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Life Cycle Energy Assessment of a School Building under Envelope Retrofit: An Approach towards Environmental Impact Reduction

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Abstract. Energy efficiency of existing buildings is a concept to manage and restrain the growth in energy consumption and one of the crucial issues due to the magnitude of the sector. Educational buildings are in charge of about 15% of the total energy consumption of the non-residential building sector. However, not only operational but also embodied energy of a building should be reduced to get the overall benefits of energy efficiency, where, using energy efficient architectural measures and low emitting materials during every retrofit action can be a logical step. The majority of buildings in Turkey and EU was built earlier than the development of the energy efficiency in the construction sector, hence, without energy retrofit, consume an enormous amount of energy that can be averted significantly by the implementation of some even not advanced retrofit measures. Furthermore, demolishing of a building to construct a new one is not a rational approach concerning cost, time and environmental pollution. The study has been focused on the impact assessment of the various architectural scenarios of energy efficiency upgrading on the Life Cycle Energy Consumption (LCEC) and Life Cycle CO_2 ($LCCO_2$) emission. Within the scope of the study, a primary school building is selected to be analysed. Through analysis, the total embodied and operational energy use and CO_2 emission regarding the life cycle phase of the building is quantitatively defined and investigated in the framework of life cycle inventory. The paper concentrates on the operation and embodied energy consumption arising from the application of a variety of measures on the building envelope. An educational building with low $LCCO_2$ emissions and LCEC in Turkey is proposed. To exemplify the approach, contributions are applied to a case study in Istanbul as a representative school building. The primary energy consumption of the case study building is calculated with a dynamic simulation tool, EnergyPlus. Afterwards, a sort of architectural energy efficient measures is implemented in the envelope while the lighting and mechanical systems remain constant. The energy used in the production and transportation of materials, which are the significant parts of the embodied energy, are taken into account as well.

1 Introduction

The energy consumption used throughout the building's lifecycle is a large amount of material production and energy demand affected by building construction, HVAC and lighting systems, maintenance, equipment and demolition. To diminish energy use and CO_2 emissions, the operational and embodied energies of buildings must be minimized. Implementation of energy efficient architectural measures and low emitting material can be a reasonable point to cut down the operational and embodied energy consumptions together with CO_2 emissions.

The majority of the buildings in Turkey and EU was built prior to the progress of the energy efficiency issue in the construction industry, hence, consumes enormous energy that can be prevented by even application of some not sophisticated retrofit measures. Besides, destruction of an existing building to construct an energy-efficient one entails to allocate considerable money, time and labour and of course are irrational while it can be retrofitted. Besides, the building envelope is the most impressive element due to being in direct interplay with outdoor environmental conditions. Only schools are in charge of about 15% of the overall energy utilisation of the commercial building sector. To increase the energy efficiency of school buildings, the energy demand should be minimized then the energy efficient systems ought to be implemented. All of these actions for existing buildings require a considerable budget. As most of these buildings are public and managed by states, high cost can prevent to conduct the action. However, considering the lifespan of the building and the cost that will be saved during this period make can

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make it attractive to states. In general, the renewal of existing buildings with higher energy efficiency and the appropriate global cost seems to be a logical step for existing barriers. At the same time, measures with a high payback period cannot affect customers.

Particularly after the oil crisis of the 1970s, energy has become an imperative matter in the agenda of all countries that meet the energy needs through imports. The rapid growth of population is already raising concerns around energy use, supply difficulties, depletion of energy resources and significant environmental impacts (depletion of ozone layer, global warming, climate change, etc.). According to the International Energy Agency's data on energy consumption tendencies, in the past two decades, primary energy consumption and CO_2 emissions augmented by 49% and 43% respectively, with an annual average growth of 2% and 1.8%. The energy-saving potential of the building sector is remarkable because buildings use a considerable quantity of world resources, consume a significant amount of energy, and are accounted for approximately 1/3 of CO_2 emissions. European Union support for improving energy efficiency, reducing energy consumption and eliminating wastage has introduced Legislation under the Kyoto protocol to reach their targets. The Energy Performance of Buildings Directive (2002/91/EC, EPBD) firstly launched in 2002 [2]. By recast EPBD in 2010 (2010/31/EU) adaptation, EU Member States faced new rough challenges [3]. Primary among them is to move towards new and retrofitted nearly-zero energy buildings by 2020 (2018 in the case of Public buildings) and apply a cost-optimal methodology to set minimum requirements for not only the envelope but also the technical systems. The following Concerted Action thus aimed at transposition and implementation of the EPBD recast, and it is conducted between 2011 and 2015 [4]. The comparative methodology framework for calculating cost-optimal levels of minimum energy performance requirements for buildings and elements is defined in the Delegated Regulation of the Commission [5] and its guideline [6].

