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Calculation of Annual Energy Requirement of Existing Constructions and Improvement Suggestions for Building Envelope: An Educational Structure Example

By Hatice Elif Arslan Beytekin[1], Filiz Senkal Sezer[2]

Abstract
The energy problem is becoming increasingly important all over the world due to its environmental and economic dimensions. Due to their high energy needs, buildings have a significant share in total energy consumption. For this reason, the design of environmentally friendly structures that use energy efficiently or the conversion of existing structures into energy efficient structures has become a priority in the policies of many countries today. In this study, using the Design Builder program, one of the international energy simulation programs that measure energy efficiency, the total annual energy requirement of an existing building selected as an example to be taken into consideration for the current application project, has been calculated. In addition, the building is divided into, and the energy needs are calculated separately for heating, cooling, electrical equipment and lighting by zone. Two different suggestions have been presented for the improvement of the building envelope in line with these results. One of the proposals was made by taking into consideration the TS 825 Thermal Insulation Regulation, valid in Turkey. In the 2nd suggestion, a general approach was taken, determining the zones where the energy needs are highest per unit area, and a building envelope suggestion providing the balancing of the energy needs for these zones to the general needs of the building has been developed.

Keywords: Energy efficiency, building envelope, design builder

1. Introduction

Energy efficiency in buildings has priority in many countries' energy policies and has a crucial role in ensuring the protection and sustainability of the environment. In Turkey, The Energy Efficiency Law, which envisages increasing the efficiency of energy sources and energy usage, to reduce the burden of energy costs on the economy and to protect the environment, followed by the Energy Performance Regulation of Buildings, which entered into force after publication on Official Gazette on 05.12.2008, has been seen to encourage work in this area. When looking at applications abroad, the development of a method for the evaluation of the performance of structures and granting of energy certifications to structures is proposed by the European Parliament and Council's Energy Performance Directive, which entered into force on 4 January 2003. Evaluating the energy performances of the structures depends on whether they comply with energy efficient design parameters, and calculations to be made according to laws and regulations. One of the simulation programs that is used to calculate the energy performance of the structure quickly and accurately is the Design Builder program which processes the data belonging to the structure. Within the scope of this study; Heating, cooling, electrical equipment and lighting energy needs of the building have been

[1]Uludag University, Faculty of Architecture, Turkey, PhD student, Architect
[2]Corresponding Author, Uludag University, Faculty of Architecture, Associate Professor, PhD.

calculated separately based on the application project of the Architectural Building of Uludağ University Architecture Faculty by using the Design Builder program, with energy needs as a result of improvements made to the building envelope to be determined and results presented comparatively.

2. Case Study

The Uludağ University Architecture Department building selected for site work is located at 40 ° 13'38.3 "N latitude 28 ° 52'37.6" E in Turkey's Bursa province, Nilüfer district, Görükle district. The site plan of the building is shown in Figure 1.

Figure 1. Bursa Uludağ University Faculty of Architecture Building (Google, 2015)

The Architecture Department Building has a plan built around a courtyard. Designed as three floors, the building has a covered area of 3568 m² (ground floor: 1428 m², 1st floor: 1200 m²; top floor: 940 m²) and 359 m² open inner courtyard area. The total building height is 11.15 m (Figure 1). The building entrance is oriented in the southwest-northeast direction. The canteen, wet floors are located in the northwest; with the classrooms located on the ground floor in southwest and northwest. The academic staff rooms are located on the 1st floor in the southeast-northwest direction.

Image 1. Building photos

Layout information of the building consist of outside climate information such as air temperature, solar radiation, air movement and humidity. For the calculations in the Design Builder simulation program, location information in epw (energy plus weather) format for the Bursa province is used. In this study, all calculations were made under real atmospheric conditions by transferring the meteorological data file prepared in line with the metrological data to the Design Builder program.

