Impact of Climate Zone and Orientation Angle on the Recurring Massing School Typologies in Turkey

Yasemin Afacan

Abstract In this study, the impact of different climate zones on same massing typologies of a typical school building with different orientation angles was quantified through building energy simulations of a case building in Turkey. The most schools in Turkey do not comply with the current energy code because they were built prior to the code. Thus, there is a crucial need to investigate their energy efficiency for potential retrofits. The results of the study exemplified how the breakdowns in energy use and carbon emissions would significantly influence design decision-making process of a school. Considering the four climate scenarios, mainly the influence of an orientation angle on energy use intensity (EUI) is higher than its influence on carbon emissions. This study differed from other sustainability researches in terms of defining building massing in schools with an emphasis on environmentally climate responsive school design, which is a holistic approach and comprehensive understanding of high-performance energy efficiency. A climate responsive massing should address the questions beyond well-known standards, and define a new holistic model that uses the optimum orientation, and surface to volume ratio of the building to reduce energy loads and achieve high-performance energy efficiency.

1 Introduction

School buildings play a critical role to contribute to the health and well-being of every society [1]. Schools represent a unique environment that differ from other building types, given that in a school, there are four times more occupants per square meter than in a typical office building [2]. Occupants spend much of their time inside classrooms. This occupancy schedule patterns make school buildings responsible for a significant portion of the total energy consumption of the non-residential sector. Schools require special attention on sustainable building managements so that early

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Y. Afacan (✉)
Department of Interior Architecture and Environmental Design, Bilkent University, Ankara, Turkey
e-mail: yasemine@bilkent.edu.tr

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decisions on building massing, classroom layouts, geometry parameters and spatial configurations of each function have critical impact on energy efficiency. Previous massing studies in schools have largely focused on solely plan layout, such as linear, corridor etc., and compactness of geometrical shape parameters related to different typologies [3], such as L-C-U-H shapes, linear corridor or central with different classroom dimensions, pavilion, slabH, slabV and courtyard types etc., to compute energy performance of schools [4–6]. However, compactness of a shape is not always the optimal solution for energy efficiency [7–9]. Even with the same shape, it is not possible to have well-specified energy measures for schools [9].

Although there are a number studies on the relationship between energy efficiency and building forms in developed countries, there is a lack of studies analysing correlations among energy use, different climate scenarios and building orientations of similar massing typologies in developing countries, such as Turkey. In Turkey, in recent years due to the difficulty of producing different projects for each school considering diverse range of climate types, time constraints, staff shortage and financial problems, the production of a typical project application has become more intense. Thus, this study investigates how the energy efficiency of a similar building massing varies depending on the four climate zones and simulates a typical Turkish school building in the four representative cities at the four different orientation angles. Based on the results of climate zone assessments, it proposes a simulation-based climate proofing in order to define a set of proper massing parameters and to decide the correlations among massing typologies, different climate zones and the key energy loads of schools, such as heating, cooling etc.

2 Energy Impacts of School Typologies

Energy impacts of buildings have been discussed first in United Nations Brundtland Commission in 1987, then UN Commission Report in 1992 on sustainable development and Kyoto Conference by UN Framework on climate change. In 2002 European Energy Efficiency Directive [10] investigated building optimization to reduce their impacts on energy consumption. In 2012 and 2018, net zero energy buildings have been presented by the European Directives [11, 12]. Hence, most of the school buildings both in Europe and in most of the countries around the world were built before those dates of the directives so that they could not satisfy energy efficiency directives [13]. Thus, there are lots of studies exploring energy efficiency in school buildings, measures related to building envelope, and enhance energy performance through environmentally responsive design.

There are uncertainties in energy performance of schools depending on the country, location and climate zones. Reviewing the literature on the energy impacts of school typologies showed that there are many different definitions of typologies and energy consumption patterns accordingly. Some studies defined typology classifications as massing types based on the overall configurations [14–16]; whereas the others described it based on the proportions of a 2D drawing [17, 18]. Afacan and

Ranjbar [9] investigated the five most commonly used school massing typologies in the contemporary school architecture: (1) Spine/street—major school functions along a central linear space; (2) City/town—a loose type of massing with more potential of legible school functions; (3) Atrium- a full height atrium serving passive solar design, thermal inertia and access outside views; (4) Strawberry/cluster—a central core providing circulation; and (5) Courtyard—flexible layout around the courtyard with enhanced energy efficiency benefits. These typologies did not differ according to the age of the students. They were prevalent for primary, secondary and high schools. They found significant differences in terms of annual energy use, annual energy cost and annual carbon dioxide (CO_2) emissions among the massing types, and suggested a new holistic model based on the ratio of surface area to volume more for reducing energy loads of a typical high-performance schools [9].

