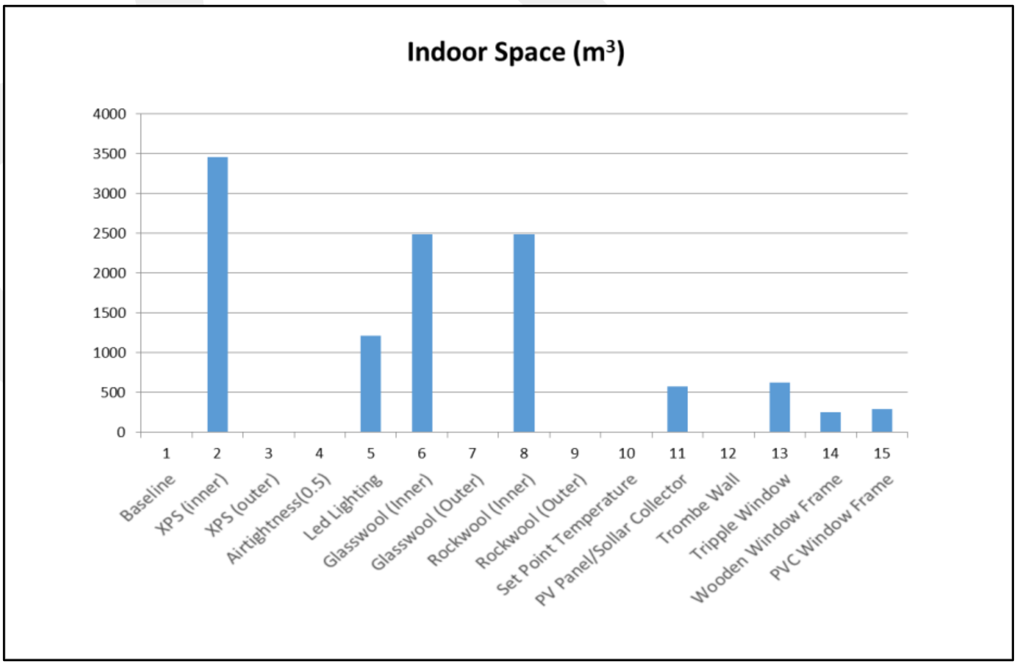


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Figure 4.9 Indoor space test result

CHAPTER 5

CONCLUSIONS

This thesis aims to improve the educational buildings by applying several retrofit strategies to the existing building enhancing its thermal environment and reducing the energy loss and providing more thermal comfort hours for the students inside of these building without having to rebuild it. The study was held in the Atilim university institution of law in Ankara, Turkey. Design-Builder program was used to do an annual simulation for the baseline model and the seven retrofit cases that included insulation material modification, lightning system modification, decreasing air leakage, set point temperature adjustment, window type and frame modification, adding Trombe wall, and adding Photo-Voltaic (PV) panels and solar collectors. Then we obtained the annul simulation output that were thermal time constant, U-values, iinstallation and maintenance cost, CO_2 emissions, energy consumption, thermal comfort hours, and inner and outer spaces requirements for the baseline model and the retrofit cases and compared between them to choose the best case that will improve the student thermal comfort hours and enhance their efficiency and the best case regarding reducing the building energy consumption during the cold season.

As detailed in the preceding chapters, the experiment mentioned above, results, and comparison between the seven cases revealed that airtightness was unaffected by any of the cases and remained consistent throughout this hypothesis at 0.7 1/h. The installation of the PV panels and solar collector on the building roof was the most expensive, costing 18140$, but it cut energy usage by 43% and CO_2 emissions by 51% while adding 2100 m^3 to the outdoor space. The setup for the Trombe wall was 10980$. The reduction in CO_2 emissions and energy usage was 21%, while the outdoor space was increased by 4500 m^3. On the other hand, changing the setpoint temperature only had a 43 % reduction in CO_2 emissions and energy usage.