In parallel with EPBD and related actions, Turkey, as a candidate country, enacted Energy Efficiency Law and Turkish Building Energy Performance Regulation. Before this, Turkey had a mandatory standard TS 825 [7], which implement heating and cooling degree-days to define required energy loads and insulation thicknesses. However, about two-thirds of all educational buildings of Turkey were constructed before the obligation of Turkish Heat Insulation standard TS825 in 2000. The most critical legislation on the energy performance of buildings in Turkey, Bep-Tr, providing a national methodology for calculating the energy performance of buildings [8].

Energy efficiency is a method of managing and preventing the growth in energy consumption and one of the most important issues due to numerous existed buildings. Demolishes of lived buildings to construct new ones are not logical approach regarding cost, time and environment. The initial solution is to reduce the energy demand of the buildings through passive solutions, and then efficient active systems must be added to get proper performance. Lastly, renewable energy resources should be integrated with the active systems to reduce the fuel consumption and CO_2 emission associated with it. Aguacil et al. [9] indicated that passive strategies could provide 40% of energy saving, while it is possible to reach 80% saving by combining passive strategies with active ones.

2 Literature review

Educational buildings are the substance part of all countries though they deplete a significant share of the nations' energy resources. In general, they are in charge of approximately 15% of the overall energy consumption of non-residential buildings [10]. Apart from this point, educational buildings suffering extensively from the deficiency of the budget compared to the others. Likewise, energy technologies have been used in the building sector after the 80s. Whereas the buildings' lifespan is almost 60-80 years, demolition and reconstruction of energy-efficient schools is not a rational solution. Energy performance of school buildings becomes essential also when considering that the Turkish population comprises of mainly young people. Based on the statistics of the Turkish Ministry of National Education, 83204 school buildings have existed in the 2013-14 academic year. During the academic year, nearly a quarter of Turkish people spend the majority of their time in schools [11].

Life cycle assessment (LCA) is a tool to scientifically analyse the environmental performance of products or processes throughout their entire life cycle, including raw material extraction, production, use, disposal and recycling. Therefore, LCA is generally considered to be a cradle to grave approach in assessing environmental impacts [12]. The concept of LCA was developed over the years, mainly in the 70s and 80s. Subsequently, the method can be used in the renovation and new constructions to be more efficient with a low footprint.

Life cycle energy (LCE) analysis is an approach that comprises all energy turnovers over a lifespan [13]. Thus, the system boundary of the study includes the use of energy in the following stages: production, operation and demolition. The production phase includes the manufacture and transportation of technical installations used in new buildings and renovations of buildings. The operation phase consists of all activities related to maintaining the comfort conditions inside the building throughout its life. The final stage, the demolition phase, involves the destruction of the building and the transfer of dismantled materials to storage areas or recycling facilities.

LCE is comprised of embodied, operational and demolition energy. The initial stages, which is the energy content of all materials used in the building and its components, the embodied energy, can be taken into account during the renovation and new construction. Operational energy is required to ensure comfort conditions and maintain buildings, including energy for HVAC, domestic hot water, lighting, and home

appliances. Demolition energy is the energy required for the demolition of a building at the end of its useful life and the transport of the material to storage areas or recycling facilities [13].

There are several studies about the LCE of different building typology towards improving their energy performance. Ramesh et al. assessed 73 cases across 13 countries including residential and office buildings [13]. They concluded that operating energy has a significant share, about 80–90%, in LCE use of buildings followed by embodied energy (10–20%), whereas demolition and other processes' energy is negligible with a little share. Ding [14] discussed the LCE assessment of Australian secondary schools. He used LCE analysis to study the total energy consumption of 20 public secondary schools in New South Wales. The results served as a model for an in-depth analysis of energy consumption and established environmental performance principles for schools. Mangan et al. [15] have investigated residential building performances for different climatic zones of Turkey regarding LCE and life cycle cost efficiency.

