Evaluation of Building Retrofitting Alternatives Towards Zero Energy School Building in Turkey

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Abstract. The building sector plays a vital role in coping with current worldwide challenges: climate change, urbanization, and environmental pollution. Building performance analysis is essential from the energy consumption, comfort, and carbon emission point of view. Different paradigms have been studied for many years, like bioclimatic architecture, sustainable architecture, green architecture, and carbon-neutral architecture. The regenerative paradigm has been a critical topic since 2016 to look toward positive impact architecture for going beyond the neutral impact. The research aims to examine the existing condition of a school building in İstanbul, Turkey, to investigate a strategy for achieving energy-efficient school building towards zero energy. The research method is based on preparing the energy model of the school and making simulations by using Design Builder software and Energy Plus software. The validated simulation is used to examine the retrofit packages for the efficiency of the school building and discuss the alternatives that are categorized as two alternatives for the insulation layer, three types of glazing alternatives, two types of the lighting system, and five alternatives for the HVAC system. By the combination of the alternatives, 111 retrofit packages are analysed. According to the comparison of the packages, the P102 scenario has the lowest results for the primary energy for electricity (P.E.E), primary energy for natural gas (P.E.N.), and the total primary energy (T.P.E) as 1.84 kWh/m^2, 1.51 kWh/m^2, and 3.35 kWh/m^2 thanks the integration of renewable energy systems; while the existing condition of the case study school building has 29.99 kWh/m^2, 63.05 kWh/m^2, and 93.05 kWh/m^2 respectively. Therefore, towards zero energy school building, the retrofit scenarios are significant to reduce the negative impact of a building on the environment by highlighting the combination of the renewable energy system and advanced HVAC system and with the integration of proper insulation thickness, efficient glazing, and lighting type. The alternatives and aspects of the research can provide a strategy for further study steps and related studies to improve the building stock towards zero energy in school buildings.

Keywords. Building Energy Efficiency, School Building, Regenerative Architecture, Primary Energy.
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1. Introduction

In the world, buildings and construction sectors are responsible for almost %40 of total energy consumption and 36% of CO2 emissions [1,2,3,5]. Energy Performance Building Directive aims to decrease greenhouse gas emissions by at least 40% by 2030 compared with 1990, as mentioned in the latest version [4]. All these targets are to decrease the negative impacts of the building sector like increasing carbon emissions, climate change, scarcity of resources, depletion of fossil fuels, population growth, and urbanization [5]. From the 20th to 21st century in the field of architecture and urbanization, to enhance a sustainable build environment, seven phases of sustainable paradigms [6] can be categorized as bioclimatic architecture [7], environmental architecture, energy-conscious architecture, sustainable architecture [8], green architecture [9], carbon-neutral architecture [10], and regenerative architecture which is mainly focused on after 2016 about providing the positive ecological built environment for both building and urban level by going beyond neutrality [11,5].

The education sector has an essential part of the world's building sector since it is stated that more than 40% of the existing schools are insufficient for providing Indoor Air Quality in the world [12]. Thus, it causes the usage of additional heating, cooling, and air-conditioning systems, which account for 60% and 70% of the total energy used in non-industrial buildings like educational facilities [13]. In Europe, 64 million students and nearly 4.5 million teachers spend their time in pre-primary schools and elementary schools [12]. In 2018, Eurostat data stated that by 2050 annual student population growth rate will increase 3 percent, which means a need for 40.000 new classrooms [14]. Thus, school buildings are a significant part of the building sector not only for the environment and economy by saving energy and being positive and neutral approaches but also to have a healthy and comfortable learning environment for children and teachers since students spend 30% percent of their time in schools [12].