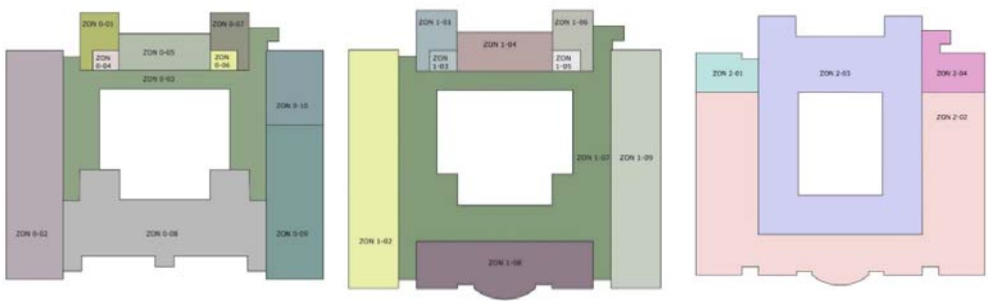
In winter, the heat required to achieve thermal comfort values is provided by an under floor heating system connected to the central system. The calculations were carried out with the following steps:

- Determination of the thermal comfort for the building and the factors related to interior of the building and distribution by month
- Separation and tabulation of zoning according to its orientation and functions
- The optical and thermo physical properties of the building envelope opaque and transparent components
- Building envelope heat conductivity coefficient calculation
- Building envelope transparency opacity ratios
- Comparing the heat transfer coefficient of building elements with the permissible values
- Calculation of annual total energy requirement
- According to the total energy need for the year, calculation of distribution by heating, cooling, lighting, electrical equipment
- Calculation of energy demand according to zones
- Calculation of energy requirements per unit area for each zone
- Determining the most energy-consuming zones for the building

For the calculations, 23 zones were created in the structure according to the location function and direction. The zones created on the floor plans are shown in Table 1. Figure 2 shows the locations of the zones on the plan.

Table 1. Coding of zones for building

GROUND FLOOR		1st FLOOR		2nd FLOOR	
ZON 0-01	MENS WC	ZON 1-01	MENS WC	ZON 2-01	STORE ROOM
ZON 0-02	CLASSROOM (NORTH WEST)	ZON 1-02	TEACHING STAFF ROOM (NORTHWEST)	ZON 2-02	CLASSROOM
ZON 0-03	CORRIDOR	ZON 1-03	STORE ROOM	ZON 2-03	STORE ROOM
ZON 0-04	CANTEEN STORE ROOM	ZON 1-04	MEETING AND SEMINAR ROOM	ZON 2-04	TECHNICAL UNITS
ZON 0-05	CANTEEN	ZON 1-05	STAFF ROOM		
ZON 0-06	TECHNICAL UNITS	ZON 1-06	WC WOMEN		
ZON 0-07	WC WOMEN	ZON 1-07	CORRIDOR		
ZON 0-08	ENTRANCE HALL	ZON 1-08	DEANS OFFICE		
ZON 0-09	CLASSROOM (SOUTH-EAST)	ZON 1-09	TEACHING STAFF ROOM (SOUTHEAST)		
ZON 0-10	CLASSROOM(EAST)				



Ground Floor Plan 1st Floor plan 2nd Floor Plan

Figure 2. Distribution of zones according to floor plans

Based on the available data, the heat transfer coefficients of the structural elements were calculated.
For smooth surfaces of the building envelope, glass Type: 3 mm colorless glass + 13 mm air space + 3 mm colorless glass, joinery type: aluminum joinery; The total heat transmission coefficient of the windows was found to be 3,159 W / m²K.
The building infiltration value was selected as 0,6 ac / h. The transparency rates of the buildings are shown in Table 2 according to their directions.

Table 2. Surface Transparency Rates

	Total	North (315 to 45⁰)	West (45 to 135⁰)	South (135 to 225⁰)	West (225 to 315⁰)
Surface Transparency Rate (%)	33.48	31.49	29.17	42.27	23.39

In the present case, the coefficient of heat transmission on outer walls was calculated to be = 1,783 W / m2K, and U = 0,817 W / m2K for the roof.
The first step towards achieving optimum energy efficiency is: The calculation of the energy requirement for the final structure as a result calculations made by using the Design Builder program for the determination of the current situation (Table 3). Figure 3 shows the distribution of the annual energy needs of the zones of the building.