The retrofit cases with the most successful one-case model used insulation material on the interior and exterior surfaces, but their construction was the most expensive. On the other hand, Rock wool insulation was the most effective of the three insulation methods, reducing CO_2 emissions by 60% and energy usage by 61% while costing 17111$.

The case building was unaffected by window retrofits that changed the window type and frames. As for student thermal comfort, which is one of the most important goals of the work, it was discovered that they were the happiest and that their productivity was high when The Rockwool insulation was employed; when the solar collector and LED lighting were used, their thermal comfort does not change significantly.

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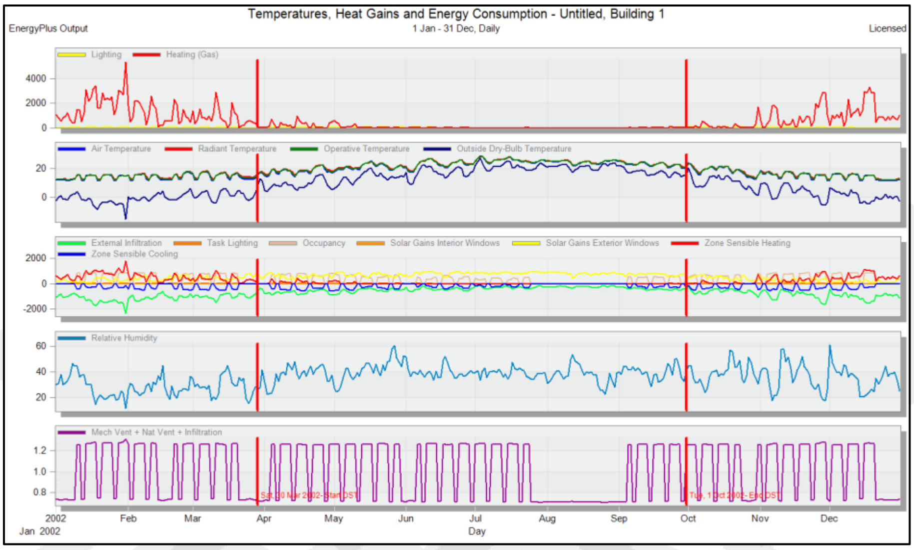
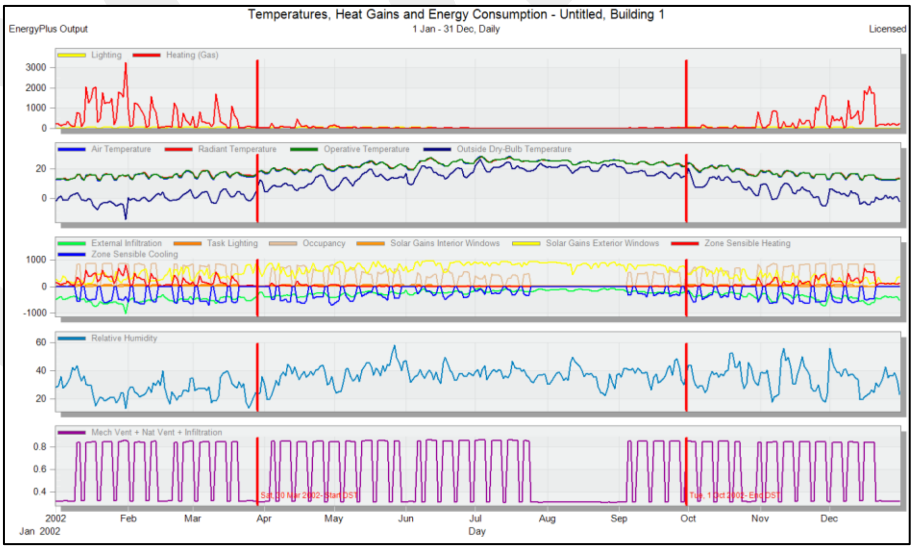
APPENDICES