According to the Statistics of the Turkish Ministry of National Education, there are 25.5 million students which means that one third of the Turkey's population spends the majority of their time in school buildings [19]. In the academic year of 2017–2018 in Turkish primary and high schools, about 18 million students taught by 1 million teachers in total 66,000 schools [20]. Thus, school buildings in Turkey have a great importance in energy consumption. The total energy consumption of non-residential sector in Turkey has increased 174% compared to the energy consumption in 1990. The schools contribute 23% to this total energy consumption, which forces the educational building retrofit to tackle this challenge [19]. Due to their high-energy consumption, high occupant density and high activity patterns, schools represent a significant category among the other building typologies to be responsible for a considerable amount of energy consumption. In UK and US, school buildings are responsible for 10% and 13% of total energy consumption respectively [13]. Since Turkey has experienced a considerable surge in energy demand [21], achieving energy efficiency in current school building stocks becomes crucial because sustainable design, planning and construction decrease energy consumption by reducing environmental pollution, controlling energy waste patterns, maintenance and transportation costs [7].

With regards to the European Energy Efficiency Directives, in 2000 Turkey considered energy efficiency measures for the schools that were newly constructed, but the majority of the existing schools were constructed before 2000 without a focus on energy performance and were not gone any energy refurbishment later on. In Turkey, typical school projects were designed by the Ministry of Public Works to be used in all regions until the year 1970 [20]. Later, in 1980, there were minor revisions in these typical projects regarding regional energy differences. After 1997, when 5-year compulsory primary education was extended to 8 years. The adaptation of existing buildings was mostly done with the addition of floors, which ignored the relationship between energy demand and massing typology.

3 Materials and Methods

3.1 Selection of Climate Zones and the Reference Cities

According to Köppen-Geiger Climate Classification [22], Turkey's climate is defined as mild Mediterranean. However, there are significant differences in climatic conditions in Turkey because of its diverse geographical characteristics. For example, in the Mediterranean region, the mountains are parallel to the sea, which makes the coastal region milder with warm summers and mild-to-cool winters than the Central Anatolia. On the other hand, the inland regions have a dry climate with hot summers and cold winters. So, the climate classification of the Turkish Standard 'TS 825 Thermal Insulation Requirements in Buildings' [23] defined 4 climate zones. In 2008, TS 825 was adapted from 'ISO 9164- thermal insulation calculation of space heating requirements for residential buildings' [24] and 'BS EN 832-thermal performance of buildings calculation for energy use for heating residential buildings' [25]. Although it neglects the cooling loads, it is still the mandatory document in Turkey regarding energy efficient heating energy requirements for all buildings. Figure 1 illustrates how these four climate zones are distributed on Turkey.

In this study, the case building was situated in Konya, which was located in the third climate zone as a hot-summer Mediterranean climate with hot summers and snowy winters [26]. The case building was constructed in 1993 without considering the energy efficiency. It had a double-loaded corridor plan, used a central heating system and was ventilated by manually opened windows. Three representative cities, Istanbul, Izmir and Erzurum, from the other three climate zones were used to simulate the projected energy efficiency performance of the case study building regarding the different climate zones (Table 1). Istanbul has a borderline Mediterranean climate, humid subtropical climate and oceanic climate, with a hot dry summer, pleasantly