Table 3. Annual energy demand distributions for the current condition

Current Condition Annual Total Energy Needs Distribution (kWh)					
	Heating Energy Consumption	Cooling Energy Consumption	Electrical Equipment Energy Consumption	Lighting Energy Consumption	Total
Total	370.688	179.204	28.422	45.304	623.618

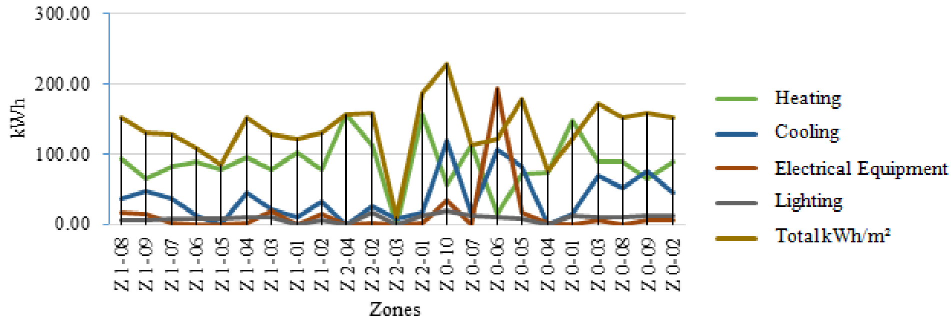


Figure 3. Distribution of total annual energy needs of buildings by zones

There is no cooling system available for the summer months. The central system does not have any HVAC system. No heat insulation was made during the construction of the building. It was found necessary during use, and certain areas were later insulated, however it has been observed that this insulation is not sufficient.

3. Improvement of Building Envelope

In order to reduce the energy expenditure in the thermal zones of the building, improvement recommendations have been made for the building envelope on the implementation project.

Suggestion 1: The total heat transfer coefficient limit values recommended for the Bursa province, located in the 2nd Region in accordance with the TS 825 Building Thermal Insulation Rules Standard, which is valid in Turkey, have been considered optimum and the building envelope has been improved in such a way that these values are ensured. According to the improvements made in accordance with the regulation, alternatives have been generated to provide for suitable thermo physical values, taking into consideration walls, roof, windows as points of improvement. Following the improvement of the building envelope according to Suggestion 1, the simulation has been repeated.

According to TS 825, the thermal conductivity coefficient value for windows should be U_P =2,4 (W/m²K). All the transparent surfaces in the building envelope have been brought to this thermal conductivity coefficient (U). In order to provide a heat transmission coefficient of U= 0,6 W/m²K, 5cm insulation is proposed for the outer walls, and for a heat transmission coefficient of U= 0,6 W/m²K, 6cm insulation is proposed for the roof.

The distribution of annual energy requirement for heating, cooling, lighting and electrical equipment as a result of the calculations are shown in Table 4. The annual total energy requirement has been calculated to decrease from the current 623.618 kWh to 465.019 kWh. The distribution of energy needs according to zones is shown in Figure 4.

Table 4. Annual energy demand distributions for the building for Suggestion 1

Annual Total Energy Distribution according to TS-825 for Suggestion 1 (kWh)					
	Heating Energy Consumption	Cooling Energy Consumption	Electrical Equipment Energy Consumption	Lighting Energy Consumption	Total
Total	197.270	196.539	27.047	44.162	465.019

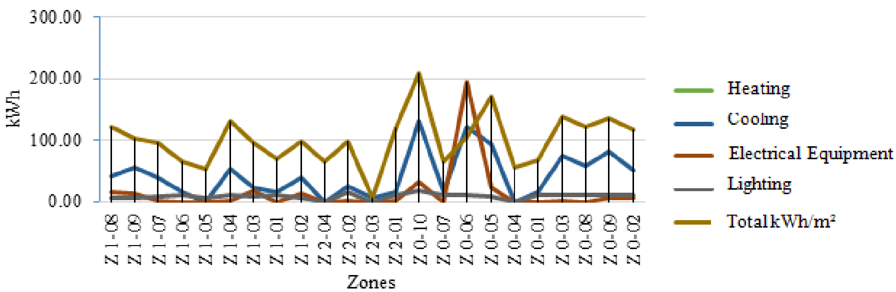


Figure 4. Distribution of annual energy needs by zone for the building according to building envelope as recommended in Suggestion 1

