INVESTIGATION of a TRADITIONAL HOUSE based on its ENERGY CONSERVATION

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ABSTRACT

In this study, a selected traditional house was investigated based its energy performance, located in Phocaea, Izmir. For this purpose, physical properties of the house was identified and accordingly the energy performance was analyzed by utilizing a dynamic simulation software. The fundamental characteristics of the traditional house, such as natural stonewalls, fireplaces, window shutters were examined and compared with the contemporary architectural elements based on their effect on energy efficiency. Results represent that the traditional stone house has better energy performance than concrete and timber house, which mostly considered in today's architecture.

Keywords : Traditional house / Energy conservation

1. INTRODUCTION

Phocaea is selected for this study where is located in coastal areas of Aegean Region. The city history goes back to the mid-century of BC VII. Therefore, it has hosted various ancient heritages. The traditional buildings in the region are constructed by considering the climatic conditions of western Aegean that is classified in warm-humid climate region. The predominantly applied construction materials are wood and stone, which are local materials of the region. They have resistant to the intense rainfalls, high humidity ratio, and high temperatures [1]. According to the "special environmental protection zone management plan" which was prepared by the Ministry of Environment and Urbanism, the region of city was set on the first-degree earthquake zone [2].

Traditional houses in Phocaea also have some architectural characteristics. The houses were located and orientated to take advantage of the wind for natural ventilation inside of the building. They usually have large and number of windows positioned on the faÇades that is high and narrow. Furthermore, as the warm climatic region, protecting the houses from the sun is also an important strategy. Because of that, the courtyards are the important architectural consideration of the area by successfully protecting houses from the sun. By this approach, huge and many number of windows provides available daylighting. The small windows are usually located in ground floor, used to eliminate humidity. On the other hand, the construction materials such as stone and wood are suitable for winter conditions. Overall, these old fashion stone houses are considered as very effective and efficient for conserving the energy. For this reason, one of the houses were selected to investigate its energy performance.

2. LITERATURE REVIEW

Research was conducted about traditional buildings in Phocaea have examined in the literature. Asatekin and Eren was led a survey on traditional houses in Phocaea to identified the building's conditions. The questions of the survey were grouped under different headings that were about physical properties, comfort conditions, functionality - family relations, renewal, protection and construction of residential buildings. The responses of the survey represent that the physical properties of the traditional buildings were built sensitively to the climatic conditions of the region in such a way to be cool in summer and warm in winter [2].

In another study, historical status, physical characteristics and socio-economic conditions of civil architecture in Phocaea district were discussed. Correspondingly, plans, faÇades, structural systems, materials and construction techniques of architectures were examined. The findings of physical characteristics of these buildings were represent that they mostly have 2 story and consisted of masonry stone walls. The outer wall corners of the buildings were constructed with the long corner stones. Stone jambs were used on the sides of the doors and windows; one or two rows of stone eaves were used in almost all of buildings. The inner partition walls were made in half-timbered. The upper floor was made of timber frame that called “Bagdadi”. The structures were similar in terms of material and facade characteristics. There were 6 different plan types in terms of architectural plan [3].

According to sustainability, which referred as using existing materials and resources more efficiently in traditional architecture, the building materials were selected for hot-humid regions. The materials that had lower thermal mass were used to keep and store heat. In this concept, wood and stones were commonly utilized as good thermal insulators [4].

Furthermore, another research was conducted with similar aim to consider the physical environment, structure and energy recovery criteria for historical buildings in the region. Other than acknowledged findings, the research also remarks about the masonry construction system with its simple plan solution and simple geometric shapes. The outer walls of the buildings were constructed with a thickness of approximately 60-65 cm stone to protect both from the wind and to minimize heat loss. As the stone was a material with low heat transmission coefficient, the research was concluded that traditional buildings are effective in providing suitable comfort conditions [5].

3. METHODOLOGY

In order to investigate energy performance of a selected traditional house and identify the physical properties, a methodology had been developed. This methodology consists of six steps. First two steps were about collecting data of environmental conditions of the region, and existing conditions of the traditional building, which are mostly related with physical properties. Third step was to develop three-dimensional modelling of the building by utilizing the collected data. The next step was to analyze the energy performance of the building. In the following step, different scenarios were developed to improve the energy performance. As final step, results were evaluated. Those were shown in Figure 1. The steps of the methodology are described in detail in the following sections.

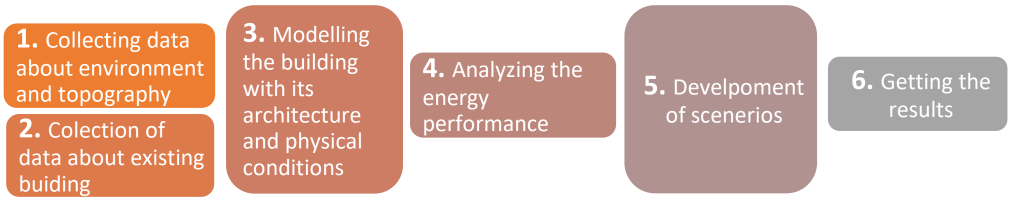


Figure 1. Steps of the applied method

3.1. Collection of Data about Environmental Condition and Topography

The city is located on a peninsula along the Aegean coast of Turkey, connected to Izmir by 70 km highway, as represented on Figure 2. Phocaea is a natural harbor. The forest area consists 50 % and the residential area consists 14 % of total area. It has four sub-districts and four villages [6]. The center of the city is set between Big Sea bay on the south and Small Sea on the north on Figure 2. The settlements around Small Sea are mostly for traditional and contemporary residential, administrative and commercial buildings while the settlements around Big Sea is mostly for holiday homes [3].

