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Research Article

FEASIBILITY OF NEARLY-ZERO ENERGY BUILDING RETROFITS BY USING RENEWABLE ENERGY SOURCES IN AN EDUCATIONAL BUILDING[1]

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ABSTRACT

Dissemination of education is vital especially in developing countries like Turkey. Besides, proper use of energy resources is required while dissemination of education is ensured. Considering the regions where energy is limited, renewable energy sources should be used to achieve the goal of a zero-energy building. Moreover, an increase of smart technologies has potential in order to decrease energy consumption in educational buildings. This paper aims to investigate renewable energy sources to decrease energy consumption to achieve nearly-zero energy building goal by implementing different energy efficient retrofitting scenarios. The retroffitting scenarios are based on renewable energy sources and are presented for an educational building located in Ankara-Turkey, through a Building Energy Simulation Tool, Design Builder Software. In order to develop an accurate model, educational building is monitored and the model is calibrated. Then, various energy efficient retrofitting scenarios are defined such as implementing PV panels, solar collectors and adding wind turbines for electricity generation.

Keywords: *Nearly-zero energy buildings, Educational buildings, Renewable energy*

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1. INTRODUCTION

Energy intensity of Turkey is higher compared with Western European countries. However, energy consumption of the country is expected to grow significantly together with increasing young urban population and industrial development potential. At the same time, elementary education of population in rural region is vital with the development of industry (Tonguc Vakfi, 2019). Besides dissemination of education, proper use of energy resources become a significant issue in developing countries such as Turkey where energy is limited. On the other hand, the building sector holds significant opportunity as 40% of the current energy consumption (Eshraghi *et al.*, 2014). Therefore, the implementing zero-energy building applications becomes crucial to meet energy saving goals, specially for educational buildings. For example, Ascione *et al.* (2015) provided renewable energy resources for an educational building in Italy. The authors investigated potential energy savings such as changing glazing with efficient ones and insulating roofs and calculated pay-back period as 10 years. Similarly, Sait (2013) suggested to increase the efficency of air-conditioner systems of educational buildings. 31% of energy was saved with a pay-back period of 2.3 years.

Nearly-zero energy building (NZEB) is not new concept for educational buildings in Europe. Zeiler and Boxem (2013) compared NZEBs with traditional educational buildings in Netherlands. The authors indicated that NZEBs produces their own energy from renewable energy resources such as solar panels and wind turbine parks. However, initial costs of investments were found high. Considering there are approximately sixty thousand schools in Turkey, educational buildings have great energy saving potential by applying energy efficient retrofit scenarios (Basarir *et al.*, 2012). Moreover, energy efficient educational buildings can improve thermal comfort of students and teachers while decreasing energy consumption of buildings. Many papers have been published to revive educational buildings in rural regions (Tonguc Vakfi, 2019; Vexliard and Aytaç, 1964; Eshraghi *et al.*, 2014; Korur, 2002; Karaomerlioglu, 1998). According to the authors' knowledge, there is no study on predicting energy consumption of educational buildings in rural zones and implementing energy efficient retrofits in Turkey.

The aim of this study is to apply nearly zero-energy applications to an educational building in a rural region. Hasanoğlan Atatürk Science High School which is located in Ankara/Turkey is selected as case building. A detailed building energy simulation tool is used to determine the influence of energy efficient retrofit scenarios. The model of Hasanoğlan Atatürk Science High School is calibrated by comparing the measured and simulated indoor air temperatures and total electricity consumptions. The applicability of the scenarios are evaluated with pay-back period criteria.

