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# Evaluation of Thermal Performance of Traditional Houses and Suggestions for Improvement: Case of Beypazarı Mehmet Üsdün House

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**Abstract**

Traditional buildings should be studied to increase their thermal performance in order to preserve cultural heritage for future generations and ensure proper functionality. This study presents a model proposal for simulating the thermal performance of traditional houses using DesignBuilder software. The results of this evaluation will be used to create suggestions for improving historical buildings. It is possible to evaluate the thermal performance of traditional houses with current analysis software and make suggestions for improving their capacity through preservation activities. Firstly, data were collected, and standards and simulation tools related to thermal performance were examined. A traditional house was chosen as a case study for creating a proposal model and conducting thermal analysis. In the second step, the data processing stage was performed, and the house model was created in DesignBuilder. The collected data were entered into DesignBuilder and simulated. The simulation results were compared with the Turkish Standards (TS 825 - Thermal insulation requirements for buildings). Finally, suggestions were presented as proposals and solutions to improve the thermal performance of historical buildings based on the findings of this study. As a result of this study, it was found that implementing underfloor heating systems in Mehmet Üsdün House increased the thermal performance of the house by 30-35%. It can be concluded that the thermal performance of historical buildings can be effectively improved through the proper utilization of these buildings.

## 1. INTRODUCTION

The basis of energy efficiency policies is the oil crisis in the 1970s, the depletion of fossil fuels and the awareness of climate change [1]. Countries are working to completely stop the gas emissions of all sectors, especially the reduction of greenhouse gas [2]. Looking at the energy consumption graph by sectors, it is known that the construction sector ranks third [3] and efforts are made to reduce emissions in this sector (Figure 1).

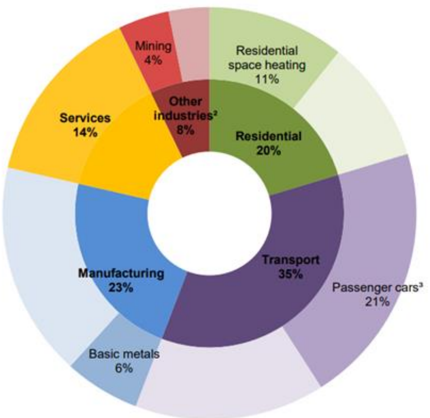


***Figure 1.*** *Total final consumption by sector [3].*

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In the construction sector, which is responsible for approximately one third of the energy consumption, 80% of this consumed energy is used for heating [4]. Studies show that with attention to the energy consumption used in buildings, 50% energy savings can be achieved [5]. Improvement of thermal performance in buildings is one of the most effective ways to reduce excessive energy consumption for heating and cooling and to provide optimum thermal comfort conditions.

ASHRAE (American Society of Heating, Refrigerating and Air-Conditioning Engineers) STANDARD 55-2020 Thermal Environmental Conditions for Human Occupancy can be cited as an international standard for thermal comfort [6]. The basis of thermal performance studies in Turkey is the 'TS 825, Turkish Thermal Insulation Standard' published in 2000. The aim of this standard is to improve the energy performance of new buildings [7]. However, the building sector does not only consist of new buildings, but also traditional architectural heritages are included in the building stock.

In the last decade, three important voluntary standard guidelines have been developed to increase energy efficiency in historic buildings, to give evaluation criteria and recommendations. The first of these is the guide published by the organization called AiCARR (Italian Association of Air Conditioning, Heating and Refrigeration) in 2014 and deals with the protection of architectural heritage as its basis. This guide explains the process of evaluating performance differences before and after increasing the energy efficiency of the building. The second is the guide published by the European Standards Committee (EN 16883:2017) in 2017, and it describes the process to be used when renovating historic buildings, containing similar items to the previous guide. The third, similar to the previous two guides, is the 'Energy Guideline for Historic Buildings' published in 2019 by ASHRAE [8]. In February 2019, ASHRAE made recommendations to improve energy efficiency in historic buildings and manage the process [9]. In Turkey, there is no guide on improving the thermal performance of traditional buildings. The only regulation that makes a statement about the historical buildings that need to be protected is the Regulation on Energy Performance in Buildings, published on December 5, 2008. However, there is no detailed explanation in this regulation [10]. Energy efficiency measures are a tool for the effective use of historical buildings in conservation studies. As stated in the Venice Charter, all science and techniques should be used in the preservation and restoration of historical buildings [11]. However, compatibility, minimum intervention, distinguishability, durability, originality of expression and respect for original texture are important [12]. Interventions should not mislead future work [13] should be given equal attention to all building elements, including the structural system, roofs, timber infill, floors, doors and windows [14] and should only be performed by trained professionals.

### 1.1. Energy Efficiency in Historic Buildings

Historical buildings are heritage items that reflect the past to the present. It is essential to preserve it and pass it on to future generations. However, while preserving historical buildings, adapting them to contemporary life is necessary. The studies aim to increase historical buildings' thermal performance and energy efficiency, maximize the relationship between improving energy efficiency, preserving architectural heritage, and increasing thermal comfort [15]. Thermal performance improvement studies make historical buildings more suitable for use and contribute to the preservation of the buildings. Preserving the built heritage also reduces energy consumption [16]. According to the BPIE, by 2050, small and medium-scale interventions will be possible to reduce $CO2$ and recover energy in historic buildings [17].

Many studies have been conducted to increase energy efficiency and thermal comfort in historical buildings. Dili et al. [18] investigated the difference in thermal comfort between traditional and modern houses in the Kerala region of India. Oikonomou and Bougiatioti [19] examined the thermal comfort of forty traditional buildings in the Florina region of Greece. Morelli et al. [20] aimed to renovate a historical building in the Denmark-Copenhagen region as a zero-energy building. Galvez et al. [21] aimed to restore a historical building in the Seville region of Spain to increase its energy efficiency. Ben and Steemers [22] examined the effect of physical variables on energy savings for historical buildings in London. Alev et al. [23] proposed renovation alternatives to improve the energy performance of historic rural houses in Estonia, Finland, and Sweden. Salata et al. [24] examined the change of thermal properties of a historical texture in Rome with vegetation. Asadi et al. [25] evaluated a selected historical building in the Yazd region of Iran within the scope of energy efficiency. Studies: The researchers, year, location, purpose, method, and result are given in Table 1.