Figure 2. Location of Phocaea [7] and Aerial view of Phocaea district center [8]

3.1.1. Climate of the city:

Turkey has five different climatic regions, which are cold climate, mild humid climate, mild dry climate, warm dry climate and warm humid climate. Depending on this classification, Phocaea is in warm humid climatic region. It is warm during summers, humid and rainy during winters. The percentage of relative humidity is very high; therefore, the sensible temperature is increased by humidity. The humidity, which is occurred by intensive rainfalls, is balanced the daily average temperature. Depending on the General Directorate of Meteorology, the average temperature, sunshine duration, and rainfall values of city is represented on Table 1 [5, 6, 7, 8, and 9].

Table 3.1.1. The Average Values over long years (1950-2015) [5]

Climate Conditions	January	February	March	April	May	June	July	August	Septemb	October	Novembe	Decembe r	Yearly
Average Temperature (°C)	8.9	9.5	11.7	15.9	20.8	25.6	28	27.7	23.7	18.8	14	10.6	17.9
Max. Average Temperature (°C)	12.5	13.5	16.3	20.9	26	30.7	33.2	32.9	29.1	23.9	18.5	14.1	22.6
Min. Average Temperature (°C)	5.9	6.2	7.8	11.3	15.5	20	22.6	22.5	18.7	14.7	10.7	7.7	13.6
Average Sunshine Duration (hour)	4.2	5.1	6.2	7.5	9.5	11.3	12.1	11.5	10.1	7.3	5.3	4.1	94.2
Average Rainy Days	11.9	10.8	9.2	8.2	5.4	2.1	0.5	0.5	2	5.6	8.9	12.5	77.6
Monthly Average Rainfall (kg/m2)	125.1	101.9	75.6	46.4	30.9	9.8	1.8	2.6	15	45.3	94.8	141.1	690.3

Daily Total Highest Precipitation		Fastest Wind Day		Highest Snow	
29.09.2006	145.3 kg/m^2	29.03.1970	127.1 km/h	4.01.1979	8.0 cm

The lowest average temperature is 8.9 °C in January and highest average temperature is 28 °C in July. The minimum and maximum average temperature has been seen respectively 5.9 °C and 33.2 °C. The daily total highest precipitation was up to 145.3 kg/m^2. Moreover, the fastest wind speed was 127.1 km/h. Additionally, the highest snow on ground was 8 cm. These represent overall information of Phocaea's climate. However, for the accurate energy performance analyses more detailed, such as hourly-based climatic data should be utilized.

3.2. Collection of Data from Existing Buildings

These research is carried out to understand applied energy efficient strategies of the traditional buildings in the region. Over years, an attitude has been formed towards the protection and restoration of conventional buildings of the region. As a result, the old- fashion buildings are still remain active in Phocaea [9].

The design approaches start from the district level by paying attention to drainage, street and pedestrian systems. The main streets of the city are about 7-8 m wide. On the other hand, the sides and the alleys are narrow. The width could be reduced to 3 m. The main characteristics of the houses are listed as;

- The ground floors are used as storage.
- The living room and guests' rooms are located on first floor.
- The courtyard is provide shaded area and also used for plenty of activities as a gathering space [9]

- Natural stone and wood are the main construction materials.

In the city center, these buildings were generally constructed with two story, and additionally they have another one story stone building in the garden. Houses have constructed with hipped roof. The city streets are generally narrow and have cobblestone pavements for draining rainfall water into ground [10]. Elevations of the most common two-story facades are displayed on Figure 3.

Figure 3. Façade with two story houses [2]

Their images from city are represented on Figure 4. The house that have a courtyard is surrounded with rubble covered stonewalls on the ground floor. These traditional stone buildings are also called by natives as “Levanten” buildings [10].

Figure 4. Examples of two story stone house with garden

The traditional houses in Phocaea, usually known as stone houses by public, has one or two story with masonry stonewall, wooden roofs, and wooden flooring. The stonewall were made by Phocaea stones called slate. Slates are a piece of rock and they are categorized a natural stone. They were used for inner and outer wall. Slate has high thermal mass that keep the house cold in summer and warm in winter. It also has very different tones of colors.

The windows and door edges in exterior facade had stone doorpost and window frames. There were one or more sequined stone eaves at the fringe level of the facade [3].

Wall system and material, In Phocaea, the traditional houses were generally built with 3 different wall techniques which are masonry stone, irregular masonry stone, and rubble stone. The built techniques and their applications are shown on Figure 5.