There are several actions worldwide toward going beyond net-zero energy building requirements. In the USA, there are 117,007 schools and nearly 73 million students. Educational facilities are responsible for 80% of energy consumption for lighting, ventilation, heating, and cooling energy consumption and they pay more than $ 6 billion per year to encounter their energy costs [15]. Therefore, *the "green school"* concept is developed for saving energy, resources, and the economy without compromising the need of students and teachers as a healthy environment [15]. In Belgium, education facilities are responsible for 1.5 percent of greenhouse gas emissions; nearly 3 million students attend 6000 schools every day. They set a target for 2021 to be carbon neutral and usage of renewable sources in educational facilities [14]. *Nearly Zero Energy Schools* program is managed to reduce energy use from 0.7 to 0 in academic buildings in Dutch by 2050; there will be an 80% reduction in primary energy consumption compared to 1990 [12]. With the aim of climate-neutral new buildings in Germany [16], there are 15.446 schools with a total consumption of 270,000 MWh [15]. Therefore, the application of "*Passive House Standards in School Buildings"* is to provide solutions to achieving *NZEB* standards in schools with the basis of the directive [17]. Providing Net Zero Energy schools strategies are mentioned as the further improvement of passive schools [18]. More than 60% of school buildings were built in Italy without energy-related regulation; 30% of them were measured as poor energy performance. Thus, the average energy use of the school's buildings is almost 290 kWh/m2/year [15]. A deep energy renovation study was conducted in Italy by achieving a %60 reduction in heating consumption and electricity neutrality regarding upgrading the performance of the envelope by including an insulation layer on the roof and floor, adding external shading devices to protect new windows, redesigning the heating system, conducting a roof PV plant [19]. The other related projects in Europe to raise awareness for sustainable strategies in schools both for new and existing ones *"School of The Future"* [20,19], *"ZEMeds"* [21], *"Educa-RUE (Rational Use of Energy)"* [22], *"Renew Schools", "Veryschool", "Teenergy Schools" and "Check It Out"* [13]. Education facilities which are a part of the non-residential building sector, seem a vital topic to saving energy, resources and having a positive impact on the three main components of sustainability in the world.

Turkey, a candidate of being a European country, shares the same significant problems and is in the adaptation process for European Union, needs to take the responsibility of decreasing the negative impacts of building stock. About the existing building stock, as it is mentioned by the European Commission, nearly half of the dwellings are over 50 years [23]. There is a meager percentage of refurbishment rate between 0.4 and 1.2 % per year; therefore, renovation of existing buildings is critical to 2050 as a long-term target [24]. Educational facilities are essential to consider both for new and existing buildings. According to the nation's non-residential energy needs, % 15 of total energy consumption is accounted for from the non-residential sector, including educational buildings. According to national statistics for 2015 and 2016 [25], 99,156 school buildings serve 23 million students and 1.290 million teachers. It means that most of the population spends more time in schools [26]. There needs to act toward regenerative architecture and positive impact architecture on educational facilities from this moment. It is necessary not only to reduce energy consumption as an economical feature by directing renewable sources but also for the environment to cope with the 21st-century environmental problems and encourage society to be more sustainable since it is proved that just by changing the behavior in school buildings, energy consumption can be sustained between %5 to 15% in a school [27]. There can be achieved %60 of primary energy savings and CO2 emission reductions; % 42 of global cost-saving in a maximum of 7 years by implementing energy-efficient retrofit scenarios on school buildings [28].

The study aims to conduct research by focusing on retrofitting an existing school building based on the alternatives of envelope measures, lighting measures, and HVAC measures. The combination of the alternatives enables the retrofit scenarios after validating the energy modeling. The comparison demonstrates the optimum scenario of retrofitting strategies toward zero-energy school buildings.

2. Methodology

For the evaluation of envelope, lighting, and HVAC measures, a school building in İstanbul, Beykoz is decided. The total building area of the school is 2044 m^2. The school building has five floors, including the basement and attic floor. There are fifty-nine different zones like classroom, library, kindergarten, and corridor. The HVAC system of the case study is based on radiator heating, boiler hot water, and natural ventilation. All the zones, excluding elevator, kitchen, staircase, fire stair, windbreak, and WCs are heated by the same mechanical system. The HVAC system is combined with packaged thermal air conditioner for the zones of "teacher room 1" and "director room 3". Design Builder 4.7 software was used for energy modelling by indicating 2D drawing of the school from the AutoCAD programme. Figure 1 shows the Design

Builder model of the school building. Figure 2 indicates the summary of the progress.

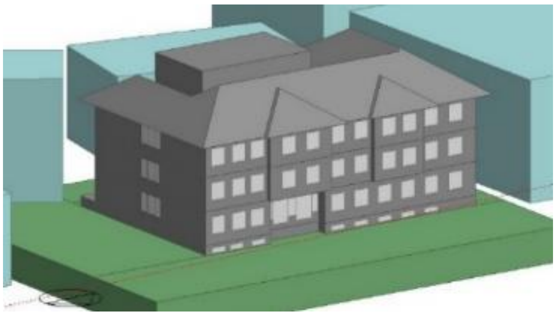


Fig. 1 – Design Builder model of the school building.