***Table 1.*** *Energy efficiency studies in historical buildings*

| Researchers | Year | Location | Study purpose | Tools | Conclusion |
|---|---|---|---|---|---|
| Dili, Naseer, and Varghese | 2010 | India Kerala | The results of scientific analyses affecting thermal comfort were compared with user responses. | Survey | Kerela's traditional residential buildings provide thermal comfort regardless of the season. |
| Oikonomou and Bougiatioti | 2011 | Greece Florida | The design elements of forty traditional houses built in the 19th and 20th centuries were identified, and their thermal comfort was examined. | Ecotect v5.2 | The form and building materials of traditional houses are a guide for today's buildings. |
| Morelli,Ronby, Mikkelsen, Minzari, Kildemoes and Tommerup | 2012 | Denmark Copenhagen | Improvement methods have been proposed to transform a historic house built in 1896 into a zero-energy building. | Be10 | A 68% saving was achieved in energy use. |
| Galvez, Hita, Martin, Conde and Linan | 2013 | Spain Seville | Two different restoration plans were compared to increase the energy efficiency of a historical building. | LIDER CALENER Survey | Of two restoration plans heat loss in winter and for cooling in summeris better has been detected. |
| Ben and Steemers | 2014 | London | The effect of users' behavior on energy savings in the house was examined. | IESVE | It has been determined that positive behavior change corresponds to 62-86% of total energy savings. |
| Alev,Eskola, Arumagi, Jokisalo, Donarelli, Siren, Brostrom and Kalamees | 2014 | Estonia Finland Sweden | Different improvements have been made to the energy performance of historic houses in three countries. | IDA- ICE | Improving the energy source provided the most significant energy savings. |
| Salata, Golasi, Lietovollaro | 2015 | Rome | Five proposed models were created to examine the effect of vegetation on thermal comfort in the historical environment. | ENVI | The potential of vegetation to reduce the thermal load of buildings in summer and winter has been determined. |
| Asadi,Fakhari and Sendi | 2016 | Iranian Yazd | The energy performance of a traditional house was evaluated. | Ecotect EnergyPlus | It has been determined that the thermal performance of the house's ground floor is more suitable than the other floors. |

In this study, the historical Mehmet Üsdün House, located in Ankara/Beypazarı was chosen for the case study. The aim of the study is to analyze and evaluate the thermal performance and to make suggestions to improve performance without damaging the building. The traditional buildings in Beypazarı have preserved their authenticity. The living floors of the houses in the urban texture are similar and the houses are actively used. For this reason, the findings obtained from the case study will be useful for other traditional houses in the urban texture.

## 2. METHOD

In the study, a model proposal has been made that evaluates the thermal performance of historical buildings and offers suggestions for improvement by preserving the authenticity of the building, and the model has been tested for the historical Mehmet Üsdün House in Beypazarı. The model consists of three stages; data collection phase, data processing phase and solution proposal phase. The structure of the model proposal is shown in Figure 2. With this model, it is aimed to preserve the architectural heritage value while increasing the thermal performance and thermal comfort conditions of the house.

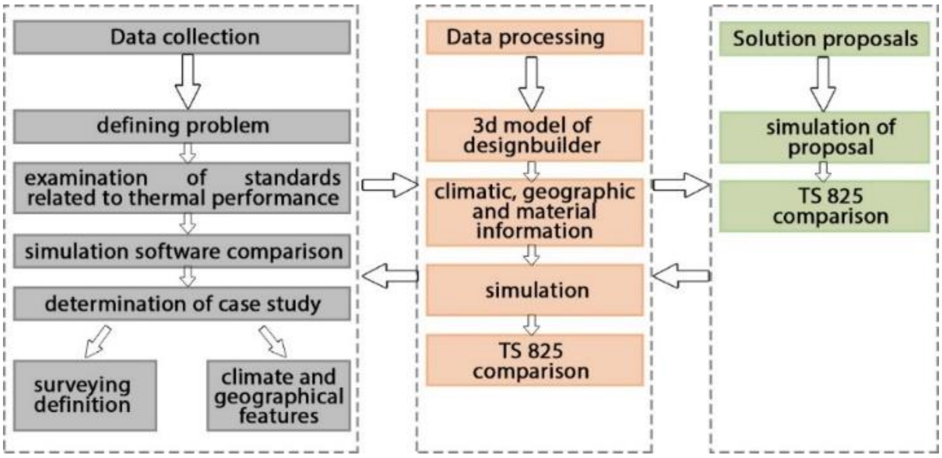



***Figure 2.*** *Structure of the model proposal*

### 2.1. Data Collection Phase

At this stage, the climate and geographical information of Mehmet Üsdün House were obtained. Then, components such as building layout, building geometry, openings, building elements, physical values of building elements, building utilization rate, existing air conditioning and electrical systems were determined.

Mehmet Üsdün House is located in Beypazarı traditional housing pattern and the house is an architectural heritage that should be transferred to the future with its authentic features that have survived to the present day. Similar to many examples of civil architecture, this house cannot adapt to today's comfort conditions and has a protection problem. For this reason, research is required to adapt the building to today's comfort conditions. Mehmet Üsdun House is located in Beytepe neighborhood, which is the first residential area of Beypazarı. The house is located in a large garden and there are no other buildings in its nearby area (Figure 3). Within the scope of the study, the survey of Mehmet Üsdün House was created and the plan, section and views of the building were drawn in Autocad 2018 software (Figure 3). Architectural details are ignored as they will not be evaluated in the thermal performance analysis.

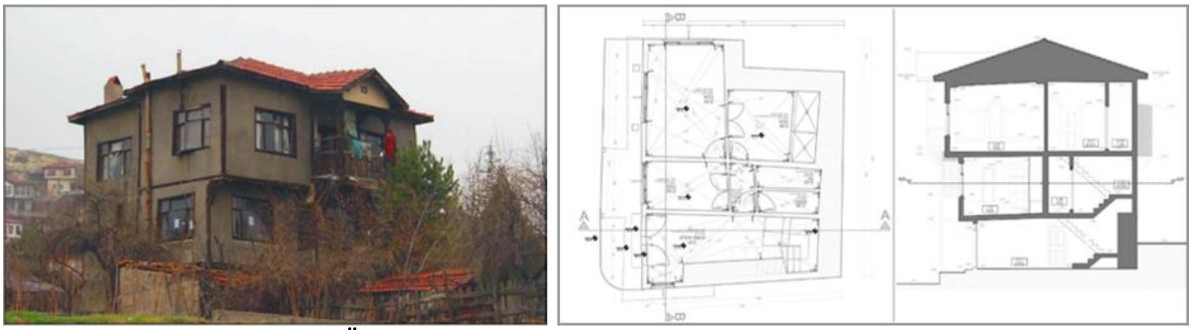
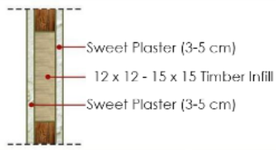


***Figure 3.*** *Mehmet Üsdün House (left) and Ground floor plan / A-A section (right)*

Mehmet Üsdün House consists of three floors and on the ground floor, as in all Beypazarı houses, there are service, warehouse, etc. space are located. The first floor is the winter floor, and on this floor there are two rooms with the functions of resting, sitting and working. The second floor is a repetition of the first floor in terms of plan layout. As the house is located on a sloping land, the ground floor is half buried. The buried walls of the house were built with a stone masonry system, and the first and second floors were built with a timber framed system.