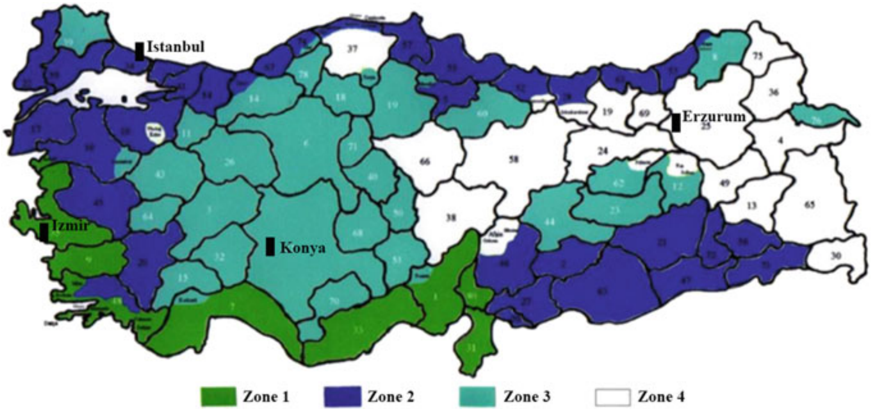

Fig. 1 Four-climate zone of Turkey based on TS 825

Table 1 Climate zone and descriptions

Zone number	City	Zone description
Zone 1	İzmir	Mediterranean climate zone—hot and dry summers, warm and rainy winters
Zone 2	İstanbul	Borderline Mediterranean climate, humid subtropical climate and oceanic climate—a hot dry summer, warm spring and autumn, and cold winters
Zone 3	Konya	Hot-summer Mediterranean—hot summers and snowy winters
Zone 4	Erzurum	Humid continental climate—hot and dry summers, and cold and snowy winters

warm spring and autumn, and cold winters with rare snow [22]. İzmir is located in the Mediterranean climate zone, where summers are hot and dry, and winters are warm and rainy. Erzurum has humid continental climate with hot and dry summers, and cold and snowy winters [22]. In the literature, there are lots of studies on the impact of different climate zones to ensure energy efficiency. This study differed from these sustainability researches in terms defining building massing in schools with an emphasis on environmentally climate responsive school design, which is a holistic approach and comprehensive understanding of high-performance energy efficiency. A climate responsive massing should address the questions beyond well-known standards, and define a new holistic model that uses the optimum orientation, and optimum surface to volume ratio of the building more for reducing energy loads than a typical high performance schools.

3.2 Building Envelope Details

The school had a total gross area of 5400 $m^{2.}$ The building was a four storey building in U-Shape with 19 classrooms and 760 primary school children and 37 teachers (Figs. 2 and 3). The construction standards of the case building are presented in Table 2, and the main parameters of the building envelope materials are given in Table 3. The central heating system with radiators was used for heating. There was no cooling equipment in the typical school building. Cooling was achieved through natural ventilation by manually operated windows. There were no automatic lighting controls. The common lighting equipment in the typical school building was fluorescent lighting, cool-white fluorescent bulbs (LPD = 12 W/m^2).

3.3 Data Analysis, Modelling and Simulation

The preliminary data collection and analysis consisted of a review of the energy bills of the school, typical occupancy data, and technical specifications of the building. A site visit was done to the building to examine actual system and get a deeper insight of the school's operation. Natural gas and electricity bills of the school were analysed to calibrate the simulation data. Inside and outside photographs of the building were taken. An infrared camera was used to capture the entire temperature profile of the building and to see temperature differences on surfaces. Figure 4 shows an example image of what the thermal camera observed regarding heat losses. The problematic areas were mostly window frames. Although they were insulated, there was no rubber gasket or weather-stripping around the opening, air escapes around the edges.

The study developed a dynamic calibrated energy simulation model of the school building by using Sefaira program simulations. Sefaira's Real-Time Analysis Plugins use EnergyPlus, a validated professional energy simulation tool [27], as their primary simulation engine to assess energy and thermal performance based on architecture,

Fig. 2 Aerial images of the site and the case building

lighting and mechanical systems, occupancy and use, and local weather. Constant feedbacks on envelope and material U values were provided by design parameters in Sefaira's Real-Time Analysis.

4 Results and Discussion

For each climate context, simulations were run for annual energy use, energy use intensity (EUI) cost and annual CO_2 emissions. In addition to the climatic parameters, the building performance was also calculated regarding the four orientations of the case building in each city; (i) baseline model; (ii) 90° rotated model; (iii) 180° rotated model, and (iv) 270° rotated model.