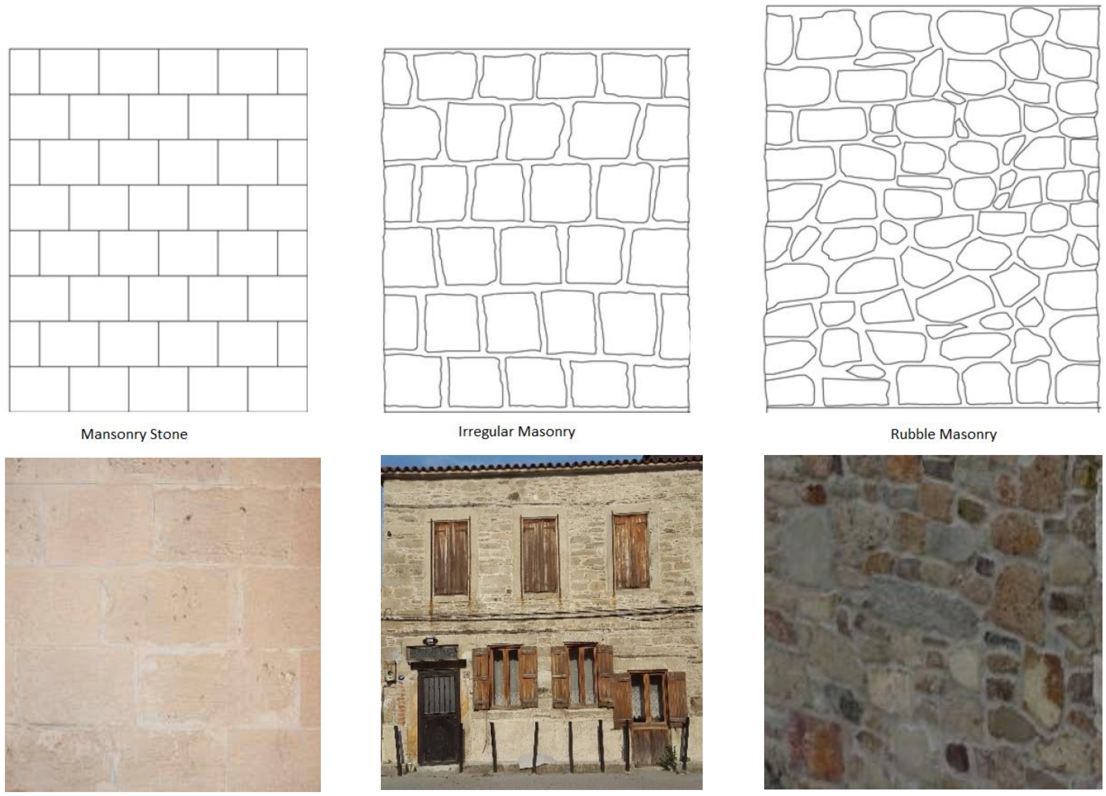


Figure 5. Examples for the three techniques

Stone structures are remarkably durable in addition it has earthquake resistant. Moreover, they resist fire, water, and insect damage. The mason needs minimum tools to build up and could be easily repaired; the material is readily available and is recyclable. In order to ensure stability, the stonewalls could be made thicker. Another advantage is that it reduces heating requirements during the cold season and cooling requirements during the hot season. In this way, the determination of the thermal capacity of a natural stone plays an important role when considering its suitability for energy saving.

Ceiling; In houses, the ceilings are usually plain and wooden. The wooden parts are placed flat and side by side in the ceilings as shown on Figure 6.

Windows and door; The windows sizes are varying. The dimensions of windows can be reached as 100-120x200-230 cm. Street facades in the upstairs often seen double or triple windows. Their shutters are wood. On the ground floor, it takes one or two windows as 100x200 cm. Their shapes are sometimes rectangular, sometimes with a curved arch. If there was a storage area on the entrance floor, there would be a separate access door for the storage area. The dimensions of storage door are smaller than the main entrance. The main entrance door is usually constructed as a very imposing gate. Door wings are ornamental wood with glass [2].

Figure 6. The wooden ceiling and window

3.3. Modeling the Building with Its Architecture and Physical Conditions

The selected traditional building is located in center of Phocaea within 38°40'12" N and 26°45'21"E coordinates. The physical properties of the building were investigated, the necessary data were collected and the energy performance of the building analyzed by utilizing the simulation software called e-Quest. The purpose of this case is to determine the heating efficiency of the stone buildings in the

Phocaea. Sufficient ventilation is provided with the help of cross ventilation with the benefit of precisely located windows. However, ventilation is not considered in our study.

The Properties of the Houses

Selected building has 2 stories. The frontage of building is directly faced to the main street where is the west side. At the end of the garden, there is a single story outbuilding for storage. While the main building is flashy, storage building, which is also constructed with masonry stone is modest. Entering the building, there is a hall, which reaches to the rear front that has a gate to garden. There is a furnace in the rooms. There is a wooden staircase between these two rooms. On the upper floor, there are two intertwined rooms. The external facade is left without plastering. However, they are enriched by ornaments. Windows in ground floor have eaves shutter and in upper story have wooden shutter. The entrance gate is made of wooden material with glass lamb and iron guardrail. Plas of first and second floor are represented on Figure 7.

Figure 7. The Floor Plan of Basement and first story

The outer walls were constructed by masonry stone which is also known Phocaea stone as mentioned on the above section. The thickness of stones was between 55 cm. The total height of building, from ground to roof is 6.80 meter. Correspondingly, interior heights are quite high. There is wood flooring on beams and there is wooden ceiling coating under beams.

The interior surfaces are plastered and painted with lime paint. At the same time, the outer surfaces are left unplaster. The chimneys that were adjacent to the stonewall were constructed with stone material. All doors, windows, ceilings, first story floors and stairs were made of wood.

The building energy performance was analyzed by developing the energy model of the building with its existing conditions. Additionally, effect of fireplaces and shutters as a shading elements were separately analyzed. Furthermore, comparison were made between the concrete and timber houses, which represent the contemporary building materials. Additionally, stoned building's energy performance also improved by insulation applications. All the cases were analyzed and their results were compared at the results sections.

3.4. Analyzing the Energy Performance

Energy performance of the building was analyzed by e-QUEST software. Information about the location, orientation, architectural characteristics, materials' physical and thermal properties, building systems, zoning considerations as well as user profiles were obtained from the building's owners, images and literatures.

Materials thermal properties are listed on Table 2 and developed building model is shown on Figure 8.