For the thermal performance analysis, the properties of the building materials used in the house were calculated. These; thickness (mm), density [d(kg/m3)], thermal conductivity [λ (W/mK)], thermal resistance [R (m2.K/W)] and thermal conductivity value [U(W/m2) .K)]. The type and thickness value of the materials were determined by the survey study. Other values (such as, thermal conductivity, density) of the materials were calculated based on TS 825. According to these calculations, details were created for all the walls, floors and roofs that make up the house. The details created for the timber framed wall, timber floor and ceiling are shown in Figure 4 and Figure 5. After calculating the material properties, some assumptions are made for the thermal performance analysis. These; the functions of the spaces in the house are the heating system and the lighting system.

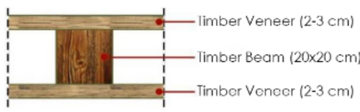
**TIMBER WALL**




| | | Material | Thickness (mm) | Thermal Conductivity λ (W/mK) | Density d (kg/m3) | Thermal Resistance R (m2.K/W) | Thermal Conductivity Value U(W/m2) .K |
|---|---|---|---|---|---|---|---|
| TIMBER FRAMED SYSTEM | | Sweet Plaster | 30-50 | 2,2 | 2500 | 0,02 | 0,74 |
| | | Timber Frame with Timber Infill | 120-150 | 0,13 | 600 | 1,15 | |
| | | Sweet Plaster | 30-50 | 2,2 | 2500 | 0,02 | |
| HEAT TRANSFER RESISTANCE | Ri | | | | | 0,13 | |
| | Re | | | | | 0,04 | |
| Rtotal | | | | | | 1,36 | |

***Figure 4.*** *Physical values of timber wall detail*

**TIMBER FLOOR**




| | | Material | Thickness (mm) | Thermal Conductivity λ (W/mK) | Density d (kg/m3) | Thermal Resistance R (m2.K/W) | Thermal Conductivity Value U(W/m2) .K |
|---|---|---|---|---|---|---|---|
| TIMBER BEAM SYSTEM | | Timber Veneer (floor) | 20 | 0,13 | 600 | 0,15 | 0,48 |
| | | Timber Beam | 200 | 0,13 | 600 | 1,54 | |
| | | Timber Veneer (ceiling) | 20 | 0,13 | 600 | 0,15 | |
| HEAT TRANSFER RESISTANCE | Ri | | | | | 0,13 | |
| | Re | | | | | 0,13 | |
| Rtotal | | | | | | 2,1 | |

***Figure 5.*** *Physical values of timber floor and ceiling*

Since each room is used as a house in traditional houses, it accommodates all functions such as sitting, resting and eating. Other spaces consist of circulation areas and wet areas such as kitchen and toilet. For this reason, space functions are divided into three groups for thermal performance analysis. The first group consists of sitting, resting and eating functions. The second group consists of circulation areas and the third group includes wet areas.

The heating system of traditional houses used to provide furnace or barbecues in the past, but today the stove is used as the heating system. It has been determined that the heating system of Mehmet Üsdün House is also a stove and it is accepted that heating is provided in all the spaces where the stove chimney is located.

In the past, the lighting need in traditional houses was provided by gas lamps and candles. However, today the lighting system has changed and fluorescent lamps have begun to be used. In the current situation of Mehmet Üsdün House, it has been determined that the lighting is provided by fluorescent lamps.

The timber framed walls of Beypazarı traditional houses are covered inside and outside with a plaster called 'sweet plaster', which is unique to the region. However, the sweet plaster on the exterior walls of the Mehmet Üsdün House was covered with cement plaster to provide insulation. In this study, the effect of the original material properties of the house on the thermal performance result is important. For this reason, cement plaster has been ignored.

Finally, for the thermal performance analysis, the outside temperature values of the area where the house is located should be known. The outside temperature value of Mehmet Üsdün House is taken from the table of monthly average outdoor temperature values given in TS 825 (Table 2). Beypazarı, where Mehmet Üsdün house is located, is in the 3rd zone in the table.

***Table 2.*** *Average outdoor temperature values, TS 825 [7]*

| | *Zone 1* | *Zone 2* | *Zone 3* | *Zone 4* | *Zone 5* |
|---|---|---|---|---|---|
| *Jan* | 8,4 | 2,9 | -0,3 | -5,4 | -10,5 |
| *Feb* | 9,0 | 4,4 | 0,1 | -4,7 | -9,1 |
| *Mar* | 11,6 | 7,3 | 4,1 | 0,3 | -2,9 |
| *Apr* | 15,8 | 12,8 | 10,1 | 7,9 | 5,3 |
| *May* | 21,2 | 18,0 | 14,4 | 12,8 | 10,6 |
| *Jun* | 26,3 | 22,5 | 18,5 | 17,3 | 14,6 |
| *Jul* | 28,7 | 24,9 | 21,7 | 21,4 | 18,6 |
| *Aug* | 27,6 | 24,3 | 21,2 | 21,1 | 18,6 |
| *Sep* | 23,5 | 19,9 | 17,2 | 16,5 | 14,1 |
| *Oct* | 18,5 | 14,1 | 11,6 | 10,3 | 7,8 |
| *Nov* | 13,0 | 8,5 | 5,6 | 3,1 | 0,6 |
| *Dec* | 9,3 | 3,8 | 1,3 | -2,8 | -6,7 |

## 2.2. Data Processing Phase

There are many evaluation methods for thermal performance analysis. AiCARR (Associazione Italiana Condizionamento dell`aria, Riscaldamento Refrigerazione) has divided the thermal performance evaluation methods in historical buildings into three groups. The first group is evaluation with visual inspection, the second group is evaluation with stationary computational models. The third group is analysis with dynamic computational models [12]. In this study, the second and third group methods specified in AiCARR were used to analyze and evaluate the thermal performance of Mehmet Üsdün House. In other words, the current and post-improvement thermal performance of Mehmet Üsdün House was calculated and compared with both building simulation software and stationary computational models.

Building simulation softwares, provides opportunities to break through the limitations of conventional building energy modelling and calculations. In addition, these software incorporate building energy modeling into the building design process [26]. In the building sector, energy simulation software is used for energy modeling, energy improvement, carbon-mitigation, and energy efficient- designs [27].