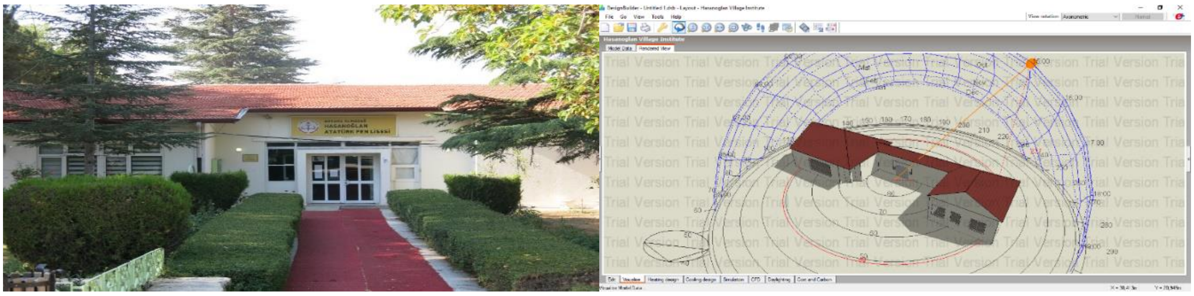
2. CASE STUDY

Ankara is situated in Central Anatolia Region of Turkey (at 32.52 E 39.56 N) which is Dsb type climate zone under the Koppen-Geiger climate classification (World Map of Koppen-Geiger Climate Classification, 2006). The average temperature is 22.3ºC and 1.4ºC during summer (May-October) and winter (December-March), respectively (Turkish State Meteorological Service, 2019). The case building is the Hasanoğlan Atatürk Science High School which is located in Ankara and lays on Northeast- Southwest direction (Figure 1).

Figure 1. The location of the Hasanoglan Atatürk Science High School

Hasanoglan Atatürk Science High School was built in 1941 by village institute students who founded other village institutes and the teachers to solve the failure in constituting the teaching staff problem for Turkey (Figure 2). The selected building is one-storey with 18 seperate zones. The total floor area of the case flat is 150.85 m^2 including administrator offices, editorial offices and long corridors. The people density is assumed as 0.11 ppl/m^2 while density of computers is 1 W/m^2. Since there are many editorial offices in the building, the density of office equipments is selected as 11 W/m^2.

Figure 2. The out-view and model of the case building

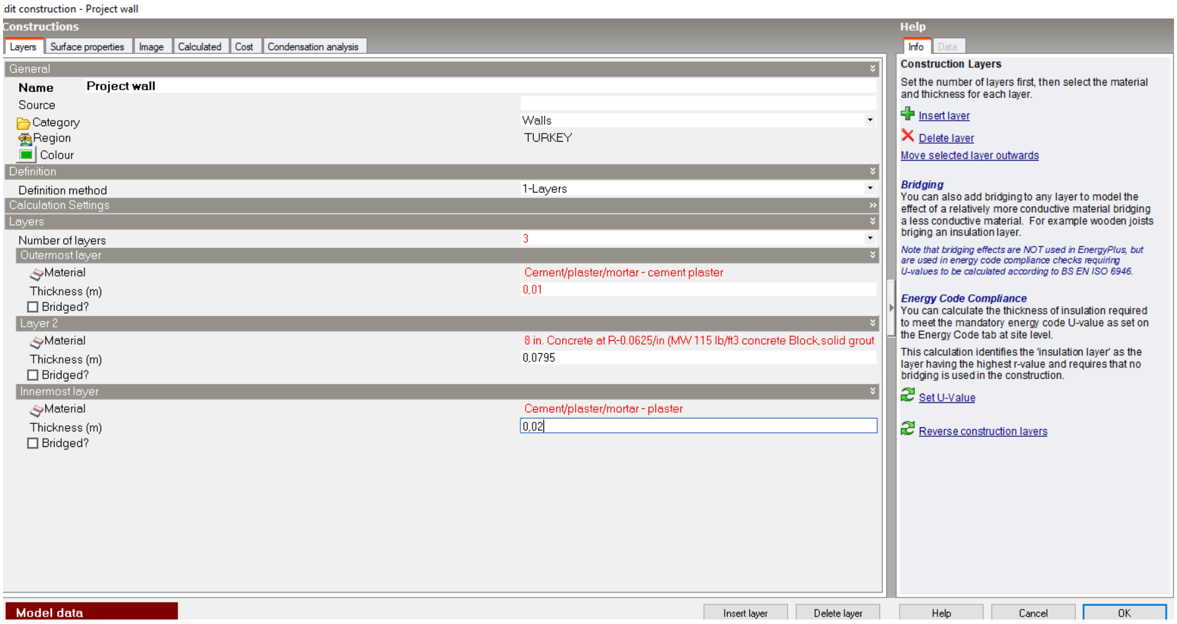


The heating and cooling system of the flat is fan-coil unit (COP=1.8) with no fresh air. The heating period is 6 months (October-April) with a set point temperature of 23°C and the cooling period is approximately 3 months from June to September with the same temperature. The operation period of heating and cooling system is from 08.00 to 19:00 on weekdays. The exterior walls consist of inner gypsum plastering (0.02 m) , brickwork inner leaf (0.19 m), XPS extruded polystyrene (0.05 m) and outer gypsum plastering (0.03 m), respectively. The walls are well-insulated with 5 cm XPS. The doors and the windows are double glazed with a PVC frames. Air tightness of the elements is 0.7 (1/h).