Table 2. Used parameters

Height of floor to floor		2.7 m	9 ft
Height of floor to ceiling		3 m	10 ft
R value for wood roof		0,17 m^2K/W	0.97 hft^2F/Btu
R value for slate wall		0.25 m^2K/W	0.04 hft^2F/Btu
Dimensions of door	Length	0.90 m	3 ft
	Height	1.80 m	6 ft
Dimensions of small windows	Length	0.90 m	3 ft
	Height	1.20 m	4 ft
Dimensions of large windows	Length	0.90 m	3 ft
	Height	1.80 m	6 ft

The R-value for wooden roof was taken from literature [11] On the other hand, the R for slate stone was calculated by dividing the thickness with λ value of slate.

- The thickness of stones was 0.55 m.
- λ value for slate = 2.2 mK/W [12]

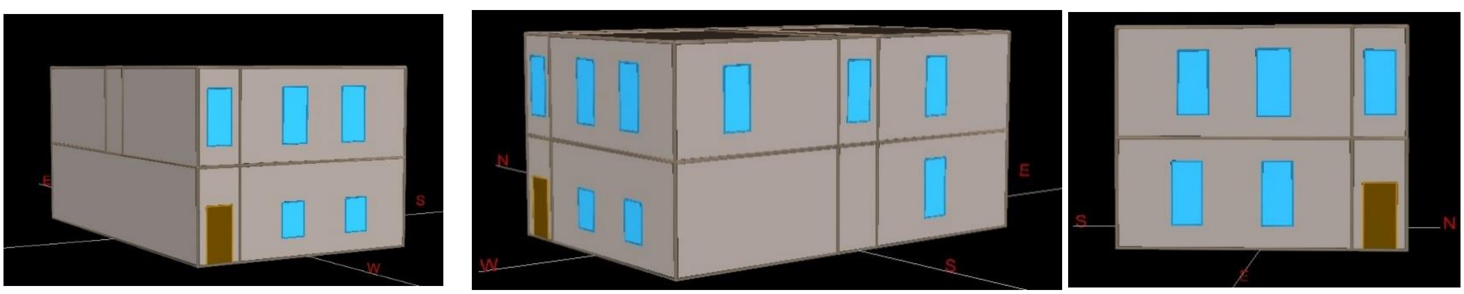


Figure 8. The building representation using e-Quest

Electricity is used for heating, water heating and lighting. Therefore, the major energy consumption of the building is the electricity which the heating has the main contribution with 60 % of total electricity consumption. The domestic water's heating is in the second ranked with 18% as represented on Figure 9 and Table 3.

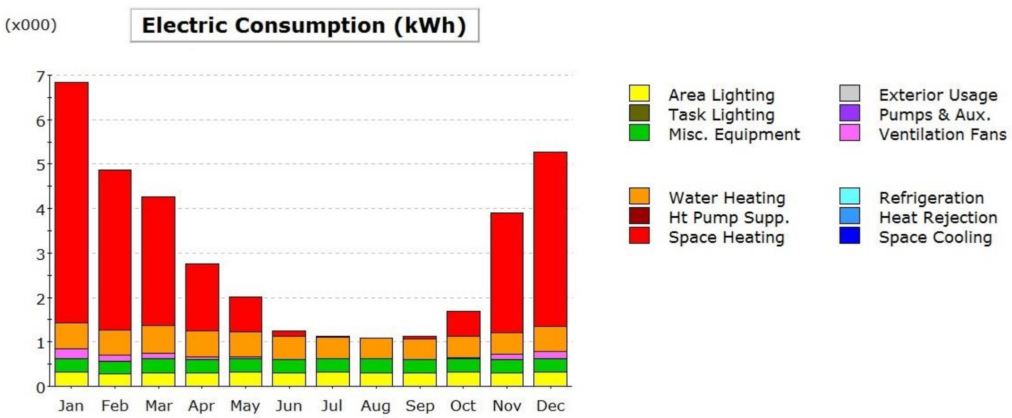


Figure 9. Electric Consumption one by one components

Annually, total electric consumption is 36,180 kWh according to space heating, domestic water, miscellaneous equipment, and area lighting. The electric consumption per m^2 is 180.9 kWh/m^2.

Table 3.4. The Amount of Electric Consumption

Electric Consumption (kWh)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Space Heat	5410	3610	2900	1500	790	130	10	0	60	560	2680	3920	21570
Hot Water	590	560	620	590	570	510	480	470	450	480	500	560	6380
Vent. Fans	220	150	120	60	30	10	0	0	0	20	110	160	890
Misc. Equip.	310	280	310	300	310	300	310	310	300	310	300	310	3650
Area Lights	320	280	310	300	310	300	320	310	300	310	300	320	3690
Total	6840	4880	4260	2750	2010	1250	1120	1090	1120	1690	3900	5260	36180

3.5. Development of Energy Performance Model with Specified Scenarios

Development of the energy performance model with the fireplace

The original plan of traditional building had fireplace. Over time the use of the fireplace was removed. In these section, the effect of fireplaces are analyzed. The results are shown graphically on Figure 10.