Some of the commonly used building energy simulation software include: EnergyPlus, TRNSYS, DOE-2, DeST, ESP-r, IDA-ICE, TRNSYS IES-VE, Modelica and Trane Trace 700 [28]. However, four popular BES tools from these software are EnergyPlus, TRNSYS, IDA-ICE and IES-VE [29]. These software are used in energy efficiency and thermal performance analysis of buildings.

Compared to other software, Energyplus was developed by the US Department of Energy and is constantly being renewed. However, EnergyPlus software has a complex interface. But, DesignBuilder software, which was developed using EnergyPlus infrastructure, provides an easy-to-use interface [30]. For this reason, DesignBuilder was used as a simulation software in this research. In the continuation of this study, the analysis results obtained in the DesignBuilder software were compared with the data in TS 825, a Turkish standard.

During the data processing phase, in the first step, the climate and geographical location features of Mehmet Üsdün House were defined to the DesignBuilder software. A 3d model of the house was made with the measurements obtained from the survey work (Figure 6). All the data obtained during the data collection phase were defined on this 3d model. The analysis process has started within the scope of the data obtained from the case study and the accepted assumptions.

***Figure 6.*** *Mehmet Üsdün House DesignBuilder model*

The internal temperature of the Mehmet Üsdün House was calculated as 10.62 °C in winter. It was observed that the highest heat loss was in the outer walls (19, 65 w/m2), and the second highest heat loss (16,78 w/m2) was caused by the windows. It has been observed that some surfaces provide heat gain, unlike elements that heat lose. While 3.20 w/m2 heat gain was achieved from the stone flooring, which is the floor of the ground floor, 1.03 w/m2 heat gain was achieved from the timber floors (Figure 7).

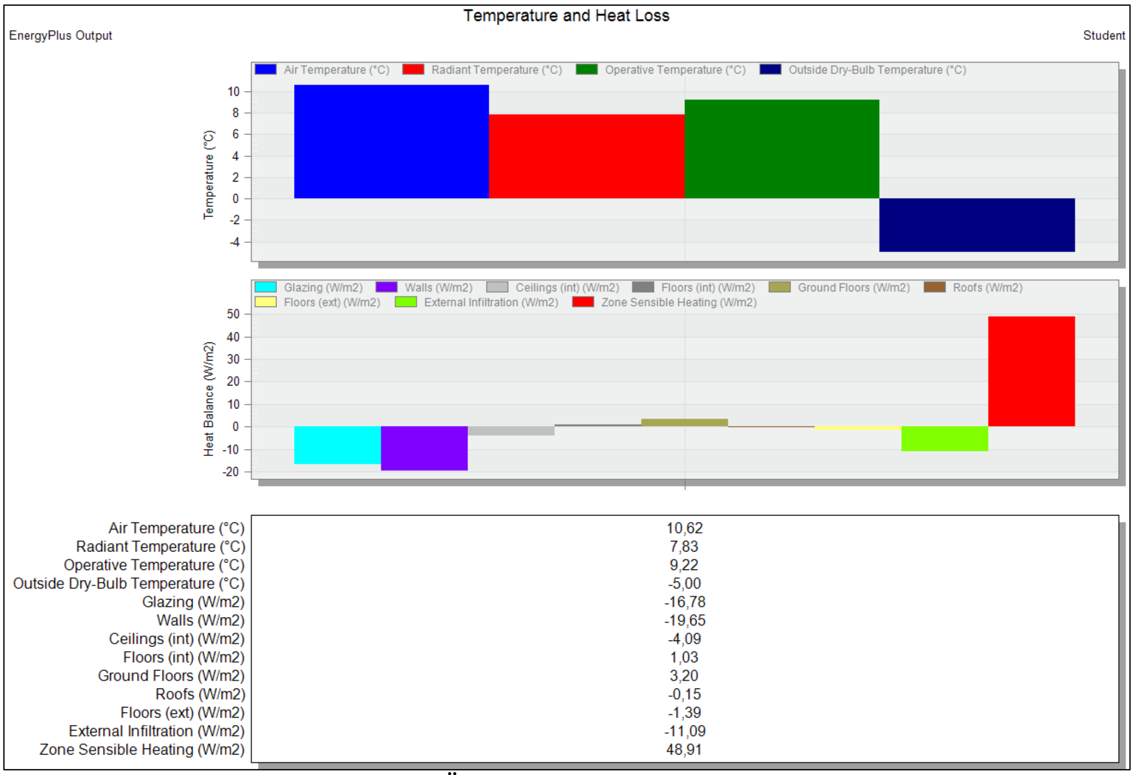



***Figure 7.*** *Mehmet Üsdün House heating design calculation*

The floors in Mehmet Üsdün House differ in terms of floor height and total volume. For this reason, besides the general calculations, the heat capacity and heat loss of each floor must be calculated. The average temperature of the ground floor (12.84 °C) was calculated higher than the general building temperature. It was observed that the room (Z-04), buried in the slope and surrounded by stone masonry walls, had a better comfort temperature of 16.25 °C compared to the other rooms (Figure 8). Since there is heating system in only two rooms on the first floor, the calculated average temperature value (9.99 °C) is lower than the general building temperature value. It was observed that the room with the best comfort temperature (15, 37 °C) on the first floor was room 1-03. This room is oriented towards the south façade and has the function of sitting, living, eating and resting (Figure 9). The average temperature value of the second floor (9.58 °C) was calculated lower than the ground floor and the first floor. The reason why the average temperature of the second floor is lower than the first floor can be associated with the use of the middle floor as a winter floor and the upper floor as a summer floor in traditional houses. This showed that the second floor needed more energy to be heated compared to the other floors. The room with the best comfort temperature (15.09 °C) on the second floor is room 2-05. This room is the most important room of the house, called the 'başoda' (Figure 10).

| Zone | Comfort Temperature (°C) | Steady-State Heat Loss (kW) | Design Capacity (W/m2) |
|---|---|---|---|
| Mehmet Üsdün Total Design Heating Capacity = 10,410 (kW) | | | |
| Ground Floor Total Design Heating Capacity = 2,630 (kW) | | | |
| Z-01 entrance hall | 2,32 | 0,00 | 0,0000 |
| Z-02 room | 16,03 | 0,43 | 101,0258 |
| Z-03 room | 15,85 | 0,91 | 89,3645 |
| Z-04 room | 16,25 | 0,76 | 68,4069 |
| Z-05 wc | 7,77 | 0,00 | 0,0000 |
| Z-06 warehouse | 6,24 | 0,00 | 0,0000 |
| Z-07 hall | 9,57 | 0,00 | 0,0000 |