The Hasanoglan Atatürk Science High School is modelled and simulated in a Building Energy Simulation (BES) tool, DesignBuilder (2019). DesignBuilder is a 3D BES tool which uses EnergyPlus simulation engine. The software is capable of modelling buildings according to their heating/cooling systems, construction metarials, building geometries, weather data and occupant schedules. The outputs of the software are heating/cooling loads and energy consumption of the building. The main advantage of using DesignBuilder is to analyse energy consumption of case building by adding renewable energy technologies such as solar panel, wind turbines etc.

The case building is modelled according to the geometry of the building, energy relevant properties of the materials, monthly climate parameters of Ankara, office equipments such as computers and photocopiers and occupant behaviours (Figure 3). Before the simulation, the model is calibrated with temperature and electricity consumption data of the case building.

Figure 3. Model construction for Hasanoglan Atatürk Science High School



Eq. (1) and (2) were used to obtain heating and cooling energy requirements of case building according to the European Standards (EN 892, 1999).

$$Q_h = Q_{hL} - \eta_{hg}\, Q_{gh} \qquad \textbf{Eq. (1)}$$

$$Q_c = Q_{cL} - \eta_{cg}\, Q_{gc} \qquad \textbf{Eq. (2)}$$

where Q_h and Q_c heating and cooling energy requirements, respectively. Q_{hL} is total heat transfer for heating mode, η_{hg} and η_{cg} are dimensionless gain utilisation factors while Q_{gh} and Q_{gc} depict total heat sources for heating and cooling modes. 314

The energy retrofit scenarios are implemented in order to reduce energy consumption of Hasanoglan Atatürk Science High School after the current energy performance is analysed via DesignBuilder simulation tool. Six different energy retrofit scenarios are taken as given below.

A: Decreasing or increasing the set-temperature by 1 °C according to the season (from 23 °C to 22 °C for winter, from 23 °C to 24 °C for summer).

B: Decreasing the air tightness in order to reduce energy consumption (from 0.7 1/h to 0.51/h).

C: Changing windows with quadruble low-e windows.

D: Ten PV panels (1.6 X 1 m, with standard 60 cells) with a total area of 16 m^2 were applied to produce electricity for the building.

E: Solar collector with a total area of 2.06 m^2 were implemented to decrease energy consumption and supply domestic hot water.

F: Adding one three-bladed wind turbine to generate electricity (with 31 m height and 55kW rated power output) (Figure 4)

Figure 4. Adding wind turbine in BES tool for Hasanoglan Atatürk Science High School

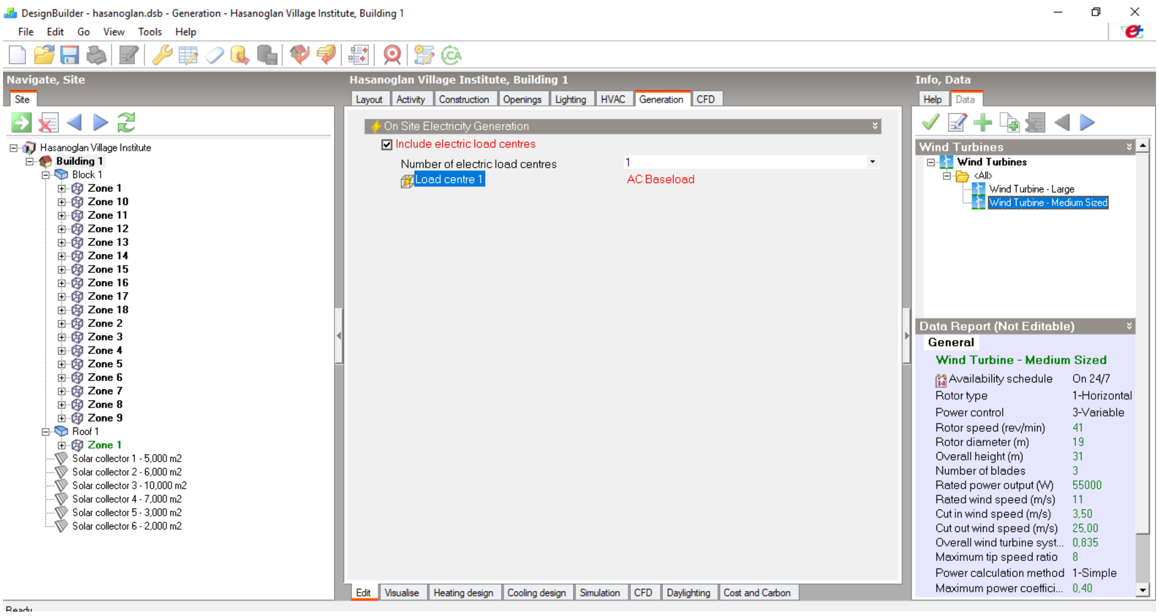


Table 1 depicts the description of six retrofitting scenarios in detail. Based on the reduction of energy consumption, pay-back periods are calculated according the formula in Eq.3 (Turhan *et al.*, 2016).