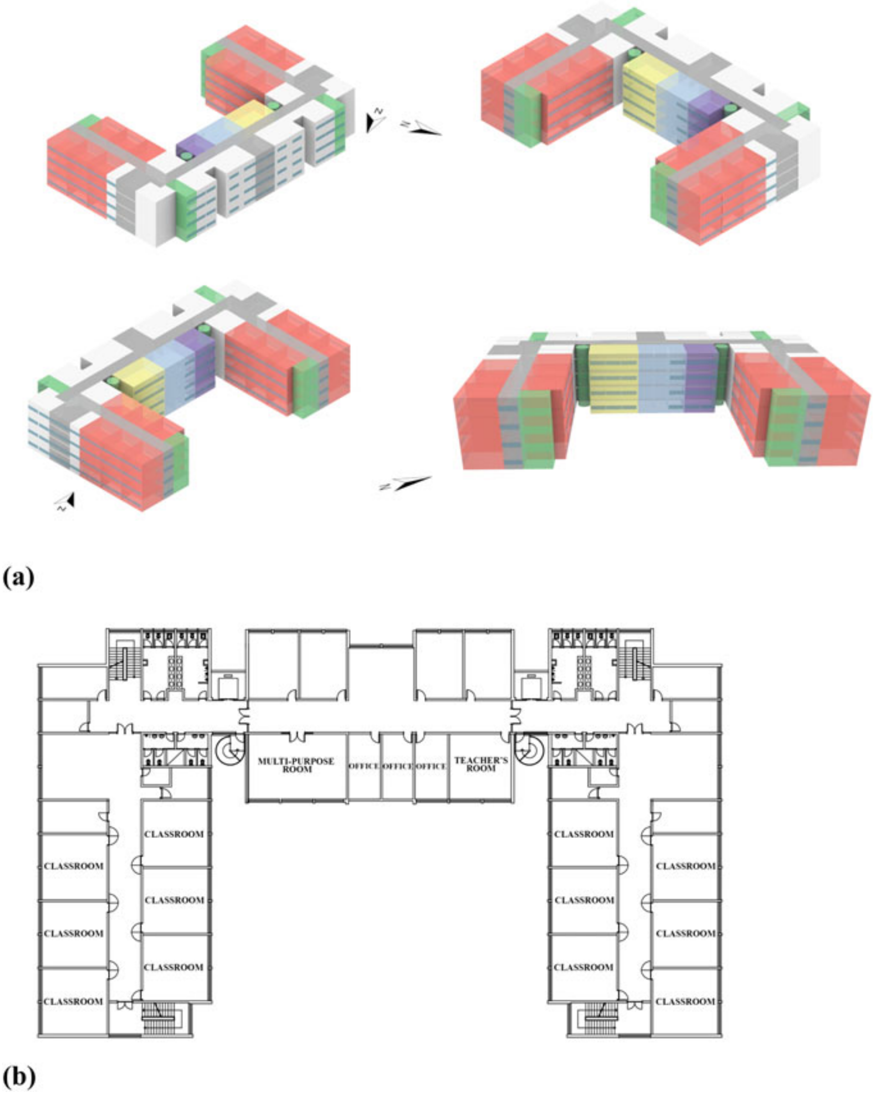

Fig. 3 **a** Plan view of the first floors of the case building; **b** four views of the case building

Table 2 The construction standards of the case building

Climate zone	City	U (W/m^2 K) External wall	Ground floor	Roof	Glazing
3	Konya	1.06	1.42	0.73	3.49

Table 3 The main parameters of the building envelope materials

Material	d (m)	λ (W/m K)	R (m^2 K/W)
External walls			
Cement plaster	0.03	1.6	0.019
Brick Wall	0.28	1.2	0.233
EPS	0.16	0.04	1.60
Cement plaster	0.03	1.6	0.019
Ground floor			
Laminate floor	0.008	0.115	0.07
Cement mortar	0.05	1.4	0.036
Plain concrete	0.10	1.65	0.03
Reinforced concrete	0.20	2.5	0.08
Damp proof membrane	0.05	0.3	0.167
Gravel	0.10	2.0	0.05
Roof			
Glasswool	0.05	0.05	1.00
Reinforced concrete	0.20	2.50	0.08
Cement plaster	0.03	1.6	0.019

4.1 Impact on Energy Consumption

The EUI changes from 103 kWh/m^2/year (minimum) to 136 kWh/m^2/year (maximum) (Table 4). These values, even the high one, are good values, because according to ASHRAE 2018 Advanced Energy Design Guide for K-12 School Buildings [28] for achieving 50% energy savings, the targeted value for EUI is around 110 kWh/m^2/year for these four climate zones. The reason for these low EUI values is the high performance envelope considering lighting and cooling. The classes are scheduled until 4.00 p.m. so that most of the time daylighting satisfies the visual performance. The summer holidays, from 1st June to 1st September, are assumed unoccupied so that less cooling or even no cooling is required. However, it should be noted that in buildings, where daylighting is not as much as available as the others, and where buildings are occupied during the summer period, the EUI is much higher.