To reflect the existing condition of the school, the data about density, equipment, and lighting of the zones were indicated according to the site analysis. The occupancy schedules related to the daily usage of the zones are indicated. The data is taken from the school administration. The schedule of the zones for occupancy, lighting, and equipment is organized based on class and breaking times. The schedule of lessons identifies the usage pattern of the corridors, storages, and WCs. The school is mainly available between 09.00 am and 16.00 pm. Still, some of the zone's schedules can differ, like the heating centre available during weekends between 08.00 am and 12.00 pm. Table 1 shows the primary occupancy management of the school building.

Tab. 1 – Schedule the organisation of the case study.

Main Zones	Weekdays	Weekends	Holidays
Classroom	09.00-16.30	Off	Off
Classroom 2	09.00-13.10	Off	Off
Kindergarten	09.00-14.00	Off	Off
Kitchen	08.00-16.30		Off
Administration and teachers	08.00-15.35	Off	Off
Heating centre	07.00-16.00	08.00-12.00	Off

The usage of the zones identifies the type of metabolism. Standing/ walking is for circulation areas. Reading seated is for classrooms, kindergarten, administration, and teacher rooms. Light manual work is for the engine room and kitchen and eating/drinking is for the canteen. Also, target illuminance is managed as 400 lux.

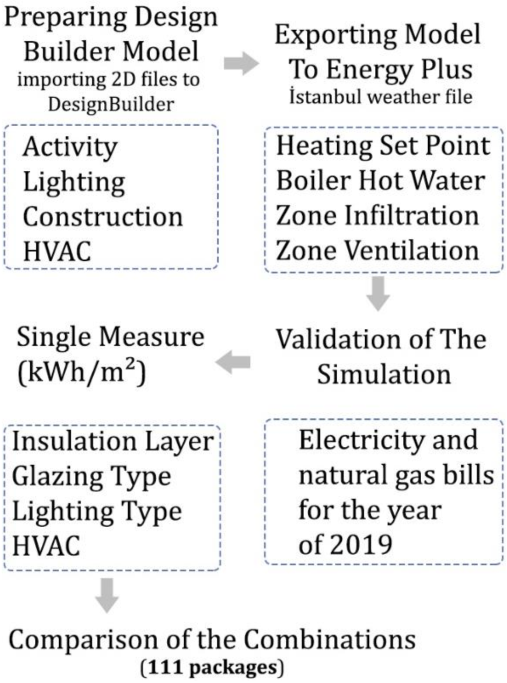


Fig. 2 – Summary of the progress.

The construction materials of the case study are indicated according to technical drawings. The materials for external walls, underground walls, roofs, internal partitions, ground floor, basement floor, and internal floors were obtained. The U value (W/m^2-K) results are compared with TS 825 Standard for İstanbul [29]. A detailed explanation is in Table 2. The comparison of the existing situation of the school with the standard shows that the U value (W/m^2-K) results of the external floor, flat roof, and glazing system exceed the standardized number. Also, the result for the basement floor can be reduced. Therefore, the retrofit scenarios are categorized as an insulation layer, lighting type, glazing type, and heating system improvements. The scenarios are compared according to equation (1), which is the primary energy calculation [28].

$$\textit{Total Primary Energy} = (\textit{Total End Uses Electricity(kwh)} \times 2{,}36) + \textit{Total End Uses Natural Gas(kwh)} \qquad (1)$$

After the modeling process, the validation of the simulation is conducted based on the bills of electricity (kWh) and natural gas (kWh) for 2019. Energy Plus software is used for this stage of the research. In the software, the heating setpoint is conducted as 24, and the nominal thermal efficiency of the boiler is taken as 0.75. About zone infiltration, for the zones that have an external wall, air changes per hour unit is indicated as 0,6 1/hr. 0,2 1/hr is for the zones of the basement floor. The rate is obtained as zero for the zones that do not have an external wall. About zone ventilation, the air changes per hour unit is indicated as 3 for the zones in the south. The zoned in the north, the value is obtained as 2. For the zones that do not have windows, the rate is indicated as 0.

Tab. 2 – The properties of the construction.