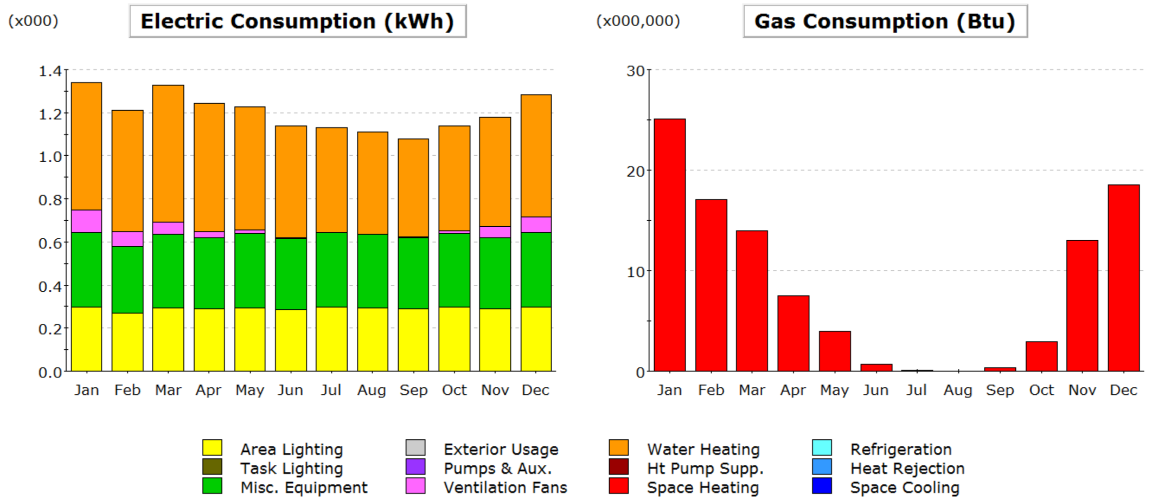


Figure 10. Electric and Gas Consumption in Fireplace Use

The usage of the area lightening and miscellaneous equipment are kept the same with current situation. However, space heating requires more energy than current situation. Annually, heating consumption is 140,370,000 Btu, which is equal to 41,142 kWh. In addition, the total energy requirement per m^2 is 223.17 kWh/m^2. When compare these amount with only electric usage, it seems that only heating by the fireplace is required more energy.

Development of the energy performance model with the concrete structure

Phocaea stone is compared with current concreate material. According to Turkish Standard, TS 825, Thermal insulation requirements for buildings are determined by climate conditions. Phocaea is given in region 1. Thus, the u value for concrete structure with insulation is taken as 0. 4 Btu/hft^{2}F [13].

The results for concrete structure are shown graphically in Figure 11. Moreover, it is assumed that electricity is used to make a comparison with the current situation of the building. The total electric consumption is 43,670 kWh, which means the electric consumption per m^2 is 218.35 kWh/m^2. This value is higher than the consumption of the stone construction.

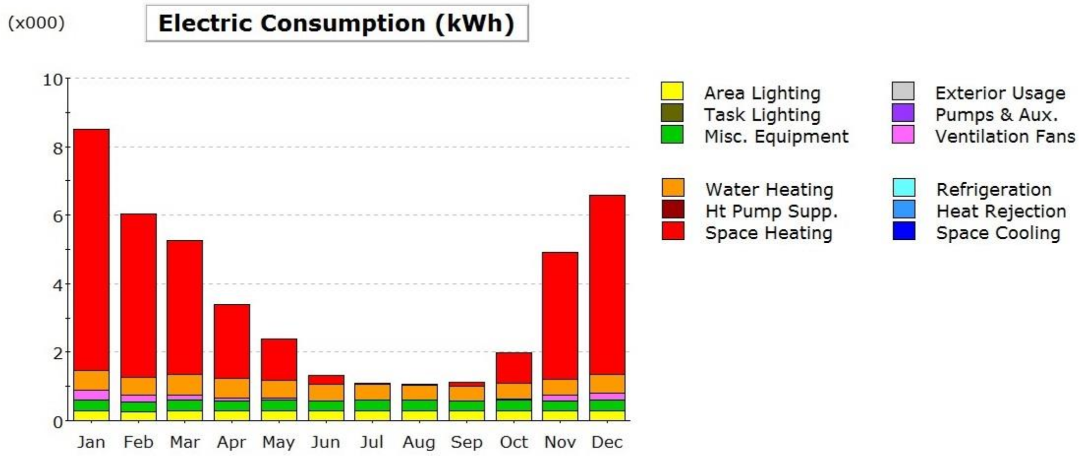
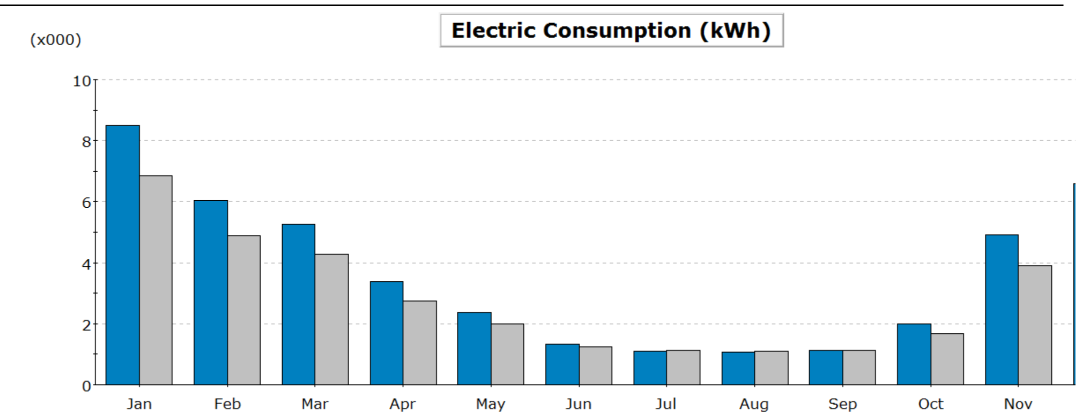