As seen from Table 4, similar to the previous researches mentioned in the literature section, this study also found that a proper orientation angle results in the reduction of energy consumption. However, different than those researches, this study identified that the impact of orientation on energy consumption in Mediterranean zones are not as much as significant compared to the zones, where summers are very hot, and winters are very cold and snowy. By orienting the building at an angle of 180°, there would be a reduction of EUI of 9% in non-Mediterranean zones, whereas 4% in Mediterranean zones. This finding is critical during the decision making process of a more environmentally responsive school massing. To maximize energy efficiency,

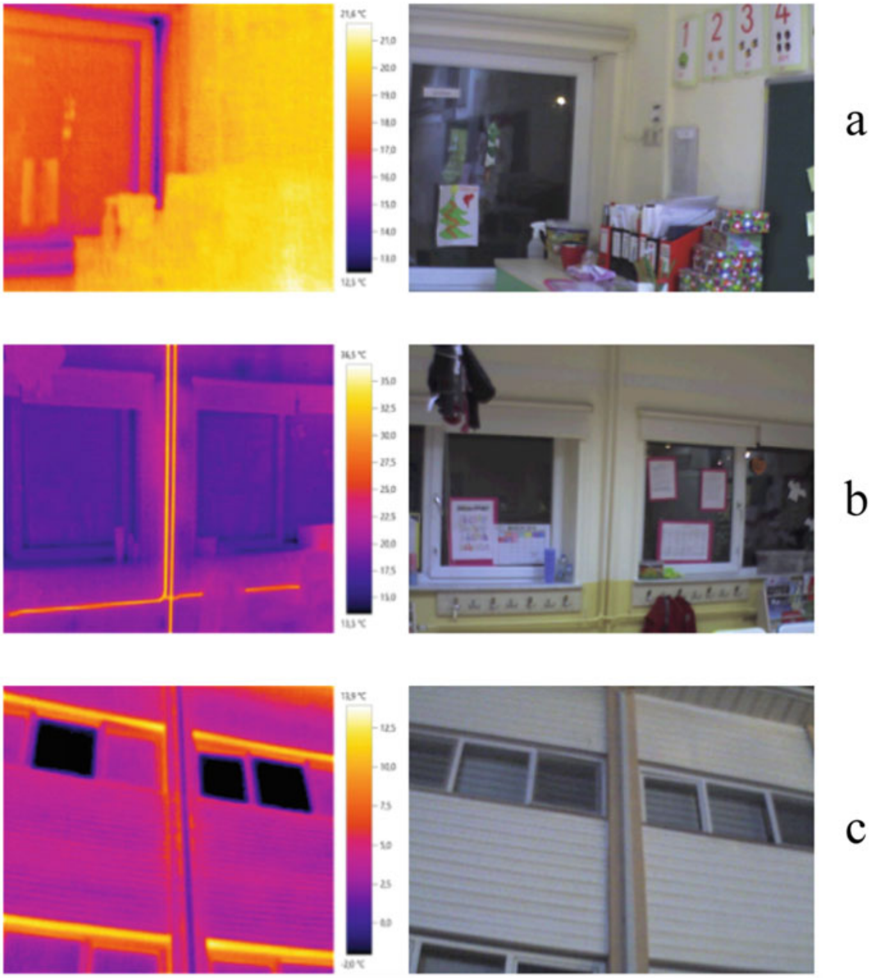

Fig. 4 Thermal camera view of a window wall **a**, **b** from inside and **c** outside

the priority could be given on the size and number of classrooms, number of stories, window to wall ratio and room depth, which could have a direct impact on annual heating and cooling energy.

Figure 5 illustrates the energy breakdown. Mainly heating energy increased in climatic zones, in which lowest winter temperatures occurred. However, comparing this heating demand profile against the cooling energy consumption, it was clear that they were not in the same pattern. This was due to the fact that cooling in Turkey is achieved by natural ventilation in most of the schools. Although this leaded to decrease cooling energy consumption, it resulted in unhealthy consequences in terms of indoor environmental quality provided to students. The CO_2, temperatures and humidity levels in classrooms without proper ventilation reach above the limits after

Table 4 The energy use intensity (EUI) of each city in four different orientations