Construction	Properties (meters)	U value (W/m^2-K)	Maximum U value in TS825
External wall	Plaster (0,03), XPS (0,03), Plaster (0,02), Brick (0,30), Plaster (0,02)	0.617	0.57
Below grade walls	Brick (0,09), Plaster (0,02), XPS (0,03), Insulating Plaster (0,02), Reinforced Concreate (0,3), Plaster (0,04)	0.645	No value
Flat roof	Gravel (0,07), Roofing Felt (0,01), XPS (0,05), Mortar (0,05), Cast Concreate (0,2), Plaster (0,03)	0.462	0.38
Pitched roof (occupied)	Clay (0,04), Air Gap (0,02), Wood (0,1)	2.214	No value
Internal partitions	Plaster (0,01), Masonry (0,15), Plaster (0,01)	0.946	No value
Ground floor	Plaster (0,02), Cast Concreate (0,3), Floor Screed (0,03), Marble (0,03)	1.622	No value
Basement floor	Cast Concreate (0,3), Screed (0,03), XPS (0,03), Floor Screed (0,05), Plaster (0,03), Ceramic (0,02)	0.386	0.57
Internal Floor	Plaster (0,02), Cast Concreate (0,3), Floor Screed (0,03), Marble (0,03)	1,499	No value
Opening	Double Clear Glazing (6mm/13mm air)	2.708	1.8

Tab. 3 – Validated simulation results.

Months	Actual Electricity (kwh)	Sim. Electricity (kwh)	Actual Natural Gas (kwh)	Sim. Natural Gas (kwh)
1	2,412.50	2,666.00	37,867.76	30,356.25
2	2,131.27	2,507.00	37,420.88	26,414.65
3	2,630.65	2,879.00	25,408.32	24,629.03
4	2,676.10	2,726.00	26,004.16	16,323.91
5	2,404.92	2,879.00	1,936.4	2,399.42
6	1,324.57	1,791.00	566.05	566.05
7	725.35	56.60	354.66	354.66
8	725.35	56.60	354.66	354.66
9	725.35	1,943.00	354.66	354.66
10	1,881.37	2,843.00	1,010.8	1,010.80
11	1,856.62	2,788.00	13,448.96	14,252.69
12	2,482.87	2,831.00	24,759.28	28,516.17
Total	21,976.9	25,966.5	169,486.67	145,532.95

According to the ASHRAE standard [30], the simulation is validated for the difference of 15% yearly and 5% monthly. The yearly electricity result is 25,966.53 kWh in the simulation, the existing situation of the school is 21,976.92 kWh. The annual result of the electricity is proper at 15%.

Tab. 4 – Single Measures.

Single Measure		P.E.E.	P.E.N.	T.P.E.
Existing Condition		**29.99**	**63.05**	**93.05**
Insulation Layer	**I1** 6;10;6	29.99	55.78	85.77
	I2 9:15;9	29.99	52.18	82.17
Glazing	**G1** Dbl LoE Clr	28.37	59.39	87.77
	G2 Triple Clr	28.35	57.97	86.33
	G3 Trp LoE	28.51	57.42	85.93
Lighting	**L1** CFL	27.33	63.7	91.04
	L2 LED	27.03	63.7	90.83
HVAC	**H1** PV Panel (10kW=11750kWh)	16.43	63.05	79.98
	H2 PV Panel (20 kW= 23500kWh)	2.86	63.05	65.91
	H3 PV Panel (30 kW=32250 kWh)	-10.69	63.05	52.36
	H4 Heat Pump	48.05	1.13	49.19
	H5 %95 efficient Condensing Boiler	29.99	46.1	76.1

According to monthly results, except for three months, the results are between 5%. The yearly result for natural gas is 145,532.95 kWh in the simulation, while the existing situation is 169,486.67 kWh. The simulation result of natural gas is in the suitable difference of 15%. Also, the monthly results are in between the proper percentage of 5% excepting January, February, and April. Table 3 displays the detail of validated simulation results.