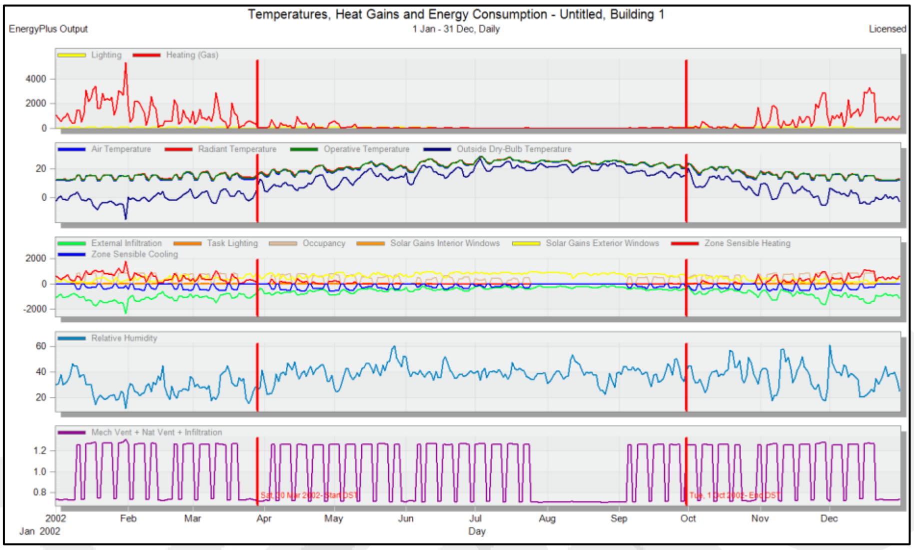
APPENDIX A: SIMULATION RESULTS FROM DESIGN BUILDER



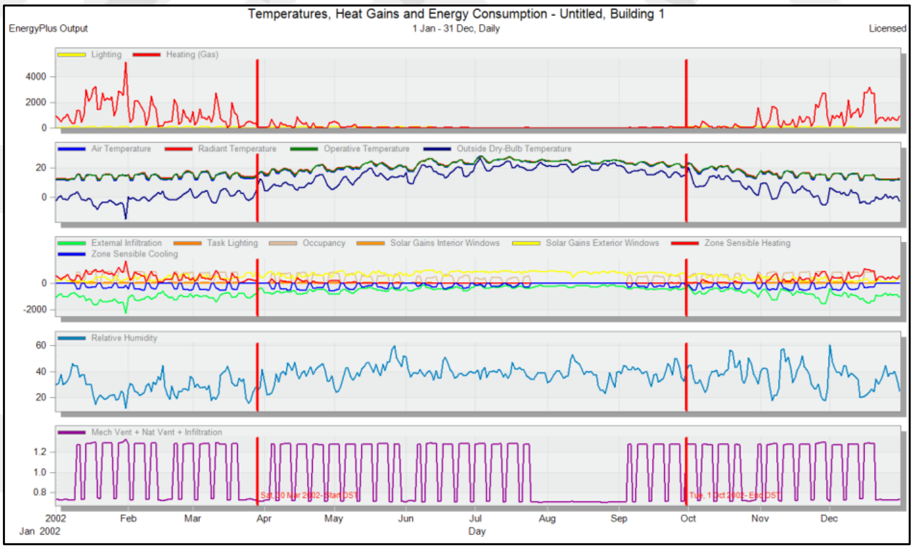
Base line simulation



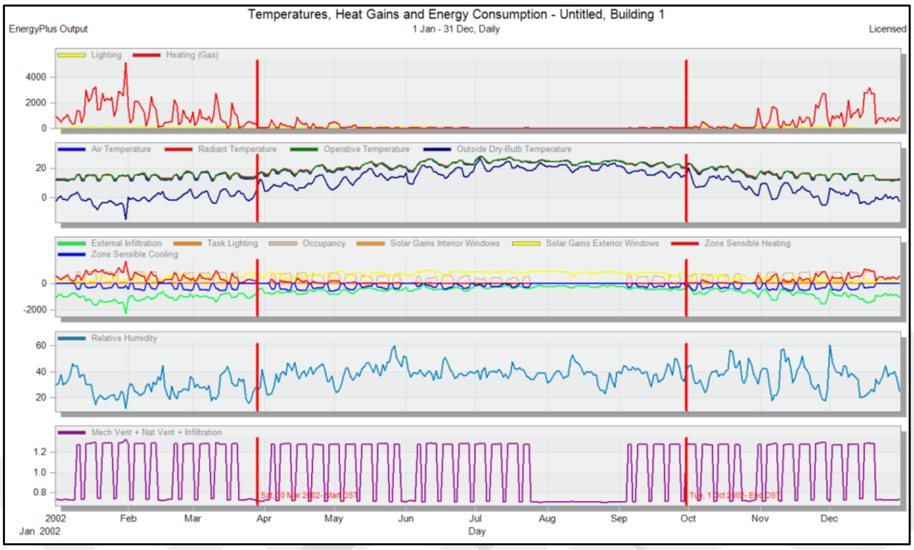