***Figure 8.*** *Heating design calculation for ground floor*

| Zone | Comfort Temperature (°C) | Steady-State Heat Loss (kW) | Design Capacity (W/m2) |
|---|---|---|---|
| Mehmet Üsdün Total Design Heating Capacity = 10,410 (kW) | | | |
| Ground Floor Total Design Heating Capacity = 2,630 (kW) | | | |
| First Floor Total Design Heating Capacity = 3,270 (kW) | | | |
| 1-01 room | 14,85 | 1,22 | 134,6913 |
| 1-02 sofa | 2,20 | 0,00 | 0,0000 |
| 1-03 room | 15,37 | 1,40 | 97,8264 |
| 1-04 kitchen | 1,87 | 0,00 | 0,0000 |
| 1-05 bathroom | -0,40 | 0,00 | 0,0000 |
| 1-06 stairs | -0,82 | 0,00 | 0,0000 |

***Figure 9.*** *Heating design calculation for first floor*

| Zone | Comfort Temperature (°C) | Steady-State Heat Loss (kW) | Design Capacity (W/m2) |
|---|---|---|---|
| Mehmet Üsdün Total Design Heating Capacity = 10,410 (kW) | | | |
| Ground Floor Total Design Heating Capacity = 2,630 (kW) | | | |
| First Floor Total Design Heating Capacity = 3,270 (kW) | | | |
| Second Floor Total Design Heating Capacity = 4, 510 (kW) | | | |
| 2-01 sofa | 0,44 | 0,00 | 0,0000 |
| 2-02 room | 14,88 | 1,59 | 144,2475 |
| 2-03 rhall | 2,54 | 0,00 | 0,0000 |
| 2-05 room | 15,09 | 2,03 | 117,9482 |
| 2-06 kitchen | -1,74 | 0,00 | 0,0000 |
| 2-08 wc | -2,99 | 0,00 | 0,0000 |
| 2-09 bathroom | -3,64 | 0,00 | 0,0000 |

***Figure 10.*** *Heating design calculation for second floor*

After the heating design calculation, the thermal performance analysis of the house and the evaluation of the energy use were made. The simulation used for the calculations was run annually because the Turkish standard (TS-825) gives the values annually. The simulation results showed that the annual energy consumption of Mehmet Üsdun House is 242.84 kWh/m2 per square meter (Figure 11).

**Site and Source Energy**

| | Total Energy [kWh] | Energy Per Total Building Area [kWh/m2] | Energy Per Conditioned Building Area [kWh/m2] |
|---|---|---|---|
| Total Site Energy | 23421.56 | 137.39 | 242.84 |
| Net Site Energy | 23421.56 | 137.39 | 242.84 |

***Figure 11.*** *Total energy consumption per square meter, DesignBuilder*

The calculated total energy consumption includes the sum of all energy consumptions (such as lighting energy). In order to evaluate the thermal performance, it is important to determine the amount allocated for the heating system. DesignBuilder simulation results showed that of the total energy consumption calculated as 242.84 kWh/m2, 221.98 kWh/m2 was used for heating and 20.86 kWh/m2 was used for lighting (Table 3).

***Table 3.*** *Distribution of total energy consumption*

| | *Electric (kWh/m$^2$)* | *Heating (kWh/m$^2$)* |
|---|---|---|
| *Lighting* | 20,86 | 0,00 |
| *HVAC* | 0,00 | 221,98 |
| *Total* | 20,86 | 221,98 |

It has been compared whether this energy used for heating is suitable according to TS 825. For this reason, using the values given in TS-825, the maximum amount of energy that the house should consume has been calculated. TS 825 has limited the maximum annual heating energy consumed by the building according to zones and Atot/Vbrut ratio (Table 4).

***Table 4.*** *Q value calculation table of TS 825 [7].*

| | | | | |
|---|---|---|---|---|
| *Zone 1* | $A_{tot}$ | $Q'_{1.DG}$ = | 36,7×A/V+6,0 | [kWh/m$^2$] |
| | $V_{brut}$ | $Q'_{1.DG}$ = | 11,9×A/V+1,9 | [kWh/m$^3$] |
| *Zone 2* | $A_{tot}$ | $Q'_{2.DG}$ = | 63,7×A/V+14,9 | [kWh/m$^2$] |
| | $V_{brut}$ | $Q'_{2.DG}$ = | 20,3×A/V+4,7 | [kWh/m$^3$] |
| *Zone 3* | $A_{tot}$ | $Q'_{3.DG}$ = | 74,2×A/V+4,7 | [kWh/m$^2$] |
| | $V_{brut}$ | $Q'_{3.DG}$ = | 23,2×A/V+7,4 | [kWh/m$^3$] |
| *Zone 4* | $A_{tot}$ | $Q'_{4.DG}$ = | 83,4×A/V+31,0 | [kWh/m$^2$] |
| | $V_{brut}$ | $Q'_{4.DG}$ = | 27,1×A/V+9,8 | [kWh/m$^3$] |
| *Zone 5* | $A_{tot}$ | $Q'_{5.DG}$ = | 88,7×A/V+30,6 | [kWh/m$^2$] |
| | $V_{brut}$ | $Q'_{5.DG}$ = | 24,5×A/V+12,1 | [kWh/m$^3$] |

‘Atot’ is the total area of the house's heat-losing surfaces (such as windows, doors, walls, floors) and ‘Vbrut’ is the building gross volume heated. These values were taken from the 3d data created in the DesignBuilder program. For Mehmet Üsdün House, the Atot value was calculated as 342.46 m2, the Vbrut value was calculated as 285.40 m3 and the ratio of these values was found to be 1,199. This ratio has been substituted in the equation given for the zone 3 where Mehmet Üsdun House is located (Table 4), and the maximum heat requirement of this house is calculated as 111.37 kWh/m2.

However, in the simulation studies, the annual heating energy need of this house was calculated as 221.98 kWh/m2 (Table 3). As a result, it has been observed that the heating system of the house is not suitable according to the calculation method given in TS 825. For this reason, it has been observed that the thermal performance of Mehmet Üsdün House is low and the performance needs to be increased. In the third phase, solution suggestions were presented to increase the thermal performance of the house.

## 2.3. Solution Proposal Phase

Intervention methods to increase thermal performance can be very various in contemporary buildings, but are limited in historical buildings. This limitation is within the scope of preserving the authenticity of the cultural property. In this context, authenticity is mentioned in the The Nara Document on Authenticity as follows “The understanding of authenticity plays a fundamental role in all scientific studies of the cultural heritage, in conservation and restoration planning, as well as within the inscription procedures used for the World Heritage Convention and other cultural heritage inventories” [31]. Regarding authenticity, The Burra Charter gives the opportunity to intervene with the following principles: ‘do as much as necessary, but change it as little as possible' and ‘Traditional techniques and materials are preferred for the conservation of significant fabric’ [32].