Figure 11. Electric Consumptions for Concrete Structure

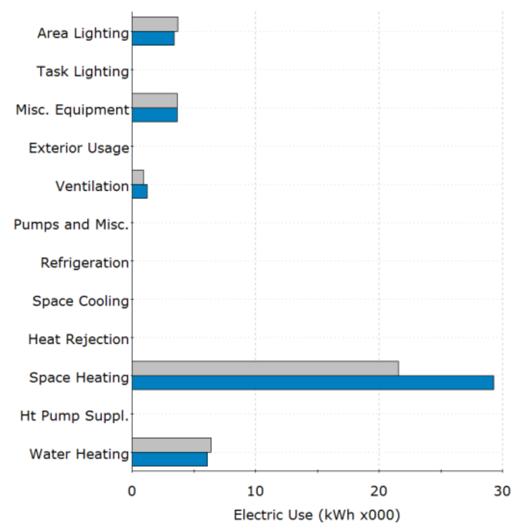
The importance difference is created by space heating. Annually electric consumption difference is shown on Table 4. The blue lines represents the concrete.

Table 4. Comparison of Electricity Consumption between Concrete and Stone Structure with respect to end-use



Electric Consumption (kWh)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Concrete Structure	8510	6040	5270	3390	2380	1330	1090	1060	1130	1980	4900	6580	43670
Stone Structure	6840	4880	4260	2750	2010	1250	1120	1090	1120	1690	3900	5260	36180

Table 4. Comparison of Electricity Consumption between Concrete and Stone Structure with respect to end-use **(Continued)**

Annual Electric Consumption by End-use	
Concrete Structure Stone Structure	

Development of the energy performance model with ***Timber structure***

The traditional stone building has timber construction as interior construction structure. In this stage, it is assumed that the outer walls were in the same way as the inner walls and then the energy efficiency of building is investigated. So that, the u value for timber structural wall is taken as 0.35 W/m^{2}K. [14]. The electric consumption for timber structure shown on Figure 12.

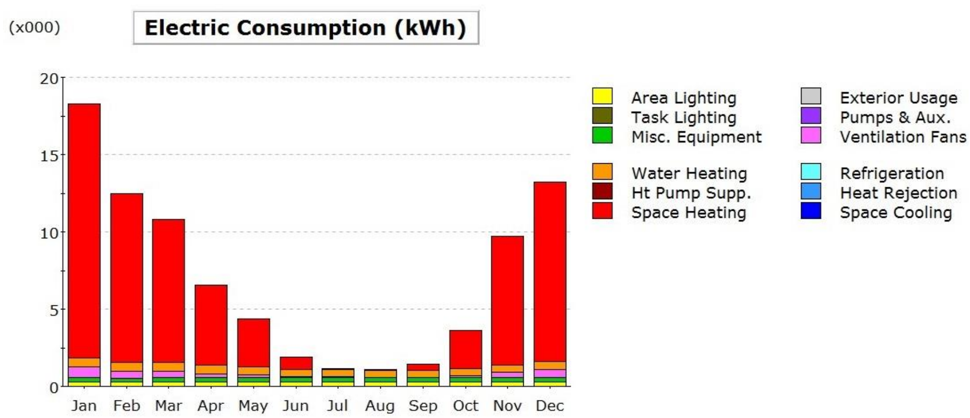


Figure 12. Electric Consumption for Timber Structure

The highest electricity need is occurred by space heating. The total need is 84,610 kWh and the electric consumption per m^2 is 423.05 kWh/m^2. Annually electric consumption difference is shown on Figure 13. The timber structure is consumed more than twice compared to Phocaea stone.

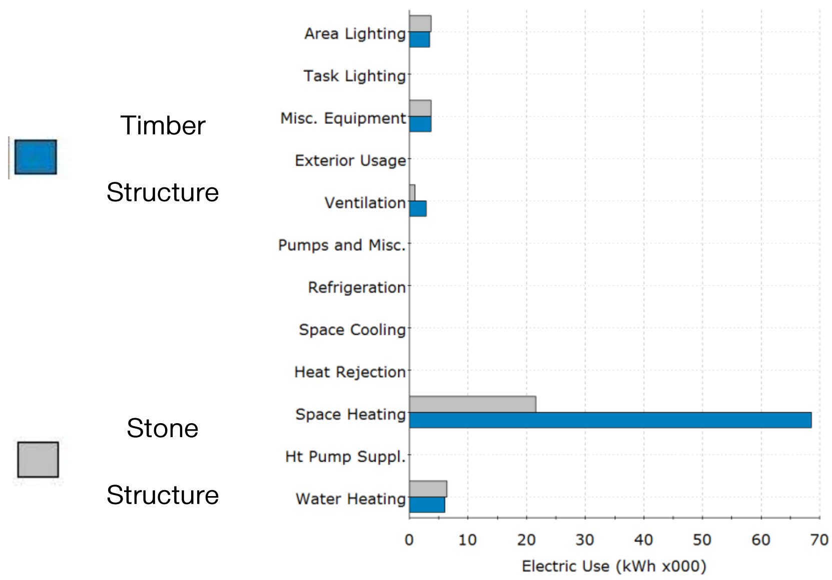


Figure 13. Annually Electric Consumption between Timber and Stone Structure by End-use

Development of the energy performance model with shutters as shading elements

In this section, effect of the shading elements on windows were examined. Stone building has medium-dark color windows shutters. The assumption was made that 20% of shutters are closed when owners are in house. Otherwise, they are closed. The electric consumption with shading element represented on Figure 14.