Air tightness simulation



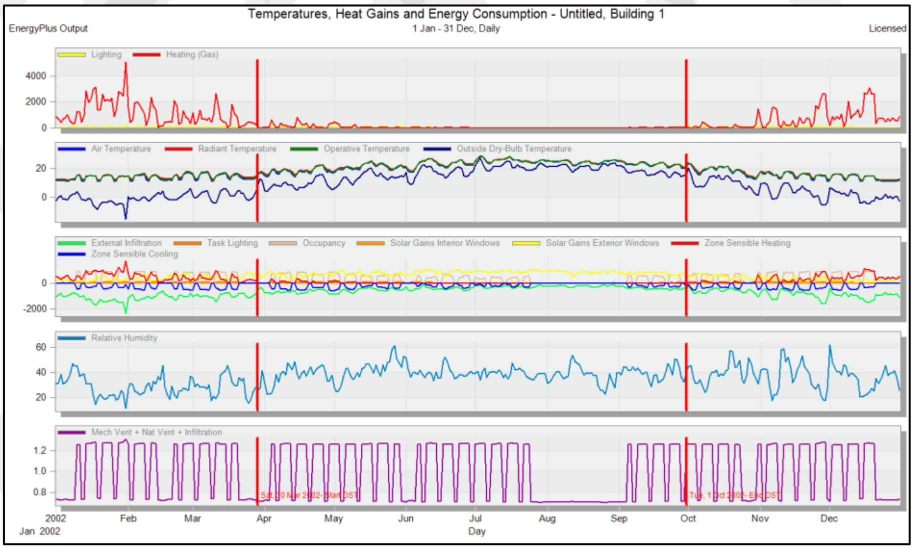
Led lightning simulation



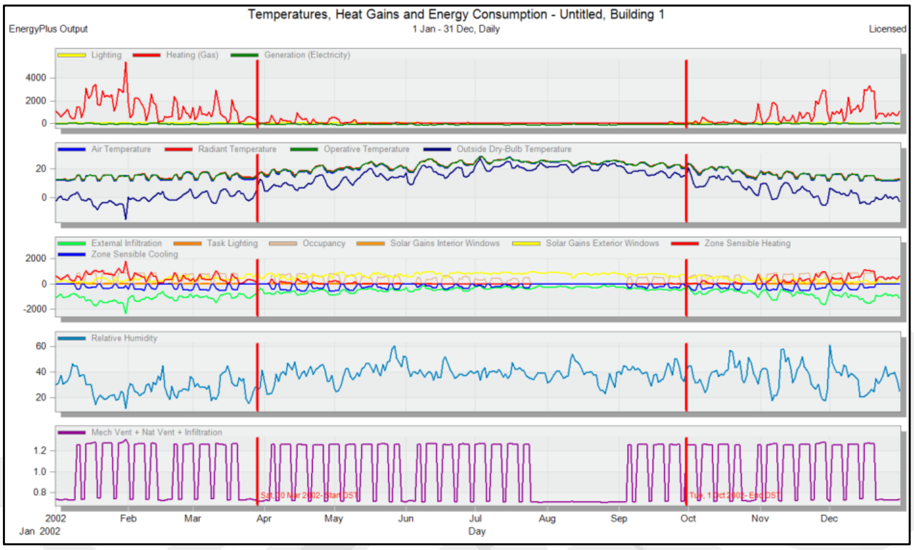
Glasswool simulation



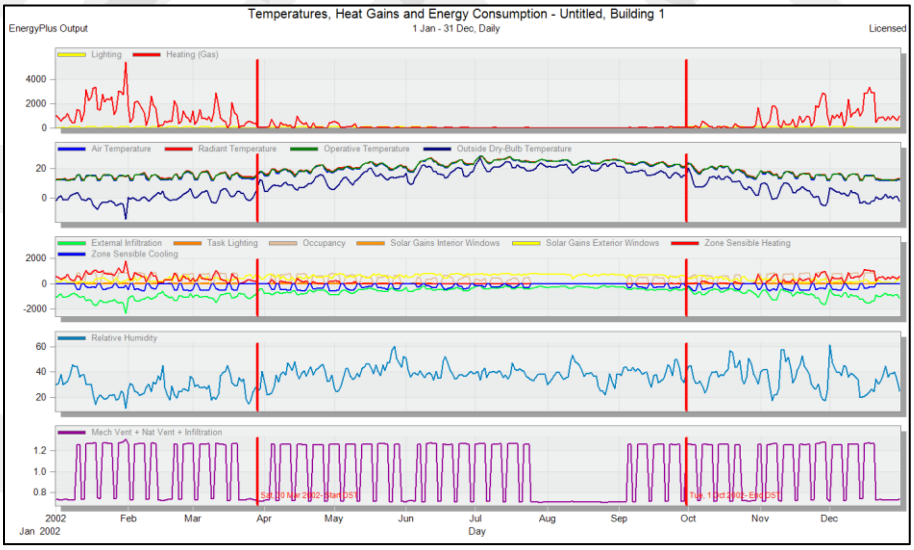