City	Orient degree	Air handling	Cooling	Heating	Energy Use	Annual cooling energy per unit area (kWh/m^2/year)	Annual heating energy per unit area (kWh/m^2/year)	EUI (kWh/m^2/year)
		AHU design airflow (L/s)	Cooling equip. design capacity (kW)	Heating equip. design capacity (kW)	HVAC (fancoil + central) energy per unit area (kWh/m^2/year)			
Konya	0°-Baseline	6427	290.4	379.9	84.94	9.62	49.29	130.34
	90°	6427	292.0	379.4	83.01	8.92	48.31	128.41
	180°	6427	273.5	377.8	81.12	8.69	46.99	125.52
	270°	6427	330.7	379.4	86.67	10.73	48.76	136.07
Erzurum	0°-Baseline	6427	292.0	351.1	80.62	17.59	33.02	126.02
	90°	6427	274.7	348.0	74.36	16.31	28.70	119.76
	180°	6427	281.3	347.0	72.45	16.11	26.79	117.85
	270°	6427	313.1	351.5	82.42	18.95	32.18	128.82
İstanbul	0°-Baseline	6427	398.2	336.6	67.97	14.81	26.00	113.37
	90°	6427	401.3	327.7	67.24	14.16	25.79	112.64
	180°	6427	394.9	328.0	65.55	13.93	24.76	110.95
	270°	6427	441.3	336.7	70.25	15.87	25.96	115.65
İzmir	0°-Baseline	6427	385.0	291.0	62.33	18.88	13.44	107.73
	90°	6427	392.7	276.7	59.70	18.05	11.04	105.10
	180°	6427	376.8	277.4	58.57	17.69	10.73	103.97
	270°	6427	424.0	290.5	65.32	20.54	13.06	109.72

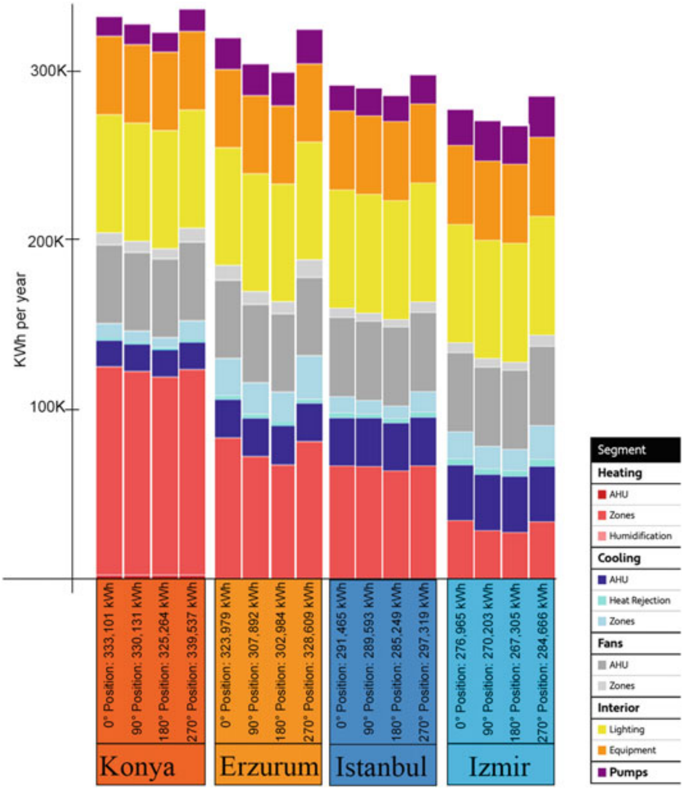

Fig. 5 The energy breakdown regarding the climate zones and orientation

twenty minutes of the occupation [2, 4]. Moreover, getting fresh air through manually operated windows also create uneven heat distribution and thermal discomfort especially for the students sitting near windows [4]. Another significant finding was that the interior energy demands regarding lighting and other electrical equipment did not differ much regarding both the climatic zones and orientation. The reason for this finding was that there were typical and similar lighting systems in most of the schools without paying attention on its impact on health, performance and stress of students. However, the use of lighting sensors has not only positive effect on glare reduction and appropriate illuminance levels, but also it directly impacts EUI value of a school building with a same massing typology.