Pay-back Period: Investment Cost/ Annual Cash Savings **(Eq.3)**

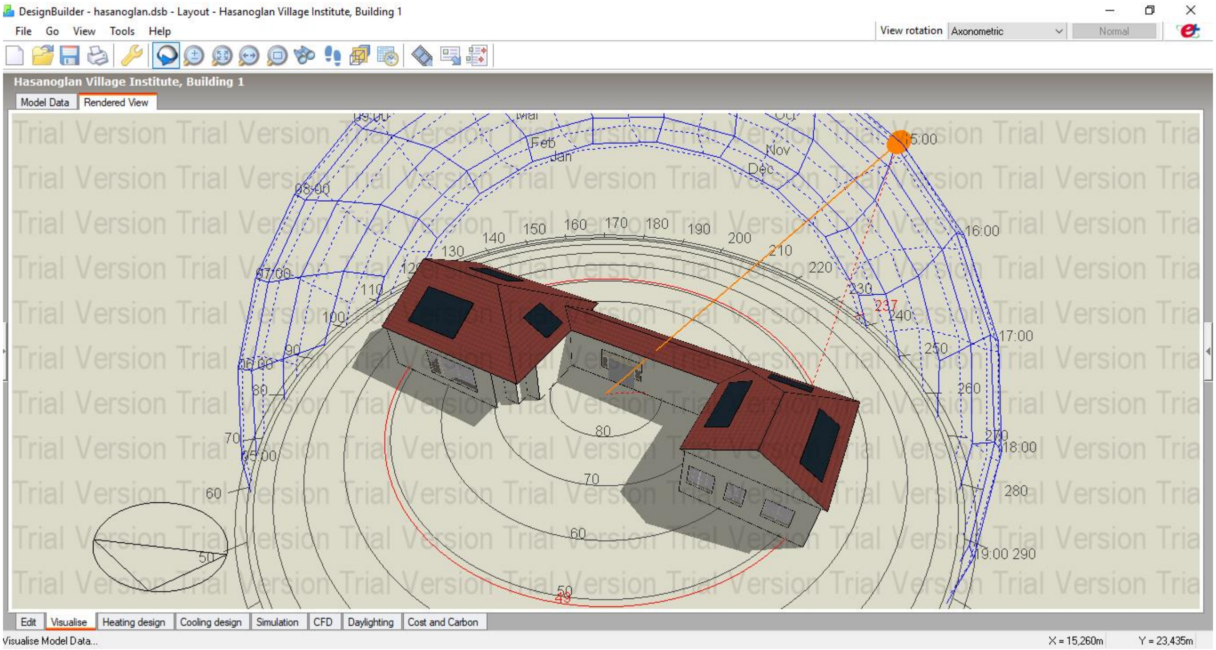
Table 1. Retrofitting Scenarios

Scenarios	*Retrofits*	*Existing*	*Improved*
Case 1	*A*	*23 °C*	*22 °C for winter, 24 °C for summer*
Case 2	*A+B*	*0.7 1/h*	*0.5 1/h*
Case 3	*A+B+C*	*1.98 (W/m²K)*	*0.77 (W/m²K)*
Case 4	*A+B+C+D*	-	*2 kWp*
Case 5	*A+B+C+D+E*	-	*2 kWh*
Case 6	*A+B+C+D+E+F*	-	*55 kW*