Rockwool simulation



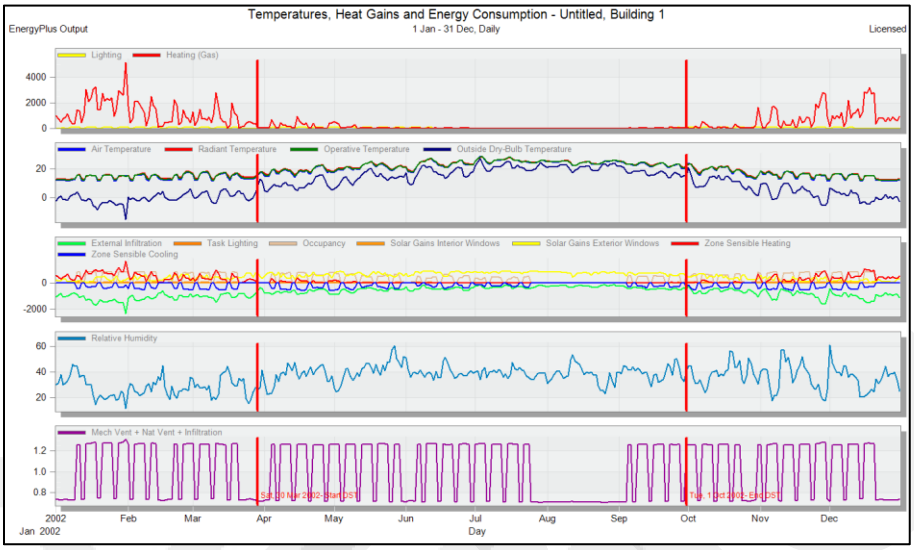
Set temperature simulation



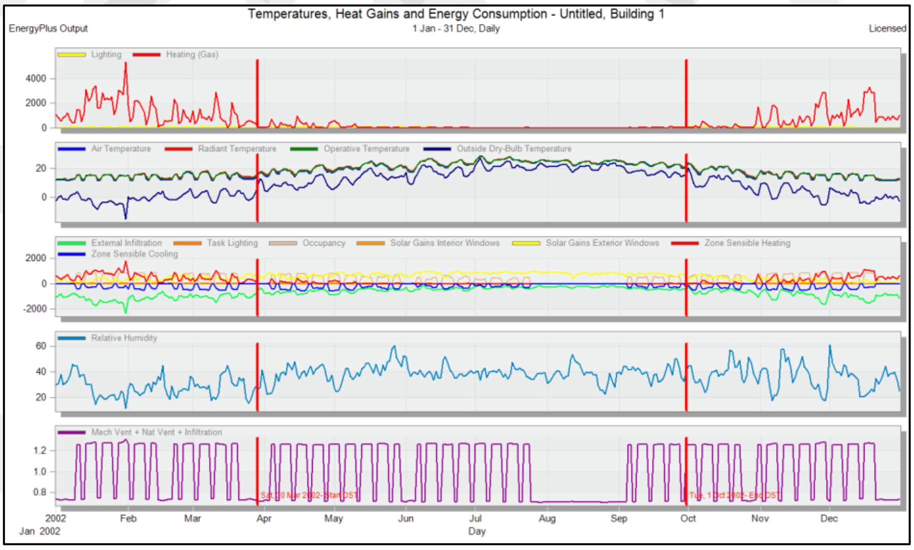
PV-panels and solar collector simulation