Throughout the study, it was intended to determine the measures used in the improvement of residential energy performance to evaluate the life cycle energy, economic and environmental performances of the buildings. Renovation of the educational buildings can produce intense energy, ecological and economic benefits, including reduction of greenhouse gas (GHG) emission and energy costs, the growth of economic benefits through job creation and market uptake. This thesis represents a basic model for educational buildings and implements life cycle analysis to a case study to define proper retrofit scenarios to reduce both energy consumption and CO_2 emissions. The objective of this study is to develop practical solutions for the improvement of energy performance and environmental impact of the educational buildings. The strategies are evaluated by a comparative method in the framework of the life cycle.

3 Methodology

To be summarised, LCA framework comprises of four main phases: definition of the scope, life cycle inventory, impact assessment, and interpretation. LCA approach can also be applied for LCE and $LCCO_2$ analysis as criteria for the environmental impact assessment [16]. The study's primary aim is to assess the LCE and the environmental performance considering the $LCCO_2$ emissions of the educational buildings in Turkey. The case study building model was created in DesignBuilder and calculation of the operational energy and carbon emissions were done Energy Plus.

3.1 Definition of the Scope of the Study

The study has been concentrated on the impact assessment of the various architectural scenarios for energy efficiency improvement on the LCEC and $LCCO_2$ emission of a building. Within the scope of the study, primary school buildings are selected to be analyzed. Through analysis, the total embodied and operational energy use and CO_2 emission concerning the life cycle phase of the building would quantitatively define and investigate in the framework of life cycle inventory. The life cycle phase of a building includes the product, construction, operation, and end of life stages [17]. As there is not adequate information regarding the end-of-life stage that comprises deconstruction, demolition, transport of wastes/demolition material, waste processing and disposal processes, the step is rarely reflected in the context of LCE analyses [18].

Moreover, according to the various studies, the energy needed for the construction and demolition of a building is negligible or can be settled at about 1% of the total life cycle energy [19]. Hence, in this research, the system boundary includes the product and the operation stages in the framework of LCE and $LCCO_2$ emission study. In Turkey, the building lifespan is assumed to be between 30–50 years generally; hence, in the current study, it is considered as 30 years.

3.2 Specifications of the Case Study Building

In Turkey, there are specified typical projects that are intended for primary school buildings by each Special Provincial Administration with an endorsement from the Turkish Ministry of Education. The typical projects are built in most of the regions with the same geometry and properties [20]. As each typical project represents some new and existing school buildings, energy behavioural studies should be conducted for them to increase national energy efficiency. Since Istanbul is the primary province of Turkey, in this study, one of the seven specified typical projects of Istanbul indicated in the Tab. 1, is chosen as a case study.

Table 1. Typical primary school projects implemented by the Istanbul Special Provincial Administration.

No	Name of project	Capacity (student no)	Number of floors	Areas (M^2)
1	MEB.2000-41	240	B+G+3	635
2	10025R-480	480	B+G+3	863
3	10025R-720	720	B+G+3	1121
4	MEB.2000-42	720	B+G+3	1.285
5	MEB.2004-53	1200	B+G+3	1.541
6	RAGIP AKIN	Private	B+G+3	789
7	RIFAT YALMAN	Private	2B+G+4	533

The selected school 10025R-480 has five stories including a basement floor, a ground floor, and three typical floors with a capacity of 480 students. Building height and floor areas are 22m and 863 m² respectively; there are 16 classrooms. The building is occupied during weekdays between 08:00 am and 5:00 pm during an academic year. The building geometry is shown in Figure 1.

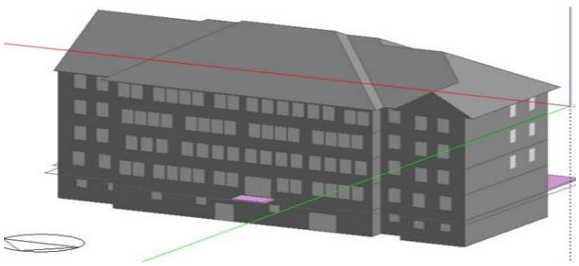

Fig. 1. Axonometric view of the case study building

The amount of U-value of the exterior wall is 1.85 $W.m^{-2}.K^{-1}$, which exceeds the required U-value of Turkish Insulation standard TS825 [21]. The building has a reinforced concrete structure with filled in brick walls. The roof is a pitched roof. Internal floors are covered with granite tiles; ground floor finishing materials are ceramic tiles. Glazing components consist of double clear with 6 mm thickness and PVC frames. The U-Value and Solar Heat Gain Coefficient (SHGC) of the case study building's glazing system are 2.7 $W.m^{-2}.K^{-1}$ and 0.81 respectively. Table 2 indicates the primary characteristics of the building components and their materials, including embodied energy and embodied carbon.