However, according to the TS 825 Building Thermal Insulation Rules Standard allowed for Turkey 2nd Region, it has been revealed that the intervention made will not alleviate the energy loss difference between the zones in general, and user comfort will not be ensured. As a result, a building envelope approach has been developed which is designed for environmental and structural variables, aiming at higher energy gain for the structure and equal energy need for all zones of the structure. The approach presented as Suggestion 2 is given below.

Suggestion 2: Z0-10, Z2-01, Z0-05, Z0-03, Z0-09 are the zones where the energy requirement per unit area are seen to be the greatest. An envelope design proposal aimed at balancing the energy needs of these zones according to the overall building is aimed. Suggestion 2 has been prepared to take into account the practical applicability of the proposed improvement measures and the spatial areas not losing their characteristics according to user needs and planning principles.

The U value of all transparent surfaces on the building envelope in Suggestion 2 have been decreased to 1,6 W/m²K. In order to provide a heat transmission coefficient of U= 0,319 W/m²K, 6cm insulation is proposed for the outer walls, and for a heat transmission coefficient of U= 0,580 W/m²K, 8cm insulation is proposed for the roof. In addition, 5 cm of insulation was applied to the outer parts of the protrusions of the building. In addition, on the southeastern aspect sun breakers have been proposed (Figure 5).

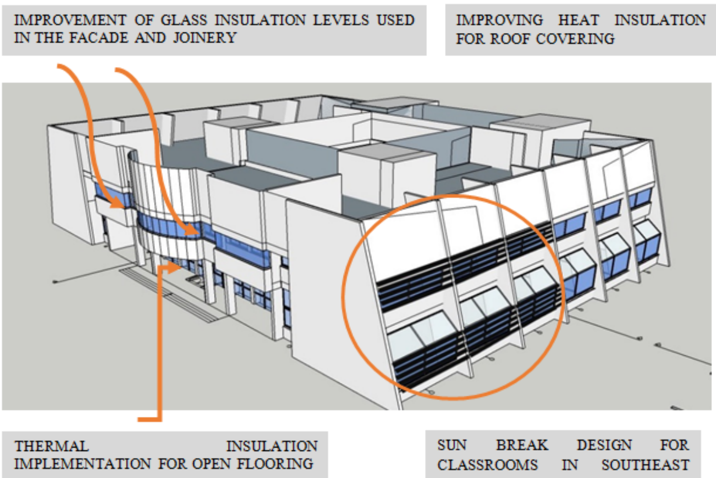


Figure 5. Areas to be reviewed on building envelope according to Suggestion 2

The total annual energy distributions of the building for Suggestion 2 are presented in Table 5, and the distributions according to zones are presented in Figure 6. The annual total energy requirement has been calculated to decrease from the current 623.618 kWh to 352.943 kWh.

Table 5. Annual energy demand distributions for the building for Suggestion 2

Annual Total Energy Distribution Suggestion 2 (kWh)					
	Heating Energy Consumption	Cooling Energy Consumption	Electrical Equipment Energy Consumption	Lighting Energy Consumption	Total
Total	69.233	212.783	27.027	43.899	352.943

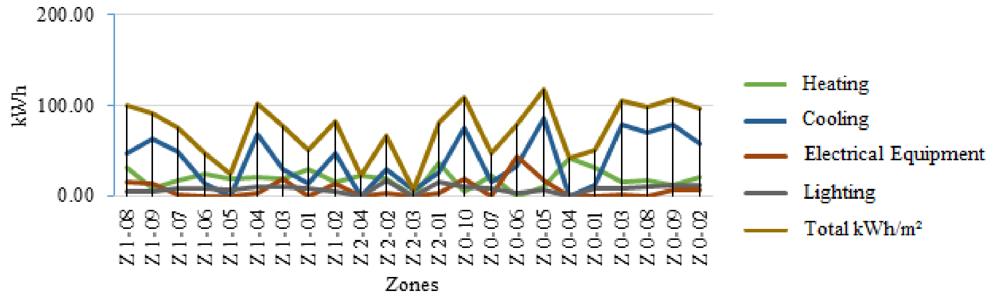


Figure 6. Distribution of annual energy needs by zone for the building according to building envelope as recommended in Suggestion 2