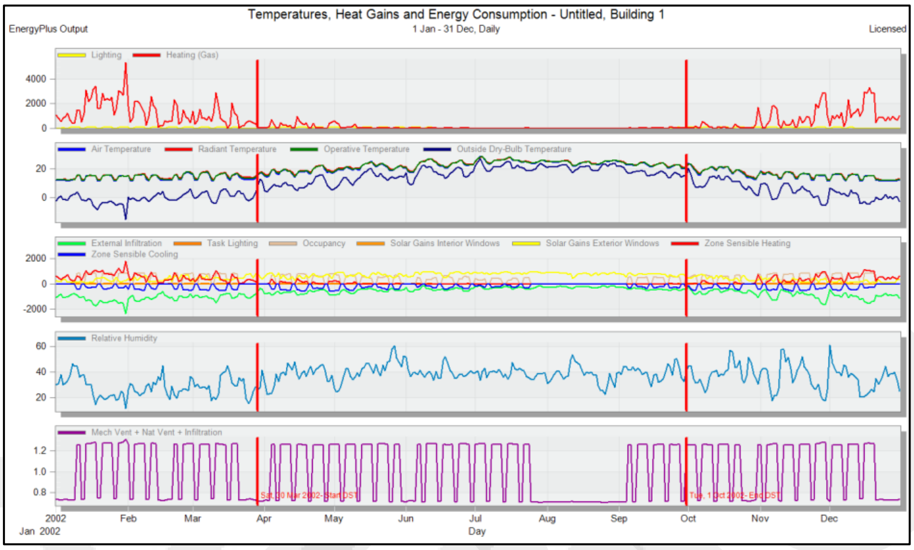
Trombe wall insulation



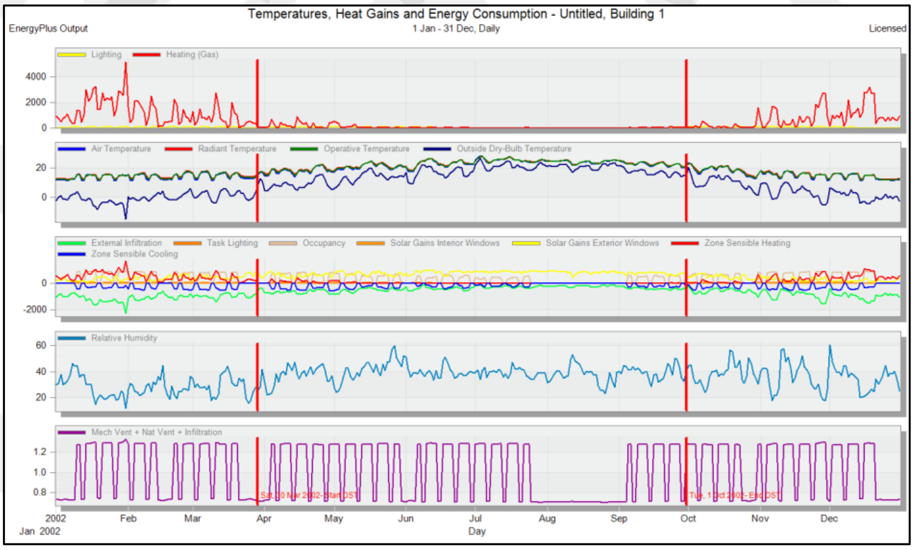
TRP-CLR simulation



UPVC simulation



Wood frame simulation



XPS simulatio

APPENDIX B: RESULT TABLE FROM DESIGN BUILDER SIMULATION

Material/Design Parameter	**λ thermal conductivity (W/mK)**	**l thickness of the material (m)**	**U value material (λ / l)**	**Total U value (λ / l)**	**Thermal Mass(Density- kg/m3)**	**Source Energy(kWh)**	**Design Heating Capacity (kW)**	**End Use Heating(kWh)**	**Time Not Comfortable Based on Simple ASHRAE 55-2004**	**Equivalent CO2 (kgCO2)**	**Net Electricity From Utility(kWh)**	**Interior Lighting (kWh)**
Base				**0.276**		**748064.740**	**522.45**	**120902.29**	**3147.000**	**230949.400**	**98264752.000**	**71667.98**
XPS (inner)	0.03	0.20	0.17	0.11	35.00	713747.21	511.58	111404.82	3149.00	323999.00	Not Changed	Not Changed
XPS (outer)	0.03	0.20	0.17	0.11	35.00	712860.81	511.50	111159.51	3147.00	323999.00	Not Changed	Not Changed
Airtightness(0.3)	N/A	N/A	N/A	N/A	N/A	506614.28	443.21	54080.21	3165.50	Not Changed	Not Changed	Not Changed
Led Lighting	N/A	N/A	N/A	N/A	N/A	647267.29	522.45	137158.8	3154.5	Not Changed	47889752	21292.98