Methods to increase thermal performance in traditional architectural heritage buildings; removal of moisture, insulation of inconspicuous spaces such as attics and basements, double glazing application by preserving the original window joinery, if the existing heating system is not sufficient, replace it with minimal intervention, deciding on the usage scenarios of the spaces etc.

Within the scope of the study; In order to increase the thermal performance, it was decided to replace the heating system (stove) used in the house. For the new heating system, underfloor heating system was chosen. Because there is no radiator in this system and the hot water pipes remain under the floor. Thus, the interior originality of the building will be preserved.

There are many types of underfloor heating system. Underfloor heating system without screed was preferred for Mehmet Üsdün House. This system is used in the renovations of existing houses and is easy to apply. In this system, hot water pipes can be placed inside a foam board with a thickness of 3-4 cm. Then the floor covering can be applied directly on it. Since it is a low thickness of 3-4 cm, it does not change the floor height in traditional houses and interferes with the building at a minimum.

In the underfloor heating system, the temperature of the hot water coming out the heat source can be adjusted. In this system, the hot water comes out at a maximum temperature of 60°C and returns at 30°C. These temperatures are such that they do not damage the original timber floor covering of the building.

In the proposed underfloor heating system, it is envisaged to remove the original timber coverings and put them back in place after the heating system. The detail of the underfloor heating system created for the timber flooring on the first and second floors of the house is shown in Figure 12. It is envisaged that the stone paving on the ground floor will be removed and placed back after the heating system. This work is possible within the scope of restoration work. The detail of the underfloor heating system created for the stone paving is shown in Figure 13.

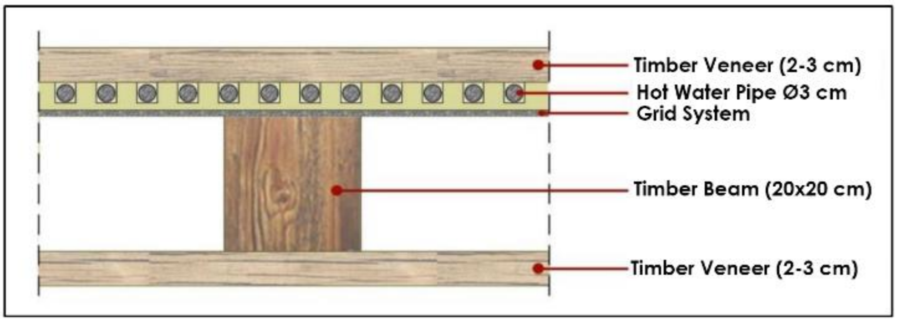



***Figure 12.*** *Underfloor heating system detail for timber floor*

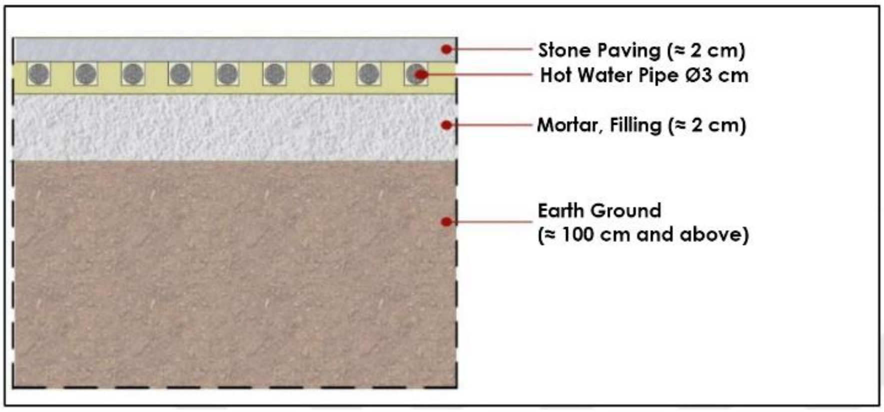



***Figure 13.*** *Underfloor heating system detail for stone paving*

It is important where the heat source will be located in the heating system and where the vertical circulation pipes will pass. Because for vertical circulation pipes, holes must be made in the original floor covering. For this reason, it was decided to locate the heat source on the ground floor, which is less important than the other floors, in the space used as a storage.  Vertical circulation pipes are passed from the ground floor to the inconspicuous bathroom spaces of the first and second floors. It has been decided that the pipes that will circulate between the rooms of the house will pass under the door. Because drilling holes in original walls is not appropriate within the scope of preservation work. The schematic plan and sectional representation of the floor heating system proposed for the house is shown in Figure 14.

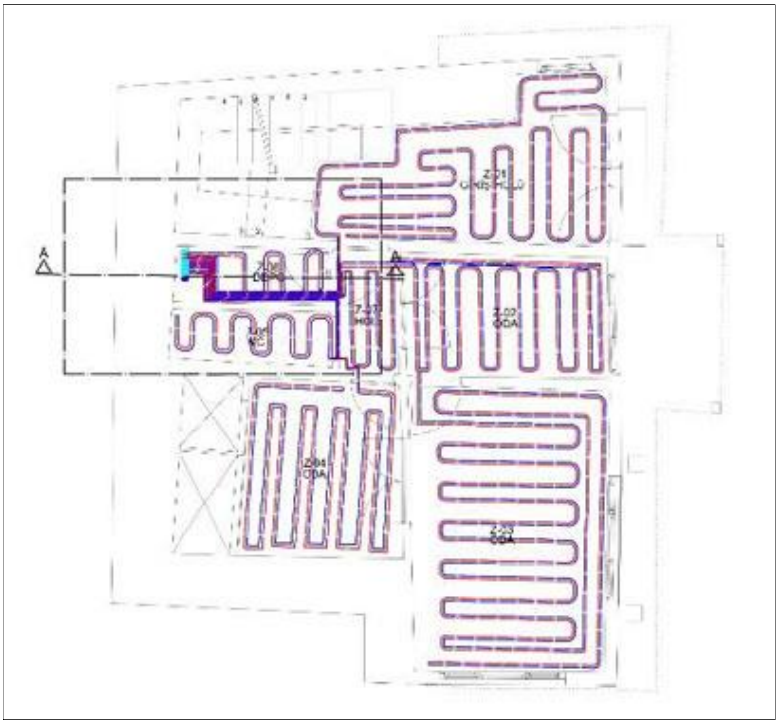


***Figure 14.*** *Underfloor heating system detail for stone paving*

In the simulation studies, the fuel type used in the heating system was evaluated on two different scenarios, natural gas and electricity. Because, the difference in fuel type varies in terms of energy efficiency and intervention. As an example of these;

- Natural gas is a more sustainable fuel type than electricity in terms of CO2 conversion factor.
- Traditional houses do not have natural gas installations and new installations require an additional investment cost. However, the electricity infrastructure is available in many houses, so the investment cost is low.
- It is mandatory to open a chimney hole in the natural gas heating system, but there is no such requirement in the electric heating system.
- For this reason, the electric heating system is more suitable in terms of protection rules than the natural gas one.
- Since natural gas is an explosive and flammable material, it is more dangerous for timber structures than electricity.
- Turkey is a foreign-dependent country in terms of electricity and natural gas energy. However, it increases its electricity production day by day. Therefore, electricity is more economically sustainable.