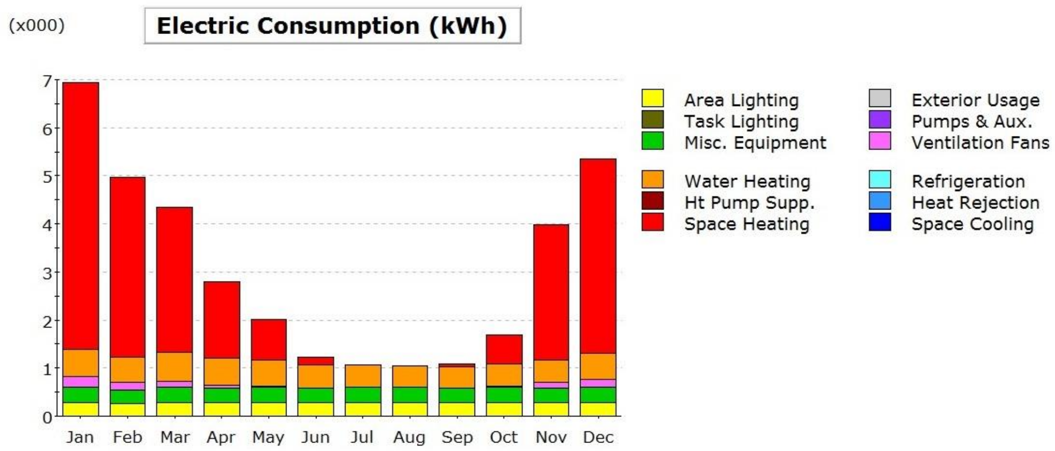


Figure 14. Electric Consumption with Shading Element

The shading effect is found adversely. They are blocked the sun lights so that the energy needs for heating are increased. The total need is 36,520 kWh and the electric consumption per m^2 is 182.6 kWh/m^2. Annually electric consumption difference is shown in below. The blue arrow represents stone structure with window shutters on Figure 15.

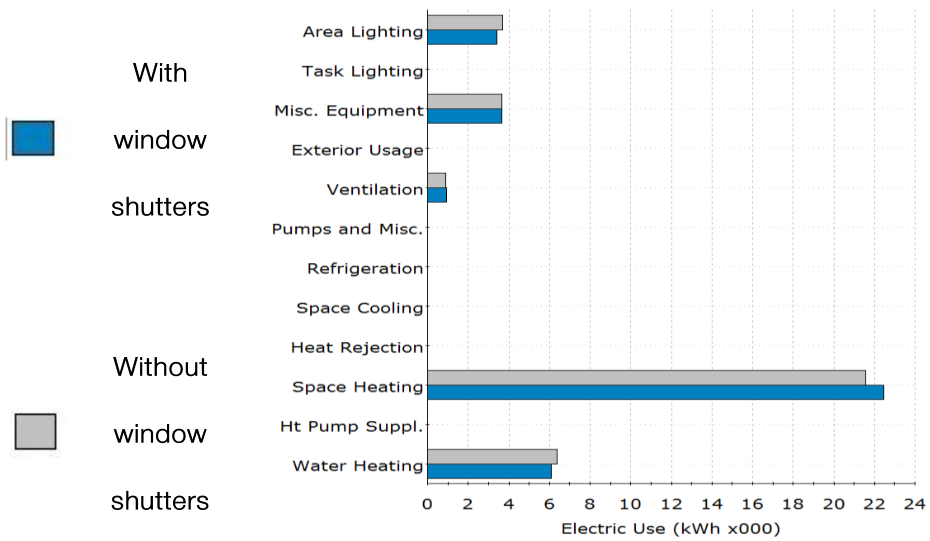


Figure 15. Annually Electric Consumption of Shading Element by End-use

Development of the energy performance model with Improvements on the stone house

To improve the stone building, windows and doors are changed and some insulations are added. Windows are changed with single Low-E materials, also doors are changed with Steel Hallow Core material. Ground base, walls and ceiling are insulated. The results are graphically represented on Figure 16.

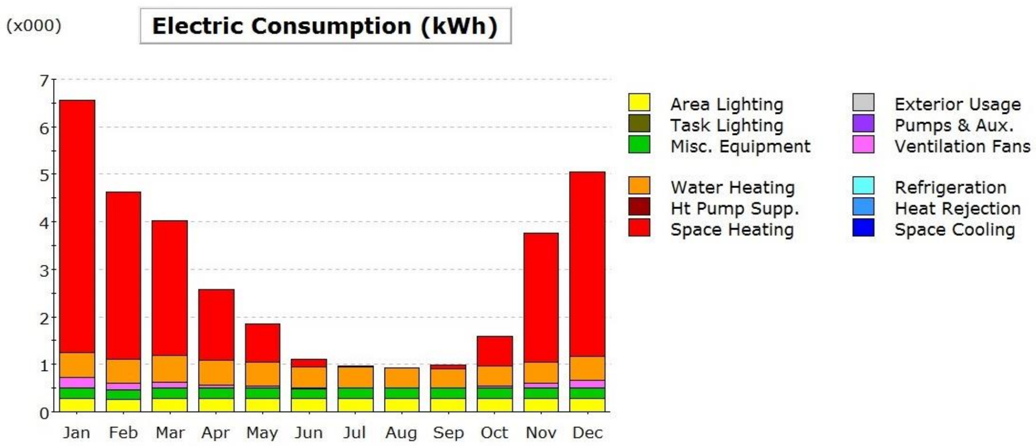


Figure 16. The Electric Consumption for Improved Stone Structure Building

When compared improved stone building and current stone building, it is clear that the electric consumption of improved one is lower. The total consumption is 34,030 kWh and the electric consumption per m^2 is 170.15 kWh/m^2. Annually electric consumption difference is shown in below. The blue arrow represents improved stone structure on Figure 17.