Glasswool (Inner)	0.04	0.20	0.18	0.11	25.00	714218.19	511.64	111535.16	3148.50	242616.20	Not Changed	Not Changed
Glasswool (Outer)	0.04	0.20	0.18	0.11	25.00	713142.38	511.58	111237.43	3147.50	242616.20	Not Changed	Not Changed
Rockwool (Inner)	0.03	0.20	0.17	0.10	100.00	713351.88	511.50	111295.41	3148.00	262039.30	Not Changed	Not Changed
Rockwool (Outer)	0.03	0.20	0.17	0.10	100.00	713142.38	511.38	111237.43	3147.50	262039.30	Not Changed	Not Changed
Set Point Temperature	N/A	N/A	N/A	N/A	N/A	684995.16	510.09	103447.61	3150.50	Not Changed	Not Changed	Not Changed
PV Panel/Sollar Collector	N/A	N/A	N/A	N/A	N/A	653417.41	522.45	121335.89	3144.00	266039.40	67884551 (%30,9 from on-site Sources)	Not Changed
Trombe Wall	N/A	N/A	N/A	N/A	N/A	737261.41	524.33	117912.44	3149.5	232531.80	Not Changed	Not Changed
Tripple Window	0.03	0.90	0.03	1.76	N/A	716025.18	510.27	112035.25	3149.50	226004.00	Not Changed	Not Changed
Wooden Window Frame	0.19	0.02	9.50	3.63	700.00	746585.40	521.51	120492.88	3147.50	Not Changed	Not Changed	Not Changed
PVC Window Frame	0.17	0.02	8.50	3.48	1390.00	746430.83	521.46	120450.10	3147.00	Not Changed	Not Changed	Not Changed