Table 2. Primary characteristics of the components.

	Material layers (from outside to inside)	EE (kWh/kg)	EC ($kgCO_2/kg$)	U-value
External Wall 1	Cement rendering	0.16	0.09	0.636
	Extruded polystyrene	23.6	2.51	
	Cement rendering	0.16	0.09	
	Brick	2.5	0.22	
	Gypsum Plastering	0.56	0.12	
External Wall 2	Cement rendering	0.16	0.09	0.636
	Extruded polystyrene	23.6	2.51	
	Water insulation	21.6	1.92	
	Brick	2.5	0.22	
	Gypsum Plastering	0.56	0.12	
Roof	cement screed	0.44	0.18	0.61
	Extruded polystyrene	23.6	2.51	
	Reinforced concrete	0.55	0.2	
	Gypsum Plastering	0.56	0.12	
Ground Floor	Concrete	0.36	0.19	0.417
	cement screed	0.44	0.18	
	school water insulation	21.6	1.92	
	Reinforced concrete	0.55	0.2	
	Concrete	0.36	0.19	
	Extruded polystyrene	23.6	2.51	
	Mortar	0.37	0.19	
	Granite	0.99	0.39	
Window	Clear glazing	4.42	0.96	2.7
	Air	-	-	
	Clear glazing	4.42	0.96	
	PVC frame	39.8	7.23	

The minimum ventilation rates in classrooms and other conditioned zones are selected from ASHRAE Standard 62.1-2013. There is not any mechanical ventilation in the real projects, so the ventilation is assumed to be done through windows of classrooms during the break times. Infiltration rate for case study building is considered as 0.5 ACH for all perimeter zones. Cooling demand starts in the spring semester from April 27 until June 15, and for the fall semester, it begins from September 15 until November 1. There is not any lighting control in classrooms. The amount of heat released by an electrical appliance is taken from ASHRAE 90.1-2007. According to TS825-2013, to reach the comfort range temperature in schools, internal occupied spaces are assumed to have a 20°C temperature for the heating period and 26°C temperature for other occupied periods. The heat generator is a boiler with 0.8 COP, and the cooling generator is a chiller with 1.5 COP. Table 3 presents the general characteristics of the case study building.

Table 3. Energy systems' characteristics.

Parameters	
Occupancy time and Schedules	Weekdays 08:00-17:00
	Fall semester =15 September until 31 January Spring semester=15 February until 15 June
Heating Setpoints	20 °C for occupied times, 0 °C for unoccupied hours
Cooling Setpoints	26 °C for occupied times, 50 °C for vacant hours
Heating System Generator	Hot water boiler, efficiency = 0.8 COP (Coefficient of Performance)
Cooling System Generator	Chiller with 1.5 COP (Coefficient of Performance)
Ventilation systems	Natural ventilation through the windows during break times
Lighting System	lighting control

3.3 Determination of the Architectural Measures to Improve the Energy Efficiency

To calculate LCE and $LCCO_2$ during the lifespan of the building, single and combined energy efficiency improvement architectural measures are applied to the modelled building in the simulation software. These measures are the most common ones that are used in the building envelope. They include the addition of thermal insulations, glazing system upgrades and PV system installation. The thermal insulations are implemented on exterior walls, roof and ground floor.

In Turkey, there are five distinctive climatic zones. According to TS825-2013, each climatic zone requires different limited U-values for building envelopes. Istanbul is located in the second zone where the limited U-value for external walls, ceiling, ground floor, and windows are 0.57, 0.38, 0.57 and 1.8 $W.m^{-2}.K^{-1}$ respectively. The thermal insulation application alternatives are assessed at three different levels. The first level is based on TS825-2013 required U-value. The second, third levels and forth are about 32 %, 50%, and 65% better than TS825 required U-values, respectively. The glazing systems' upgrades are also applied through fourth levels. The first level of glass improvement is based on TS825-2013, with 1.8 $W.m^{-2}.K^{-1}$ U-value and 0.70 SHGC. Double glass systems provide the second

and third level of glass improvement with 1.6 and 1.3 $W.m^{-2}.K^{-1}$ U-value and 0.56 SHGC. The fourth level of glass upgrade includes triple Low-E glazing and has a U-value and an SHGC equal to 1.1 $W.m^{-2}.K^{-1}$ and 0.52 respectively.