For the existing condition of the school building, the primary energy for electricity is 29.99 kWh/m^2; the primary energy for natural gas is 63.05 kWh/m^2; the total primary energy is 93.05 kWh/m^2. There are four main retrofit alternatives: increasing the thickness of the insulation layer, changing the glazing type, changing the lighting type, and suggesting different HVAC systems. There are two alternatives for improving the insulation: two times of existing condition and three times for external wall, flat roof, and basement floor, respectively. Three alternatives of the glazing type are Dbl LoE (e=1) Clr 6mm/13mm Air, Triple Clr 3mm/13mm Air, and Triple LoE (e2=e5=1) Clr 3mm/13mm Air. Fluorescent compact (CFL) and LED are the lighting alternatives. For the HVAC system, the main ones are photovoltaic (PV) panel, heat pump, and condensing boiler with 95% efficiency. The potential of generating electricity from PV panel implementation has three alternatives as 10Kw, 20kW, and 30Kw, respectively. Table 4 indicates the detailed explanation of single alternatives with the calculations of primary energy. In the table, P.E.E. is the abbreviation of primary energy for electricity (kWh/m^2); P.E.N. is the abbreviation of primary energy for natural gas (kWh/m^2), and T.P.E. is the abbreviation of total primary energy (kWh/m^2).

The efficiency rate of CFL is between 62% and 80% [31,32]. The average of the numbers is 76%, calculated in the alternative scenario. The efficiency rate of LED is between 75% and 93% [33]. Thus, the average of the numbers is 85% indicated in the scenario. Also, the generated electricity number thanks to PV panels is identified according to the radiation received by Turkey as 10kW solar panel generates electricity between 11.000 kWh and 12.500 kWh per year [34]. Thus, the average is 11.750 is considered in the research.

3. Results and Discussion

According to combinations of four single alternatives, 111 retrofit packages have been organized by including two alternatives for insulation thickness, three types of glazing, two types of lighting, and five alternatives for HVAC systems. Also, the HVAC alternatives of H1 and H5 are combined with H1, H2, and H3. The results of the 111 packages in terms of P.E.E., P.E.N, and T.P.E. are indicated in Figure 3.

The packages between P1 and P12 are the combinations of the 10kW PV panel. The minimum result for the primary energy for electricity is in P10 with 17.71 kWh/m^2. In contrast, the minimum value for the primary energy for natural gas is 62.69 kWh/m^2 in P6. P12 has the minimum value for total primary energy with 80.49 kWh/m^2 thanks to I2, G3, and L2 combinations.

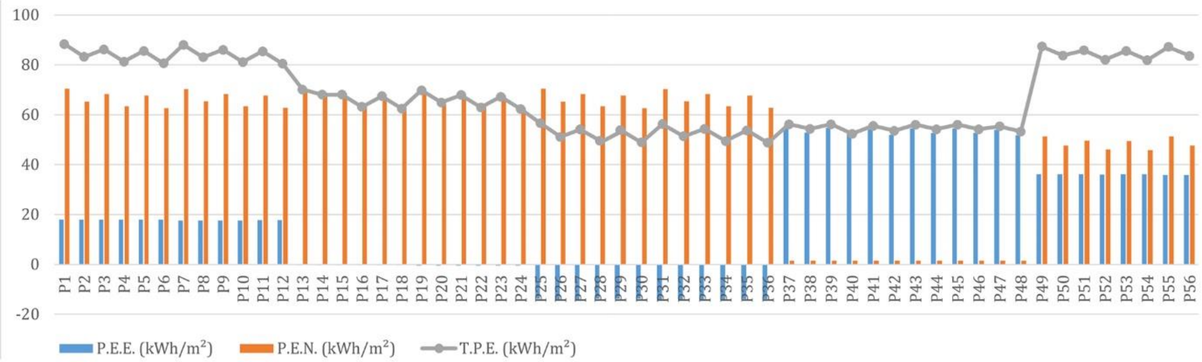
The packages between P13 and P24 integrate a 20kW PV panel. Package 20 has the lowest primary energy of electricity at -0.47 kWh/m^2. P24 has the lowest primary energy for natural gas and total primary energy at 62.77 kWh/m^2 and 62.32 kWh/m^2, respectively.

For the 30 kW PV panel combinations that are between the packages P25 and P36, the minimum result for the P.E.E. is in the scenario of P32 as -14.01 kWh/m^2. P.E.N and T.P.E, P36 has the minimum result of 62.77 kWh/m^2, and 48.77 kWh/m^2, respectively. The main finding for the packages between P1 and P36 which is the combinations of PV panel scenarios is that although the P.E.E. results are remarkably decreased especially by combining 30 kW PV panel and G3 type glazing alternative, the P.E.N. results are close to the existing condition of the school which is 63.05 kWh/m^2.