### 2.3.1 Underfloor Heating System with Natural Gas

In DesignBuilder software, the existing heating system has been replaced with a natural gas underfloor heating system. The simulation results showed that the comfort temperature has increased in all spaces of the house and the amount of heat provided by the heating system has increased (Figure 15).

In the simulations of the current situation of the house, the annual heating energy calculated as 221.98 kwh/m2 has decreased to 153.47 kwh/m2 with the natural gas underfloor heating system (Table 5). This indicates that the thermal performance has increased by 30-35%.

| Zone | Comfort Temperature (°C) | Steady-State Heat Loss (kW) | Design Capacity (W/m2) |
|---|---|---|---|
| Mehmet Üsdün Total Design Heating Capacity = 17,390 (kW) | | | |
| Ground Floor Total Design Heating Capacity = 4,250 (kW) | | | |
| Z-01 entrance hall | 15,63 | 1,19 | 121,6786 |
| Z-02 room | 16,55 | 0,32 | 74,9309 |
| Z-03 room | 15,67 | 0,98 | 98,5809 |
| Z-04 room | 16,52 | 0,65 | 58,6159 |
| Z-05 wc | 17,32 | 0,10 | 53,4014 |
| Z-06 warehouse | 17,22 | 0,12 | 56,6000 |
| Z-07 hall | 17,54 | 0,05 | 37,9587 |
| First Floor Total Design Heating Capacity = 4,990 (kW) | | | |
| 1-01 room | 15,45 | 0,97 | 107,2074 |
| 1-02 sofa | 16,14 | 0,75 | 92,1330 |
| 1-03 room | 15,79 | 1,16 | 81,3095 |
| 1-04 kitchen | 16,75 | 0,44 | 66,9887 |
| 1-05 bathroom | 17,11 | 0,17 | 53,3409 |
| 1-05 stairs | 16,51 | 0,50 | 157,5640 |
| Second Floor Total Design Heating Capacity = 6,440 (kW) | | | |
| 201 sofa | 16,82 | 0,60 | 73,6811 |
| 2-02 room | 15,33 | 1,34 | 121,3978 |
| 2-03 hall | 16,44 | 0,32 | 113,3278 |
| 2-05 room | 15,64 | 1,63 | 95,1074 |
| 2-06 kitchen | 16,25 | 0,81 | 92,3336 |
| 2-08 wc | 16,91 | 0,09 | 147,0861 |
| 2-09 bathroom | 16,22 | 0,36 | 147,3548 |

***Figure 15**. Underfloor heating system with natural gas, summary table*

***Table 5.** Q Distribution of total energy consumption per square meter as a result of natural gas underfloor heating*

| | *Electric (kWh/m$^2$)* | *Heating (kWh/m$^2$)* |
|---|---|---|
| *Lighting* | 20,86 | 0,00 |
| *HVAC* | 0,44 | 153,47 |
| *Total* | 21,03 | 153,47 |

#### 2.3.2. Underfloor Heating System with Electric

In the DesignBuilder software, the data entry for the heating system is exactly the same for natural gas and electric systems. For this reason, only the fuel type has been changed. After changing the fuel type to electric, the simulation results gave almost the same results as the natural gas heating system. The only thing that changed was the fuel type (Table 6).

***Table 6.** Q Distribution of total energy consumption per square meter as a result of electric underfloor Heating*

| | *Electric (kWh/m$^2$)* | *Other heating (kWh/m$^2$)* |
|---|---|---|
| *Lighting* | 20,86 | 0,00 |
| *HVAC* | 153,64 | 0,00 |
| *Total* | 174,50 | 0,00 |

In the heating system, it was concluded that only the differentiation of the fuel type does not make a difference in the total energy consumption. This is due to the fact that the following are the same: Ventilation time, user density, hot water from the boiler, etc.

The simulation data obtained for the proposed natural gas and electric underfloor heating system were evaluated according to TS 825. Together with the proposed heating systems, the amount of heat consumed by the house was found to be 153 kWh/m2. This value is higher than the value obtained from TS 825 (111,37 kWh/m2). The proposed systems could not meet the required value given in TS 825. However, 30-35% thermal improvement was achieved. Since the aim of the study is to improve the thermal performance, the study has achieved its purpose. There was no difference between the effects of natural gas and electric heating systems on thermal performance. However, it was observed that there was a significant difference in the CO2 ratios caused by the fuel types. The amount of CO2 produced by the existing heating system of the house and the amounts produced by the proposed heating systems are given in figure 16, 17 and 18.