Within the framework of the study, installation of PV modules on the pitched roof is another single improvement measure. At the first level, 25% of the pitched roof is assumed occupied by PV which is calculated 66 PVs. At second, third and fourth levels PV amounts on the roof are 50%, 75%, and 100% respectively. The photovoltaic type is monocrystalline (Mono-CSI) cells. Some cells in one series are 55. Every module of photovoltaic is 1.6 m^2. Table 4 presents the alternatives for the single and combined architectural measures to improve energy efficiency.

3.4 Life cycle Inventory

A life cycle inventory (LCI) is the data collection part for LCA. For educational buildings, LCE and $LCCO_2$ inventories comprise the establishing of the energy consumption and CO_2 emission amount of the product and operation phases. To determine the energy consumed in these phases for each of improvement alternatives, embodied the energy and embodied carbon per unit values for the building components were extracted from GABI 6.0 LCA software [22] and for PV system components it was derived directly from literature [23]. For determination of the embodied energy and embodied carbon coefficients, the process analysis method takes into account. The production process from the level of raw material extraction within the scope of "cradle to gate" approach is caught on a basis. Since the lifespans of the materials included in improvement scenarios are more than the lifespan of the building described in the methodology, renovation after improvements is not predicted during the rest of the building lifetime. Thus, recurring embodied energy and carbon are not taken into account. The primary energy consumption is considered for calculating the energy consumption of the operation stage. The primary energy conversion factors for the fuel types consumed in Turkey are given as 1.00 for natural gas and 2.36 for electricity [24]. The DesignBuilder and EnergyPlus simulation tools were utilised to calculate the HVAC systems' final energy consumption during the usage stage of all alternatives [25, 26]. Moreover, for calculation CO_2 emission during the operation stage, the emission factors for natural gas and electricity were taken as 0.234 and 0.626 $kg.eq.CO_2.kWh^{-1}$, respectively [27].

4. Results

In the base building the highest end-use consumption is allocated to HVAC systems with 51% which are including cooling, Fan, and pumps. The second and third most end users are heating and lighting with 31% and 13% respectively. The least end-use energy consumption belongs to the interior equipment with just 5% of total consumption. Figure 2 represents a comparison of the building End-use consumptions. Total electricity consumption in the base condition is 22 KWh/m^2, and natural gas consumption is 10.46 KWh/m^2. Figure 3 shows the amount of End-use energy consumption by different sectors in the base condition.

Table 4. Alternatives of energy efficiency improvement.

Alt. No.		Description
Wall	AL.1	U-value=0.57 $W/m^2.^oK$
	Al.2	U-value=0.38 $W/m^2.^oK$
	Al.3	U-value=0.28 $W/m^2.^oK$
	Al.4	U-value=0.18 $W/m^2.^oK$
Roof	AL.5	U-value=0.38 $W/m^2.^oK$
	Al.6	U-value=0.25 $W/m^2.^oK$
	Al.7	U-value=0.19 $W/m^2.^oK$
	Al.8	U-value=0.14 $W/m^2.^oK$
Ground	AL.9	U-value=0.57 $W/m^2.^oK$
	Al.10	U-value=0.38 $W/m^2.^oK$
	Al.11	U-value=0.28 $W/m^2.^oK$
	Al.12	U-value=0.18 $W/m^2.^oK$
Glazing	AL.13	Double glass U = 1.8 $W/m^2.^oK$, Tvis = 0.79, SHGC = 0.70 , UPVC Frame U = 1.8 $W/m^2.^oK$
	Al.14	Double glass U = 1.6 $W/m^2.^oK$, Tvis = 0.79, SHGC = 0.56, UPVC Frame U = 1.8 $W/m^2.^oK$
	Al.15	Double glass U = 1.3 $W/m^2.^oK$, Tvis = 0.71, SHGC = 0.44, UPVC Frame U = 1.8 $W/m^2.^oK$
	Al.16	Triple low-e U = 1.1 $W/m^2.^oK$, Tvis = 0.67, SHGC = 0.52, UPVC Frame U = 1.8 $W/m^2.^oK$
PV	Al.17	66 PV system covering 25% of the roof
	Al.18	132 PV system covering 50% of the roof
	Al.19	198 PV system covering 75% of the roof
	Al.20	264 PV system covering 100% of the roof
Opaque	Al.21	Combination of Al.1, Al.5and Al.9
	Al.22	Combination of Al.2, Al.6, and Al.10
	Al.23	Combination of Al.3, Al.7, and Al.11
	Al.24	Combination of Al.4, Al.8, and Al.12
Op+Gl	Al.25	Combination of Al.17 and Al.13
	Al.26	Combination of Al.18 and Al.14
	Al.27	Combination of Al.19 and Al.15
	Al.28	Combination of Al.20 and Al.16
Op+PV	Al.29	Combination of Al.21 and PV system
	Al.30	Combination of Al.22 and PV system
	Al.31	Combination of Al.23 and PV system
	Al.32	Combination of Al.24 and PV system
Op+Gl+PV	Al.33	Combination of Al.25 with a PV system
	Al.34	Combination of Al.26 with a PV system
	Al.35	Combination of Al.27 with a PV system
	Al.36	Combination of Al.28 with a PV system