For the three different conditions that occur together with the improvements made, the aggregate annual energy needs are shown collectively in Figure 7.

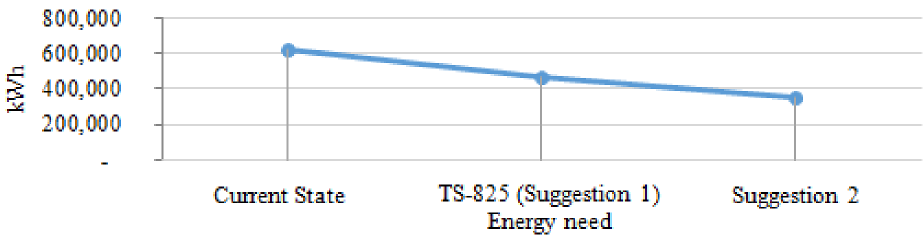


Figure 7. Change in energy demand distribution for building (kWh)

In addition to energy consumption, the CO_2 problem that arises during this consumption is another important point to consider for a sustainable life. The amounts of CO_2 absorption varying with energy distribution are given in Figure 8.

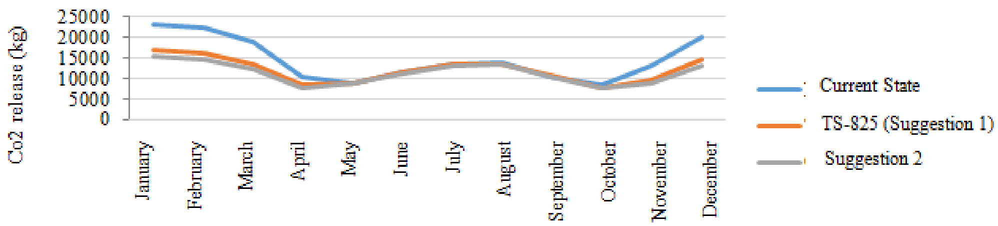
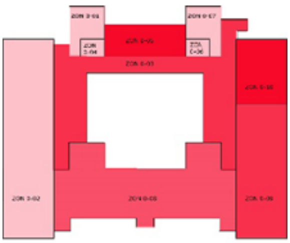


Figure 8. Building annual CO2 emission (kg) diagram

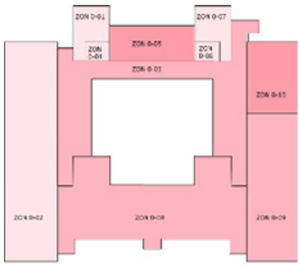
The Analysis-Target table for the improvement of the building envelope is presented in Table 6 as a comparative example.

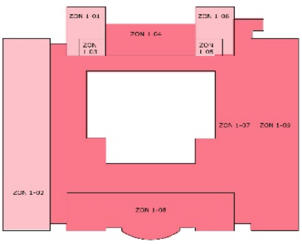
Table 6. Improvement of building envelope: Analysis-Target Table