4.2 Impact on CO_2 Emissions

The highest annual net CO_2 emissions were obtained in both Erzurum and İzmir at the orientation angle of 270° (Table 5). Although these two climate zones were the least

Table 5 Annual energy costs and CO_2 emissions of each city in four different orientations

City	Orient degree	Energy costs						CO_2 Emissions
		Annual Energy Cost ($)	Annual Elect. Cost ($)	Annual Gas Cost ($)	Annual Energy Cost Per Area ($/m2)	Annual Elect. Cost Per Area ($/m2)	Annual Gas Cost Per Area ($/m2)	Annual Net CO_2 Emissions (kg/ CO_2e/year)
Konya	Baseline	67,262.9	55,809.6	11,453.3	26.16	21.71	4.45	1,131,572.18
	90°	66,378.3	55,152.5	11,225.8	25.82	21.45	4.37	129,801.63
	180°	65,677.0	54,757.9	10,919.1	25.55	21.30	4.25	128,332.10
	270°	68,689.4	57,358.0	11,331.4	26.72	22.31	4.41	134,172.17
Erzurum	Baseline	71,699.4	64,025.4	7674.0	27.89	24.90	2.98	137,883.31
	90°	69,358.9	62,687.8	6671.2	26.98	24.38	2.59	132,989.74
	180°	68,916.5	62,689.7	6226.8	27.81	24.38	2.42	131,931.61
	270°	73,320.4	65,840.7	7479.7	28.52	25.61	2.91	140,808.56
İstanbul	Baseline	66,190.4	60,146.5	6043.9	25.75	23.39	2.35	126,746.08
	90°	65,785.2	59,790.3	5994.9	25.59	23.26	2.33	125,963.88
	180°	65,093.8	59,339.6	5754.3	25.32	23.08	2.24	124,547.31
	270°	67,780.0	61,747.3	6032.6	26.36	24.02	2.35	129,708.18
İzmir	Baseline	68,034.9	64,910.0	3124.9	26.46	25.25	1.22	128,666.32
	90°	67,318.0	64,750.8	2567.2	27.18	25.19	1.00	127,036.67
	180°	66,687.3	64,194.0	2493.3	26.94	24.97	0.97	125,820.51
	270°	70,271.9	67,236.2	3035.7	29.33	26.15	1.18	138,796.76

efficient for the case building in terms of carbon emissions, the EUI values in Erzurum and Izmir were not the highest values (Fig. 6). The reason for this emission result was the differences in breakdowns of energy performance and emissions regardless of the climate type. It was striking that the emissions of the cooling load in these two cities were higher than the other two. In Izmir, cooling load was mainly concerned with AHU systems, and in Erzurum with zone cooling. This result highlighted the essential role of climate based heating and cooling strategies in terms of the decarbonisation of electric industry, rather than prototyping of the same heating and cooling systems, which caused higher values of annual energy use. These simulated results were also in line with the literature and underline the critical importance of indoor comfort conditions that were also strongly correlated with passive and active measures of a building envelope and interior architecture of the school building. As illustrated in Table 5, annual energy costs per area were also higher in these cities. This result confirmed that emissions due to the heating could be reduced but this reduction could lead to the increased of carbon emissions due to cooling. As it was stated by Dino and Akgul [29], the intensity of cooling is much more higher than heating for Turkey.