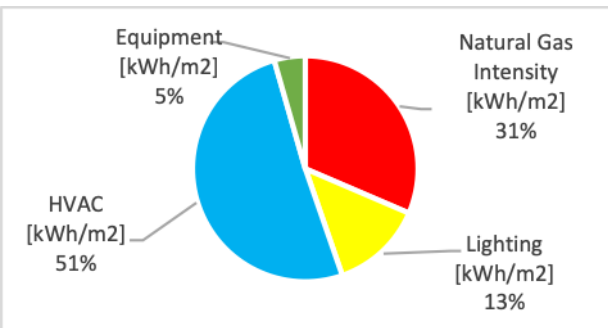

Fig. 2. Distribution of End-use energy consumptions.

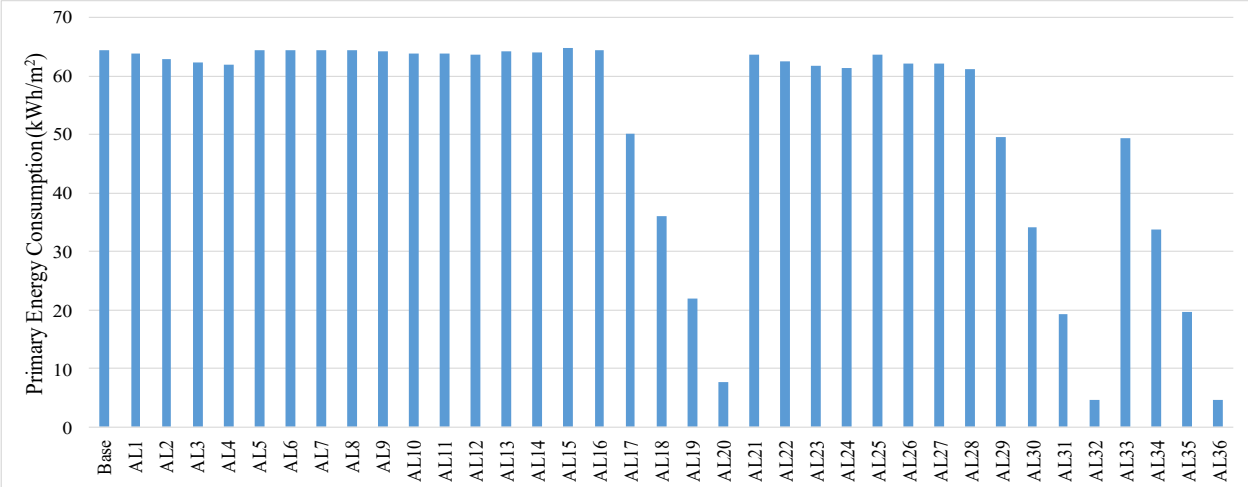

Fig.4. primary energy consumption of the building under different improvement scenarios

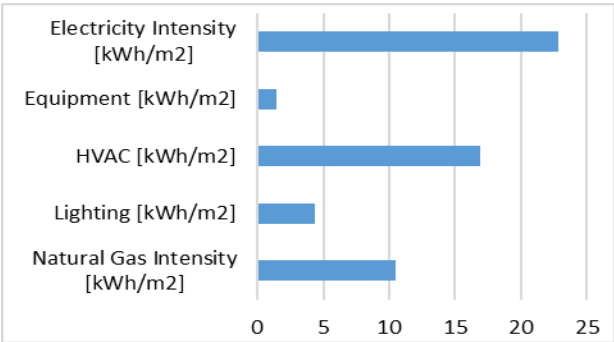

Fig. 3. Amount of End-use energy consumption.