The heat pump alternatives and their scenarios are between P37 and P48. The combinations of heat pumps have a considerable decrease for the results of P.E.N. as 1.51 kWh/m^2. However, the minimum values of P.E.E. and T.P.E are 51.75 kWh/m^2 and 53.26 kWh/m^2, respectively, in the P48 scenario.

The 95% efficient condensing boiler combinations are between P49 and P60. The packages of P55 and P56 has the minimum results for P.E.E with 35.89 kWh/m^2, while the minimum result for P.E.N. is 45.80 kWh/m^2 in the scenario of P54. According to the T.P.E., P60 has a minimum result of 81.77 kWh/m^2. To exemplify the impact of PV panel alternatives by the combination of a 95% efficient boiler, the packages between P61 and P96 were analyzed. P86 has a -14.18 kWh/m^2 P.E.E result which is the least number for P.E.E in the 111 scenarios. P.E.N is 47.61 kWh/m^2, and T.P.E. is 31.86 kWh/m^2, which is approximately one-third of the existing condition of the school building.

The packages between P97 and P111 combine scenarios by integrating both heat pump and PV panel alternatives. The results of the related packages show that a combination of heat pump and PV panel enables a significant decrease for the P.E.E. by comparing with the results of offering a 95% efficient condensing boiler and PV panel. Suggesting only a heat pump, PV panel, and the efficient condensing boiler is not enough to achieve the aims of zero energy school building. The combination of heat pump and PV panel implementation verifies the statement.



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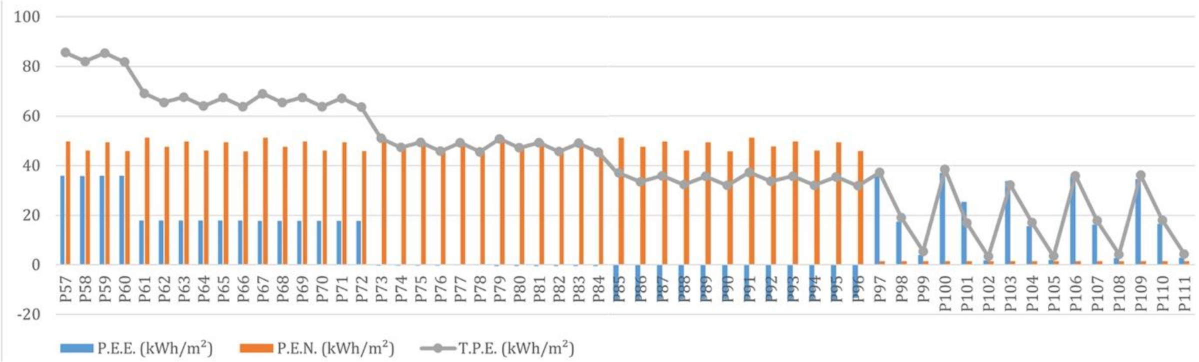

Fig. 3 – Simulation results for 111 packages.

P102 is the best scenario in the 111 packages with the results of P.E.E, P.E.N, and T.P.E as 1.84 kWh/m^2, 1.51 kWh/m^2, and 3.54 kWh/m^2 respectively. The scenario includes the alternatives of I2. G3, and L2. Table 5 shows the lowest results for P.E.E., P.E.N., and T.P.E by the packages with different HVAC alternative combinations. All the scenarios include I2 alternative as the maximum thickness of the insulation layer. Most of them are combined with G3 as the Triple LoE glazing alternatives and L2 as the LED lighting type. Therefore, these three alternatives can be mentioned as the efficient single alternatives of the retrofit packages.

4. Conclusion

Energy efficiency for educational buildings is critical since a significant part of the population as students and teachers spend most of their time in schools. Therefore, the research focuses on increasing the energy efficiency of a school building in İstanbul, Turkey, towards zero energy.

111 retrofit packages were examined in the study with the combination of the two different thicknesses for insulation layer, three types of glazing system, two alternatives for lighting types as CFL and LED, also five alternatives for the HVAC system. The results are compared according to primary energy for electricity, primary energy for natural gas, and total primary energy. The package of P102 has the lowest results for P.E.E, P.E.N., and

Tab. 5 – Packages with minimum primary energy for electricity (kWh/m^2), natural gas (kWh/m^2), and total primary energy (kWh/m^2).