3. RESULTS AND DISCUSSION

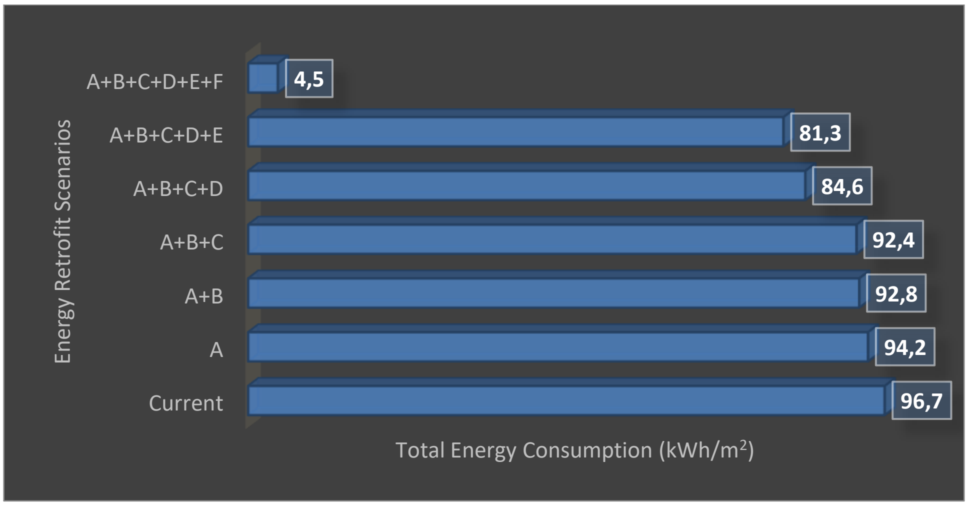
The BES model is calibrated according to the ASHRAE Guideline 14 (ASHRAE, 2002). Six different energy retrefitting scenarios are implemented after constructing and calibrating model accurately. Figure 5 shows the final model of the Hasanoglan Atatürk Science High School after implementing six energy retrofitting scenarios including renewable energy technologies.

Figure 5. Decreasing energy consumption of Hasanoglan Atatürk Science High School towards a nearly-zero energy building



The reduction in energy consumption for the case building is shown in Figure 6. Changing the set-temperature of heating and cooling system saves 2.6% of energy without any pay-back period. Since the window number in the building is low, changing the window type to high performance low-e windows seems not logical (pay-back period is 7.8 years). Results show that retrofit Case 4 reduces the total annual energy consumption by 12%. With adding solar collector to the system, 15% of energy can be saved with a pay-back period of 8.4 years.

Figure 6. The total energy consumption of retrofits



However, the most important retrofit is implementing wind power system to the Hasanoglan Atatürk Science High School building. The initial costs of constructing a 31 m wind turbine is around 50000 pounds. This number can be seemed as high with a pay-back period of 14 years. However, implementing wind power system to the Hasanoglan Atatürk Science High School saves 95.3% of energy. Furthermore, by increasing the number or power of wind turbines, the Hasanoglan Atatürk Science High School can sell electricity to the city electricity grids which can make the building "positive-energy building". Table 2 summarizes the energy retrofit scenarios and energy savings with pay-back periods.

Table 2. Energy consumption of the Hasanoglan Atatürk Science High School with respect to energy retrofits

	Total energy consumption (kWh/year)	Total energy consumption per area (kWh/m² year)	Energy Saving (%)	Cost (TL)	Pay-back period (Year)
Case educational building	*14586*	*96.69*	-	-	-
Case 1	*14203.7*	*94.15*	*2.62*	-	-
Case 2	*14001.04*	*92.81*	*4.01*	*150*	*0.48*
Case 3	*13949*	*92.40*	*4.36*	*4750*	*7,81*
Case 4	*12763.14*	*84.60*	*12.49*	*20990*	*8.41*
Case 5	*12261.73*	*81.28*	*15.93*	*26240*	*8.49*
Case 6	*678.24*	*4.49*	*95,35*	*405095*	*14,11*
Note: Labour charges are added to the prices, 1 $= 5.8 TL, 1£ = 7.57 TL, 1 € =6.55 TL					

4. CONCLUSIONS

An administrive building in Hasanoglan Atatürk Science High School Campus was selected as a case study in order to apply zero-energy building concept. The energy performance of the case building was simulated via of Design Builder building energy performanse simulation program. The tool was calibrated with real data according to the standards. The improvements in decreasing the energy consumption applying various retrofitting scenarios were shown. The results show that using renewable energy sources such as solar and wind power, 95% of energy consumption can be saved. Another outcome of the study is that the energy consumption of educational buildings such as Hasanoglan Atatürk Science High School should be lower with a development of technology and using renewable energy sources. Note finally that this study is an elementary work which does not include whole buildings in campus. By applying energy retrofits to the whole buildings, more energy savings would be obtained. Furthermore, energy efficiency of the Hasanoglan Atatürk Science High School can be improved by using more efficient appliances, lighting system and raising awareness on energy efficiency of the administrator and students.

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