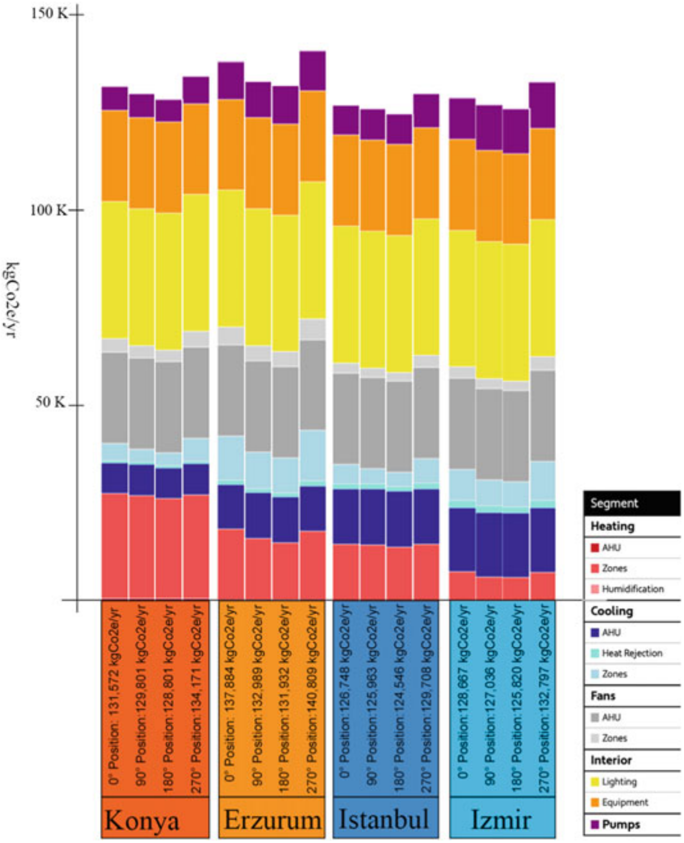

Fig. 6 The CO_2 emissions breakdown regarding the climate zones and orientations

According to the findings, several retrofit scenarios could be developed. As passive strategies, the U values of roof, walls and glazing could be lowered to reduce both CO_2 emissions and energy consumption. Shading devices or shutters could be added into the critical facades. A green roof would also help lowering urban heat island effect, as well as providing recreational space for children. As active strategies, air-conditioning equipment or heat recovery units could be introduced to classrooms considering their structural system and suspended ceiling availability. The HVAC management is a complex and dynamic issue that should be considered along carbon density and electricity generations.

To further discuss the results, the study identified the essential role of the two following massing strategies: (i) optimizing the building orientation and (ii) defining a set of massing parameters. Building orientation is an energy performance-related factor that cannot be modified, but managed through retrofit passive design strategies. It plays a key role in energy efficient school design. However, it is not enough alone. Making optimized decisions on orientation parameters at the conceptual stage of design process could help to maximize all aspects of energy performance. Decisions on orientation in construction or occupation phase would be too late. Thus, the simulated results in the study pointed to the future need to explore measures for climate adaptation of a proper massing typology and to taking account interior layout and classroom proportions based on the various orientation angles. So, the study proposed a multi-criteria decision making optimization that should include a more extensive manipulation of interior and exterior relationships. Although the simulations done in the study were limited with the four climate zones, and four orientation angles for each zone, for future studies a decision matrix for retrofitting strategies could be constructed, where a new set of climate variables could be identified, and prioritized data of design requirements could be correlated with those variables.

In addition to the proper choice of a good site and orientation based on the variables of that site, spatial layout design and functional organizations are essential components of defining a set of massing parameters. We have not found any earlier studies configuring climate-based massing types for minimal energy use based on multiple usage and seasonal and daily occupancy schedule. To achieve such efficiency and improve energy performance, this study presented a unique opportunity for the exploration of what a school massing type should offer for designing new buildings as well as retrofitting existing according to different climate scenarios. Thus, it suggested climate based exploration strategies of building massing in schools with an emphasis on environmentally responsible school interior design.

5 Conclusion

In this study, the impact of different climate zones on the same massing typologies with different orientation angles was quantified through building energy simulations of a case building in Turkey. The results of the study exemplified how the breakdowns in energy use and carbon emissions would significantly influence design decision-making process of a school building. It could result in different massing and orientation choices to achieve energy efficiency. In the study, as expected, different climate zones resulted in different heating and cooling requirements. Considering the four climate scenarios, mainly the influence of orientation angle on EUI was higher than its influence on carbon emissions. Considering the four orientation angles, energy use in itself of each zone remained relatively constant regarding heating loads, but energy use varied considerably regarding cooling loads. However, carbon emissions of each zone remained constant regarding both the heating and cooling loads. These results contributed to the advancement of the research in developing countries that are undergoing rapid building and urban regeneration process, because it does not only propose strategies for new school design, but also retrofitting the existing ones trough a simulation-based climate proofing. The implications of this study could be summarized from the two points of view. The first point is related with its practical implications suggesting that the Ministry of Public Works could use the typical school projects across all the regions by taking adaptive actions on different heating and cooling loads through passive measures. In this context, the same school massing could be treated as a shell, which is later modified in site depending on the trade-offs between climatic conditions and energy consumption patterns. The second point is that there is a need for adaptive energy models specific to school buildings. Instead of referring to the climate zone requirements, these models should take the hottest occupied and coldest occupied months into consideration to calculate CO_2 emissions. To extend the contribution of this study in design practice and generalize the effect of school building massing on energy efficiency, a detailed climate impact analysis, where combinations of building shapes, window to wall ratio, room depth and orientation parameters, could be performed as a future study. In addition, both design and construction of schools should consider the subjective preference of users even during massing decisions. Proper school massing will not only improve energy savings, but also enhance subjective feeling of all users.

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