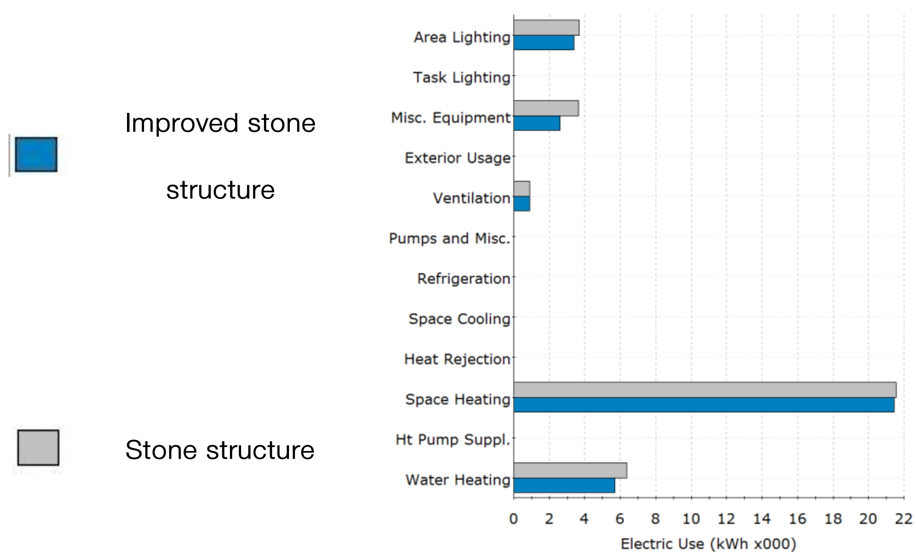


Figure 17. Annually Electric Consumption by End-use

3.6. Results

After all simulations are done, the comparison of them are represented on Table 5. Taking the annual consumptions into account, the most suitable structure is stone.

Table 5. Annual Consumptions for each cases

Structure	kWh	kWh/m^2
Improved Stone Structure	34,030	170
Stone Structure	36,180	181
Concrete Structure	43,670	218
Timber Structure	84,610	423

Additionally, electricity consumption from simulations were taken into account to compare the annually end-use on Figure 18

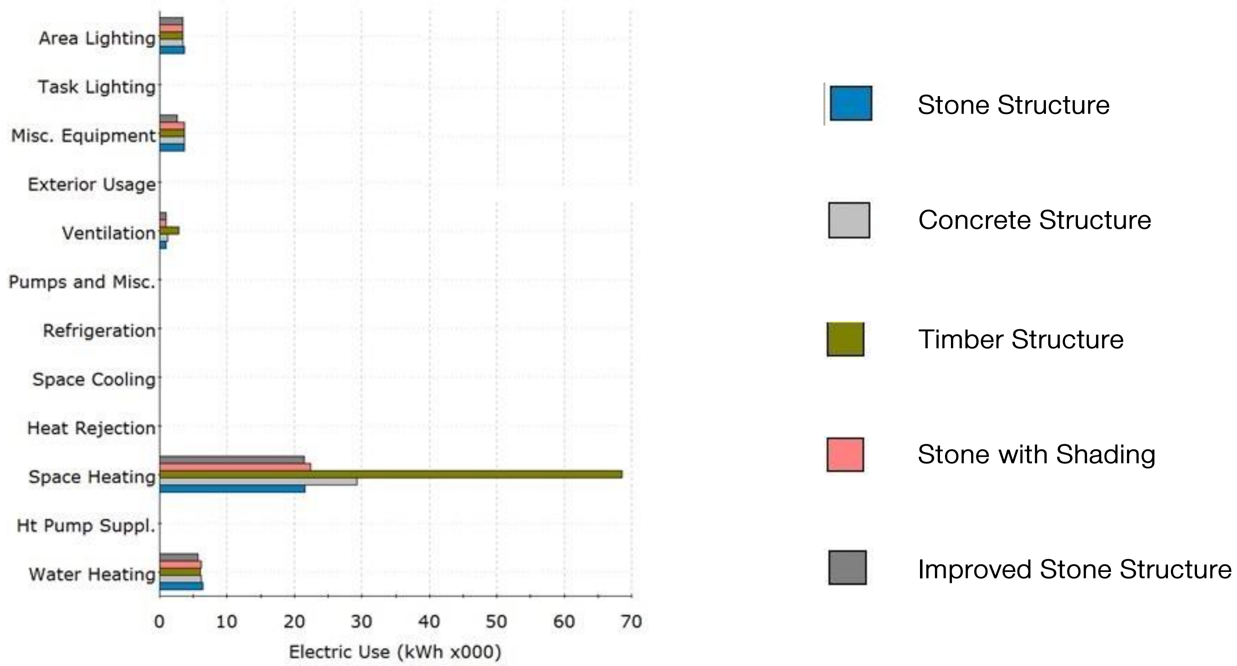


Figure 18. Annually Electric Consumption by End-use

The efficiency of building is depending on structural materials, location of windows and doors with their materials. It is obvious that improvements on traditional buildings brings better energy efficiencies.

4. CONCLUSION

The aim of this work is to investigate the energy efficiency of traditional building in Phocaea though it's heating performance. Therefore, the energy performance of selected house was analyzed and comparison made with different alternatives, which represent the present house structures. Results are shown that the most suitable structural material is stone. In addition, the most energy needs of the house is for the space heating. If the traditional stone house's conductivity level is improved by adding some insulation materials, the energy performance would be further improved.

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