By comparison of the primary energy consumption of all scenarios and the base building in figure 4, it is clear that there is a considerable saving in AL.20, 32 and 36 which is almost 90%. Not surprisingly, all of these packages, 100% of the roof are covered by PV systems. By covering 25% and 50% of the roof, primary energy consumption has reduced almost 20% and 45% in 17, 18, 29, 30, 33 and 34 alternatives. By adding thermal insulation, it is possible to decrease the primary energy consumption by 4%. During the whole life cycle, the base building will be responsible for 5509.4 tonnes of CO_2 emission and 12776.1 MWh primary energy consumption. The results indicate that there are about 81% CO_2 emission and 57% primary energy saving potential. By general overview of figure 5, it is clear that the scenarios with PV systems have lower LCEC and $LCCO_2$ emission. According to the results, AL36, AL32, and AL.20 have the lowest LCE and $LCCO_2$ emissions. PV systems in mentioned packages are covered 100% of a pitched roof. As a result, the amount of energy consumption and CO_2 emissions will be decreased. Among measures without PV AL.24 and 28, have lower $LCCO_2$ and better scenarios are AL4, AL.3, and AL.26. AL 6, 7, 8, 15, and 16 have higher LCE despite lower $LCCO_2$ emissions. Optimum alternatives for LCE and $LCCO_2$ emission could be Al 36, 32 and alternative 20. Alternative 20 is a single measure, which includes 198 PV on the roof. AL 32 is the combination of 198 PV with 65% better thermal insulation of the opaque systems than TS 825 required level. AL36 includes the glazing system improvement as well. Figure 5 displays the distribution of the LCEC through $LCCO_2$ emissions.

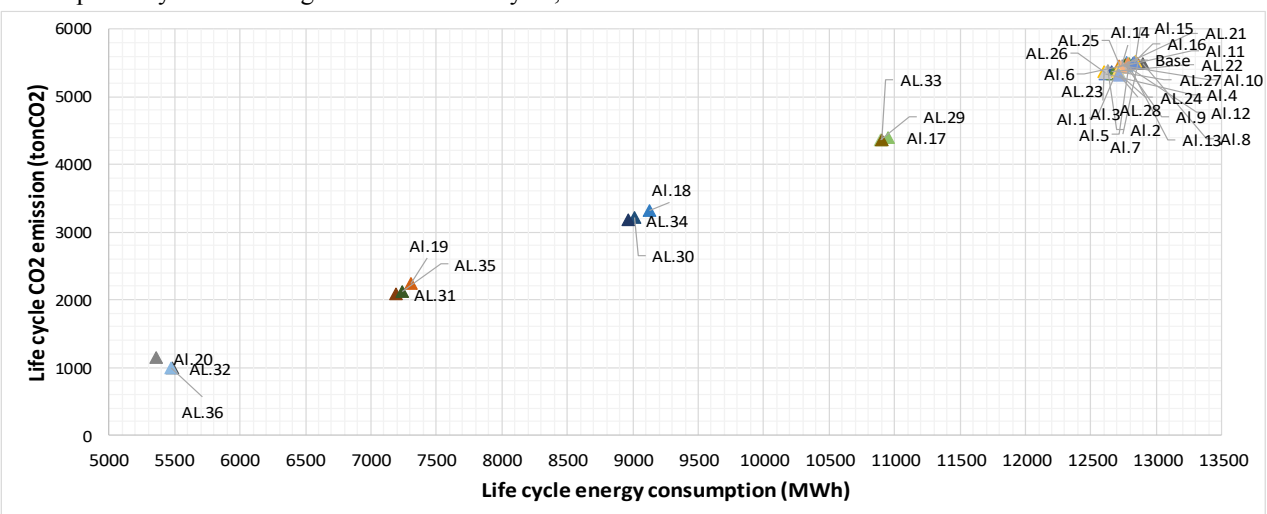

Fig. 5. Distribution of the LCEC through $LCCO_2$ emissions.