Package	P.E.E.	P.E.N	T.P.E
P6: I2, G3, L1, H1	17.96	62.69	80.65
P10: I2, G2, L2, H1	17.71	63.42	81.13
P12: I2, G3, L2, H1	17.72	62.77	80.49
P20: I2, G1, L2, H2	-0.47	65.37	64.90
P24: I2, G3, L2, H2	-0.45	62.77	62.32
P26: I2, G1, L1, H3	-14.18	65.29	51.10
P32: I2, G1, L2, H3	-14.01	65.37	51.35
P36: I2, G3, L2, H3	-13.99	62.77	48.77
P40: I2, G2, L1, H4	52.81	1.51	54.32
P48: I2, G3, L2, H4	51.75	1.51	53.26
P54: I2, G3, L1, H5	36.14	45.80	81.94
P60: I2, G3, L2, H5	35.91	45.86	81.77
P70: I2, G2, L2, H1+H5	17.71	46.11	63.82
P78: I2, G3, L1, H2+H5	-0.22	45.80	45.58
P80: I2, G1, L2, H2+H5	-0.47	47.68	47.21
P86: I2, G1, L1, H3+H5	-14.18	47.61	33.43
P96: I2, G3, L2, H3+H5	-13.39	45.86	31.86
P102:I2, G3, L2, H3+H4	1.84	1.51	3.35
P105:I2, G3, L1, H3+H4	2.03	1.51	3.54

T.P.E. as 1.84 kWh/m^2, 1.51 kWh/m^2, and 3.35 kWh/m^2; while the existing condition of the case study school building has 29.99 kWh/m^2, 63.05 kWh/m^2, and 93.05 kWh/m^2 respectively. P102 combines a 30 kW PV panel and heat pump with I2, G3, and L2 alternatives for insulation layer, glazing, and lighting. The result of the retrofit scenarios can provide a basis towards zero energy school building level by highlighting the importance of renewable energy integration for the alternatives of advanced HVAC system types can make a remarkable decrease for the results of primary energy for electricity, natural gas, and total primary energy results.

The regenerative paradigm toward positive impact architecture is an essential research area in recent years to decrease the negative impacts of the building sector. As a further step of the research, by taking as a base the P102 scenario, the different alternatives, and renewable energy solutions can be examined toward positive impact on a school building, since the result of the retrofit scenarios displays those single combinations are not enough to achieve the efficiency level of the building towards regenerative and positive impact architecture. These can be critical for further studies related to the topic. Since a major part of schools in Turkey use natural ventilation as a basis, retrofitting scenarios do not include mechanical ventilation. The research does not include the integration of comfort, system, and cost. Further studies can also consider the results and aspects of the scenarios in their research and analysis.

5. Acknowledgement

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6. References

[1] Abergel T, Delmastro C, Lane K. Tracking Buildings 2020 [Internet]. Paris: International Energy Agency; [updated 2020; cited2022 Jan2]. Available from: https://www.iea.org/reports/tracking-buildings-2020.

[2] Directive 2002/91/EC of the European Parliament and of the Council of 16 December 2002 on the Energy Performance of Buildings. Off J Eur Union. 2003; 1:65-71.

[3] EPBD recast. Directive 2010/31/EU of the European Parliament and of council of 19 May 2010 on the energy performance of buildings (recast). Off J Eur Union. 2010: 13-35.

[4] Directive (EU) 2018/844 of the European Parliament of the Council of 30 May 2018 amending Directive 2010/31/EU on the energy performance of buildings and Directive 2012/ 27/ EU on energy efficiency. Off J Eur Union. 2018: 75-91.

[5] Attia S. Regenerative and positive impact architecture: learning from case studies. Springer International Publishing; 2018.

[6] Attia S. Towards regenerative and positive impact architecture: a comparison of two net zero energy buildings. Sustainable Cities and Society. 2016; 26: 393-406.

[7] Sala M, Gallo C, Sayigh A. Architecture- Comfort and Energy. Elsevier; 1999.

[8] Lechner N. Heating, cooling, lighting: sustainable design methods for architects. John Wiley & Son; 2014.

[9] Bauer M, Mösle P, Schwards M. Green building: guidebook for sustainable architecture. Springer Science & Business Media; 2009.

[10] La Roche P. Carbon-neutral architectural design. CRC Press; 2017.

[11] Shandiz SC, Rismanchi B, Foliente G. Energy master planning for net-zero emission communities: state of the art and research challenges. Renewable and Sustainable Energy Reviews. 2021; 137(110600):110600.