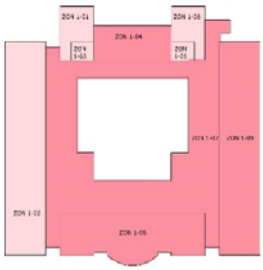
CURRENT STATE	SUGGESTION 1	SUGGESTION 2
The zones with the greatest need for heating-cooling energy are: **Z0-10**; east facing classroom areas, **Z2-01**; top floor storage area, **Z0-05**; ground floor northwest facing canteen, **Z0-03**; ground floor corridor and **Z0-09**; ground floor southeast facing classroom areas. **Z1-08**; 1st floor deans office	On opaque and transparent surfaces, a general improvement has been made in the building envelope. Alternatives have been produced to meet the minimum recommended values for the TS 825 standard. However, in the building as a whole, imbalances in energy distribution have not been eliminated.	Opaque surfaces: Z0-10 classroom (south east) Z2-01 top floor store room Z0-05 canteen (north west) Z0-03 corridor Z0-09 classroom (south east) Z1-08 deans office (south west open flooring) zones building envelope improvements have been foreseen. On transparent surfaces: Z0-02, Z1-02 (North) low reflective surface glass Z0-09, Z0-10 (Southeast, east) sun break design has been foreseen.

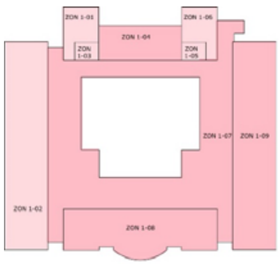

Ground floor

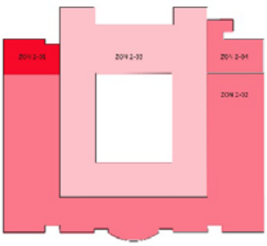

Ground floor

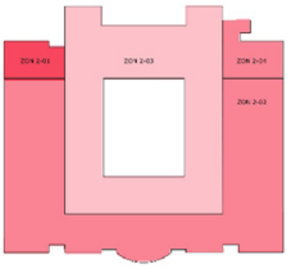

Ground floor

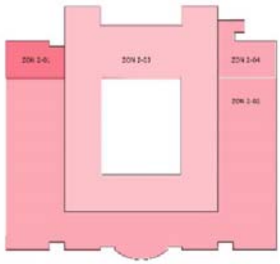

1. Floor


1st Floor


1st Floor


2. Floor


2nd Floor


2nd Floor

(The darkest area on the color scale represents the zones where the most energy needs arise).

4. Conclusion and Evaluation

In this study, by starting with the application project of an existing building; total annual energy needs have been calculated according to the Design Building program. The building was divided into thermal zones and the energy needs of the building according to the zones were determined and Suggestion 1 and Suggestion 2 were prepared for the improvement of the building envelope.

Since the heat transfer coefficient values of the layers constituting the building envelope in the present case are well below the TS 825 Thermal Insulation standards, the first building envelope has been brought to the minimum values according to the TS 825 Building Thermal Insulation Rules Standard. As a result of this application, it was seen that the annual energy needs of the building decreased by 25.4%.

However, according to analysis and calculations made in accordance with Suggestion 1; the differences in the energy distribution of zones separated within the building could not be eliminated. In addition, optimum standards for indoor comfort conditions have not been achieved in all zones. An improvement made to the entire building according to standard has been deemed to only provide energy savings to a point.

When taking the position, direction and function of each zone in the building into consideration, it has been determined that the energy needs of Z0-10, Z2-01, Z0-05, Z0-03, Z0-09 are higher than other zones. Suggestion 2 has been prepared for better energy efficiency as local improvements made in these zones and the values given by TS 825 standards are inadequate. Calculations made for Suggestion 2 resulted in a decrease of annual energy requirements of 43.4%.

In this study, an examination and evaluation of the building envelope was made according to energy efficiency. In the site study, an attempt was made to improve the building envelope in terms of insulation systems and daylight control systems.

In new buildings, a building can be made energy efficient by directing the design in this line, and project decisions, material selections and applications being made with this in mind. However, energy efficiency can be provided in an existing building by making improvements on the building. This brings with it additional costs in terms of financing. Thus, the decision to make an existing building energy efficient must be considered with an economic aspect.

The goal in energy conservation is to ensure that all users are in equal comfort conditions. All the units that make up the building are in constant interaction with each other and with the external environment. Therefore, a change proposed for a single unit not only affects that independent section but also affects the building as a whole. When heat and energy conservation is aimed, it will affect the entire building. In order for energy needs to be balanced, the locations of the zones of the structure must be balanced in the design phase.

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