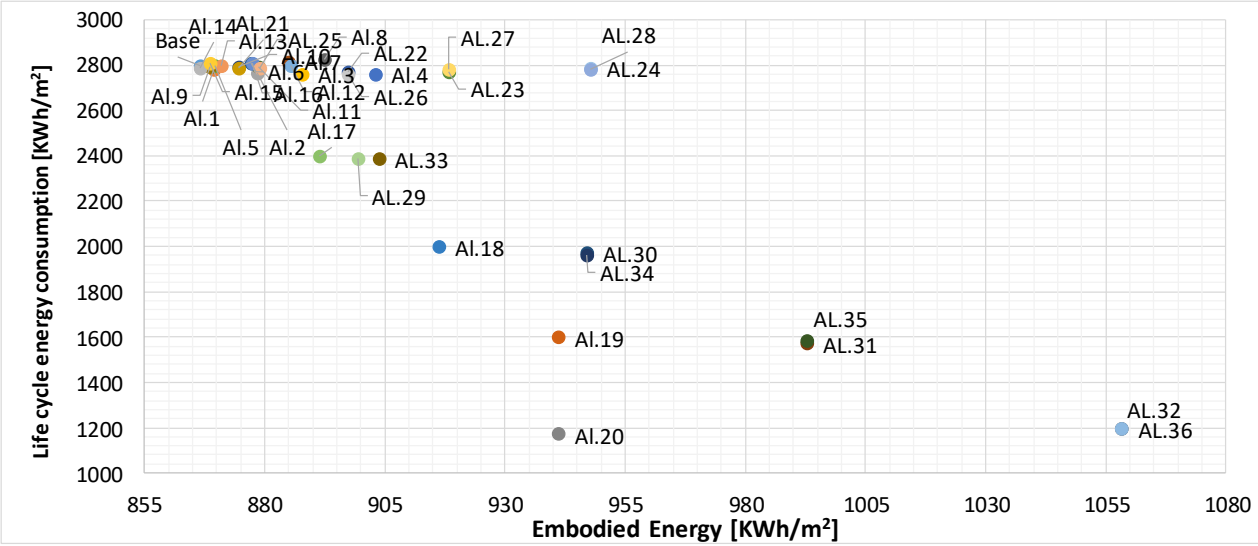

Fig. 6. LCE versus Embodied Energy of different improvement scenarios.

Figure 6 illustrates LCE versus Embodied Energy for the case study building and retrofit options. The options with greater embodied energy resulted in minimum energy consumption during the life cycle. Al.36 has the highest embodied energy and lowest LCEC amongst improvement scenarios. This option includes total opaque enhancements with a U-value 65% better than TS825 required amount, glazing system improvements and 100% PV installation. Not surprisingly, case study building has not only the lowest embodied energy but also the highest LCEC amongst all alternatives.

5. Conclusion

The primary objective of the study is to reduce the energy consumption and CO_2 emission during the life cycle of the educational building by implementing the architectural energy efficiency improvements scenarios. Intrinsically, educational buildings encompass a significant portion of building stock in every country. By fulfilling the recommended procedure, it is possible to boost the benefits of energy saving as well as the reduction of CO_2 emission on the environment en masse.

Throughout the study, different architectural measures to increase energy efficiency during the assumed life cycle are applied to one of the typical existing primary schools, and the results are assessed. The results of LCE and LCCO2 analyses indicate that alternatives including the improvements in whole opaque and glazing systems together with photovoltaic system installation have the most energy saving and the lowest CO2 emission despite the increase in total embodied energy. In other words, the alternatives with a higher amount of embodied energy resulted in more reduction in LCEC and LCCO2 emission. Furthermore, by implementing energy efficiency strategies like proper thermal insulation, it is possible to provide approximately 25% and 27% reduction potential of LCE and LCCO2 emissions, respectively.

Compare to the conventional methods to determine the energy CO2 emission saving potential, the method that is used in this study is more accurate as it used a holistic approach by taking the whole life cycle of the building. A similar approach should have been expanded to other kinds of buildings to reduce the societies' LCE and LCCO2 emissions in a considerable amount to obtain the enormous benefits extended from direct profits like energy cost saving and healthy environment to indirect advantages such as employment and economic growth rate increments. How calculations are done is not free of uncertainty since there are many input data with quite uncertain origins to be implemented in the computations and determining the results. The sources of such data are very critical to have an accurate prediction, it can be different from country to country, and even it depends on the material producer's factory. Thus, it is vital to perform a comprehensive study to define the embodied energy of various materials in all countries including Turkey to have more reliable results.

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