[12] Golshan M, Thoen H, Zeiler W. Dutch sustainable schools towards energy positive. Journal of Building Engineering. 2018; 19:161-171.

[13] Gil-Baez M, Barrios-Pudara A, Molina-Huelva M, et al. Natural ventilation systems in 21st centuary for near zero energy school buildings. Energy. 2017; 137:1186-1200.

[14] Attia S, Shadmanfar N, Ricci F. Developing two benchmark model for nearly zero energy schools. Applied Energy. 2020; 263:114614.

[15] AlFaris F, Juaidi A, Manzano-Agugliaro F. Improvement of efficiency through an energy management program as a sustainable practice in schools. Journal of Clear Production. 2016; 138:794-805.

[16] Ascione F, Bianco N, De Masi R.F, Mauro G.M, et al. Energy retrofit of educational buildings: transient energy simulations, model calibration and multi-objective optimization towards nearly zero-energy performance. Energy and Buildings. 2017; 144:303-319.

[17] Wang Y, Du J, Kuckelkorn A, et al. Identifying the feasibility of establishing a passive house school in central Europe: an energy performance

and carbon emissions monitoring study in Germany. Renewable and Sustainable Energy Reviews. 2019; 113:109256.

[18] Zeiler W, Boxem G. Net-zero energy building schools. Renewable Energy; 49:282-286.

[19] Zinzi M, Battistini G, Ragazzini V. Energy and environmental monitoring of a school building deep energy renovation in Italy. Energy Procedia. 2015; 79:3318-3323.

[20] Morck O, Thomsen K.E, Jorgensen B.E. School of the future: deep energy renovation of the Hedegaards School in Denmark. Energy Procedia. 2015; 78:3324-3329.

[21] Dalla Mora T, Righi A, Peron F, et al. Cost-optimal measures for renovation of existing school building towards Nzeb. Energy Procedia. 2017; 140:288-302.

[22] Desideri U, Leonardi D, Arcioni L, et al. European projects Educa-RUE: an example of energy efficiency paths in educational buildings. Applied Energy. 2012; 97:384-395.

[23] Sekki T, Airaksinen M, Saari A. Effect of energy measures on the values of energy efficiency indicators in Finnish daycare and school buildings. Energy and Buildings. 2017; 139:124-132.

[24] Assimakopoulos M, De Masi R.F, Fotopoulou A, et al. Holistic approach for energy retrofit with volumetric add-ons toward nzeb target: case study of a dormitory in Athens. Energy and Buildings. 2020; 207:109630.

[25] Turkish Ministry of National Education. National education statistics-formal education-2015-2016. Ankara: National Education Strategy Development Presidency; 2015.

[26] Ashrafian T, Moazzen N. The impact of glazing ratio and window configuration on occupants' comfort and energy demand: the case study of a school building in Eskisehir, Turkey. Sustainable Cities and Society. 2019; 47:101483.

[27] Salleh M.N.M, Kandar M.Z, Sakip S.R.M, et al. User's perception of energy efficiency in school design. Procedia-Social and Behavioral Sciences. 2014; 170: 155-164.

[28] Moazzen N, Ashrafian T, Yılmaz Z, et al. A multi-criteria approach to affordable energy-efficient retrofit of primary school buildings. Applied Energy. 2020; 268:115046.

[29] Turkish Standardization Institute. TS825: Thermal insulation requirements for buildings. TSE; 2013.

[30] American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE). ASHRAE Guideline 14: Measurement of Energy, Demand, and Water Saving. Atlanta, US; 2014. ISSN: 1049-894X.

[31] Soori P.K, Alzubaidi S. Study on improving the efficiency of office building's lighting system design. IEE GCC Conference and Exhibition. 2011:585-588.

[32] Mills B, Schleich J. Household transitions to energy efficient light. Energy Economics. 2014; 46:151-60.

[33] Perdahçı C, Hanlı U. Verimli aydınlatma Yöntemleri. EVK 2009. 2009:323-7.

[34] My Energy Solar. 10 kW Güneş Enerjisi Kurulum Maliyeti 2020 [Internet]. [place unknown]: [publisher unknown]; 2020 [cited 2022 Jan 6]. Available from: https://www.myenerjisolar.com/10-kw-gunes-enerjisi-kurulum-maliyeti-2020/

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