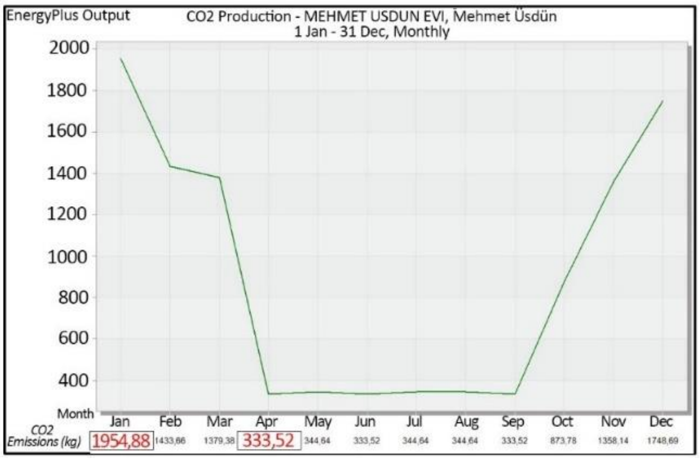



***Figure 16**. Underfloor heating system with natural gas, summary table*

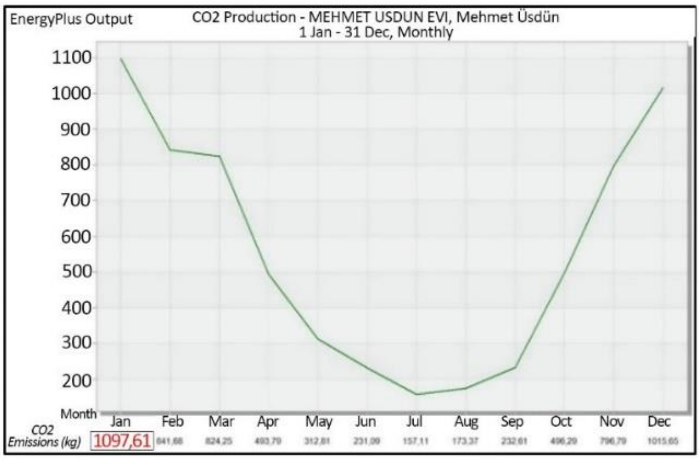



***Figure 17**. CO2 production distribution of the house's natural gas heating system by month*

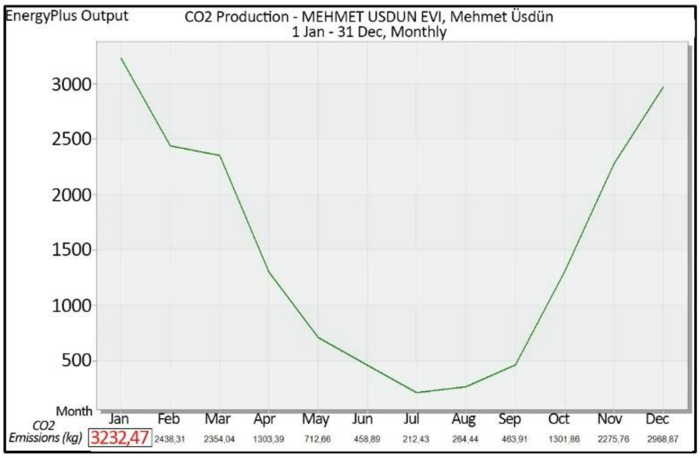



***Figure 18**. CO2 production distribution of the house's electric heating system by month*

Considering the distribution of CO2 emissions from the existing heating system, it is seen that the highest emission was in January and reached 1954.88 kg and started to decrease with April. For a natural gas underfloor heating system, the fuel type was converted from coal to natural gas in DesignBuilder.

Natural gas is a more efficient fuel type than coal in terms of CO2 conversion coefficient. For this reason, with the use of natural gas, CO2 emissions decreased to 1097.61 kg, resulting in a 50% reduction. When the fuel type is converted to electricity, the amount of CO2 produced by the house has increased by 60%, reaching 3232.47 kg. This is related to the fact that the CO2 conversion coefficient of electricity is greater than that of natural gas. The summary table of simulation data between the heating system in the current situation of the house and the proposed heating systems is given in table 7.

***Table 7.*** *Calculated data for Mehmet Üsdün House, current situation and proposed heating systems*

| | | *Current situation* | *Heating system with natural gas* | *Heating system with electric* |
|---|---|---|---|---|
| *Air Temperature* | | 10,62 °C | 13,47 °C | 13,47 °C |
| *Heat Loss* | Glazing | 16,78 w/m$^2$ | 3,55 w/m$^2$ | 3,55 w/m$^2$ |
| | Walls | 19,65 w/m$^2$ | 5,49 w/m$^2$ | 5,49 w/m$^2$ |
| | Ceiling (int) | 4,09 w/m$^2$ | 0,68 w/m$^2$ | 0,68 w/m$^2$ |
| | Floors (ext) | 1,39 w/m$^2$ | 0,27 w/m$^2$ | 0,27 w/m$^2$ |
| | External Infiltration | 11,09 w/m$^2$ | 2,80 w/m$^2$ | 2,80 w/m$^2$ |
| *Heat Gain* | Floors (int) | 1,03 w/m$^2$ | 0,68 w/m$^2$ | 0,68 w/m$^2$ |
| | Ground Floors | 3,20 w/m$^2$ | 0,03 w/m$^2$ | 0,03 w/m$^2$ |
| *Total Energy Consumed* | Lighting | 20,86 kWh/m$^2$ | 20,86 kWh/m$^2$ | 20,86 kWh/m$^2$ |
| | HVAC | 221,98 kWh/m$^2$ | 153,91 kWh/m$^2$ | 153,64 kWh/m$^2$ |
| | Total | 242,84 kWh/m$^2$ | 174,77 kWh/m$^2$ | 174,50 kWh/m$^2$ |
| *CO2 emissions (annual)* | | 10783,02 kg | 6673,06 kg | 17987,04 kg |

## 3. CONCLUSION

Studies on increasing the thermal performances of cultural heritage are rare in the literature. Re-evaluation of the existing historical building stock in today's usage conditions is a sustainable approach. Making energy improvements of historical buildings is important both for reaching today's comfort conditions and for world energy policies. In this context, within the scope of the study, it has been observed that the thermal performances can be increased without harming the authenticity of the architectural cultural heritage. This study is very important in terms of reducing the need for new constructions with the use of existing building stock and minimizing the use of natural resources.

When the thermal performance of Mehmet Üsdün House was evaluated within the scope of the study, the following results were obtained:

- It has been determined that the current thermal performance of the building does not meet today's standards in general and the existing heating system is not suitable when compared to the values given in TS 825.
- As a result of the simulation studies, it was concluded that the thermal performance of the building should be increased in different scopes such as the heating system, construction technique, material type and layers of the building components.
- Considering the originality of the façade, an additional layer such as thermal insulation was not proposed for Mehmet Üsdün House, but a new heating system was proposed.
- The change in the heating system was simulated and, considering this change, two scenarios were studied, before and after the building.

Together with the proposed underfloor heating system;

- The annual heating energy need of the house has decreased to 153 kWh/m2 when both fuel types are used.
- The thermal performance has increased by 30-35%.

- The total amount of energy consumed annually has decreased.
- With the natural gas heating system, the CO2 emission decreased from 1954.88 kg to 1097.61 kg, reducing by approximately 45%. Together with the electric heating system, it reached 3232.47 kg and increased by approximately 60%.

It has been observed that the change in the type of fuel used in the proposed underfloor heating system differs during the intervention process. Since there is no natural gas installation in the house, it can be said that an additional intervention is required for the natural gas heating system and the intervention will be more compared to the electric heating system.

After the proposed heating system, the simulation results could not fully meet the criteria given in TS 825. For this reason, it has been concluded that the revision of the heating system is not a sufficient solution on its own. With this recommendation, it has been observed that additional measures such as thermal insulation and the application of double glazing to the windows should be taken.

Although the types of fuels used in the proposed heating system increase thermal performance, they are fossil fuels and are not renewable. The fuel type to be used should be selected from systems that can produce renewable energy such as solar energy (solar panels, etc.). The development of these methods will be beneficial in the context of sustainability. But, while using these fuel types, care should be taken to preserve the authenticity of historical buildings. In addition to these measures, the post-intervention structure should be monitored and its behavior should be monitored over a long period of time.

In the monitoring process, the positive and negative aspects of the application should be followed and it should be an example for future studies.

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