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Article

Evaluation of thermal performance of an elementary school building with the experimental method: Double-skin façade system

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ABSTRACT

A double-skin façade is one of the generally preferred energy-efficient design strategies to reduce energy consumption in buildings. In this study, one of the two similar, south-oriented classrooms in a one-story elementary school building in Ereğli, Konya, Türkiye, was turned into a Test Classroom by installing double-skin façade and the other classroom was designated as the Basic Classroom, and hourly ambient temperatures were measured in both classrooms. Hourly ambient temperature values were measured in the Test Classroom and Basic Classroom on 6 consecutive days between January 26 and January 31 during the heating period. The working principle of double-skin façade systems is based on heating the adjacent space by transferring warmed air from the cavity to the adjacent space in the heating period, cooling the adjacent space by transferring warmed air from cavity to outside environment in the cooling period using the openings such as windows and vents on the façade of cavity and glass façade. Openings (windows and vents) in the Test Classroom and glass façade were kept open or closed for periods of 24 h depending on whether it was the heating period to create different experiment set-ups. Ambient temperatures that were obtained with the measurements done in different experiment set-ups with different conditions were analyzed and values of the Test Classroom and Basic Classroom were compared. According to the measurements, 0.3°C and 3.0°C higher temperatures were recorded in the Test Classroom compared to the Basic Classroom between January 26 and January 31 (heating period).

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INTRODUCTION

Limited fossil energy sources, higher cost of extracting energy from these sources, and the environmental damage caused by these fossil fuels make energy conservation a must and increase the importance of renewable energy sources and sustainable environment concepts. The majority of energy is used to meet climatic and visual comfort requirements in buildings and mostly fossil energy sources which are generally limited and cause environmental problems are preferred (Yılmaz et al., 2006.)

Sustainability can be described as "meeting the needs of today without damaging the sources that future

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Ambient temperature measurement devices used in this study were provided by the ITU Scientific Research Project titled "Use of Solar Energy in Single-Storey Elementary School Buildings with Passive Systems"; hotwire anemometer that measures air movement was provided by the Association of Building Physics and aluminum profile elements and glass materials were provided, transferred and glass façade was built by Çuhadaroğlu Alüminyum Sanayi ve Ticaret A. Ş.

generations will need," "transferring today's sources to future generations," and "principles of social, economic, and environmental priorities of the harmony that need to be established between humankind and ecosystems at local and global levels today and in the coming centuries" (Utkutuğ, 2011). The most important step of sustainable architecture which is defined as the design and construction of buildings that meet occupants' needs using local and natural sources without damaging the environment and depleting the sources of future generations is to use renewable sources instead of fossil sources to meet their energy requirements and design and build energy-efficient buildings and settlements.

Based on this perspective, the goal today is to design buildings that can promote occupant comfort with minimum energy consumption. Energy requirements can be reduced by designing buildings according to the climate and environmental conditions they are in and using renewable energy sources where possible. Furthermore, as an effective solution to ever-growing construction industry with the addition of new buildings, which accounts for 39% of CO_2 emission, 36% of energy consumption, 50% of raw material production, and 1/3 of drinking water consumption and therefore increases energy consumption and contributes to global warming, envelopes of existing buildings can be improved using advanced technological products (Ascione et al., 2021). A study in Spain on existing single-family and block housing typologies which were constructed between 1980 and 2007 in 13 different climate zones investigated and simulated according to the improvements in envelope and observed that the retrofitting of existing building walls with 10 cm and roofs with 5 cm of insulation and substitution of single glazing by double glazing resulted in a reduction in consumption values from 37.7% to 58% depending on the climate zone and housing typology (Sanchez et al., 2022).

Renewable energy sources should be preferred instead of fossil fuels because, in addition to being sustainable, they reduce export dependency on fuel, do not cause high import costs, their impact on the environment is low and they can be found everywhere in the world.

When we look at the distribution of the energy consumed in Türkiye among the industries, according to the "2020 General Energy Balance Table" of the Republic of Türkiye Ministry of Energy and Natural Resources the amount of energy used in buildings comes third in the total energy consumption with 24% consumption rate after industrial goods (33%) and transportation (25%). In the same table, fossil fuels come first with 68% of all energy sources and solar energy is used only at a rate of 1% as an energy source (Republic of Türkiye, Ministry of Energy and Natural Resources, n.d). A higher rate of use of fossil fuel shows that our country is export-dependent on energy. Effective use of such sources in Türkiye which has a wealth of renewable energy sources will reduce dependency on export energy products and contribute to alleviating environmental problems caused by consumption of fossil fuel energy. Solar energy which is the primary source among renewable energy sources has become increasingly important since it is easily available and does not have any harmful effect on the environment.

An energy-efficient building is a building designed to achieve minimum energy consumption by minimizing the role of active systems that consume energy from the settlement scale to the material scale without compromising comfort conditions using passive design strategies. A passive solar system which is one of the most important passive design strategies includes the design and operational process of solar energy for heating and cooling purposes. In these systems which are designed to heat or cool buildings by providing optimum values to the building's design parameters without using any mechanical system, the building itself acts as a solar power collector and collects, stores solar radiation, and transforms it into heat and allows the use of this heat in other parts of the building during the heating period (Yılmaz et al., 2006). In the cooling period, the building is cooled by integrating systems that remove the heating effect of solar radiation into the building and with the correct design of building elements. Although passive solar systems have some disadvantages which one is that their activity lasts only for 16–18 h/day and other sources should be used for heating/cooling in the remaining period, these systems used for heating/cooling save a significant amount (Aktas and Kırçiçek, 2021).

Passive heating systems are classified into three main groups: Direct gain systems, indirect gain systems, and combined systems. Solar radiation gain through south-oriented windows (for the northern hemisphere) in direct gain systems is absorbed by building components such as floor, ceiling, and wall, and when the temperature drops at night, this stored energy is reintroduced into the environment through thermal radiation and convection. There is a thermal mass to store heat between south-oriented windows and interior space in indirect gain systems; solar radiation is absorbed and stored by the thermal mass and heat is reintroduced into the interior environment depending on the time. Combined gain systems are like a combination of direct and indirect systems; a greenhouse is created between south-oriented windows and thermal mass to transfer/exchange air between the greenhouse and adjacent unit through ventilation windows or openings on the lower and upper parts of the greenhouse (Yılmaz et al., 2006).

Double-skin façades as one of the mixed systems are often used as a passive system since it can easily be integrated into existing buildings. A double-skin façade consists of an external transparent component, an intermediate cavity, and interior transparent or opaque-transparent surface and is widely used for energy gain. In winter, windows looking into the interior environment are kept open to let the air heat in the cavity into the interior environment and windows facing the exterior environment are kept closed in order not to lose the heat in the cavity. In summer, windows looking into the interior space are kept closed and windows facing exterior environment are kept open to reduce the temperature in the cavity (Figure 1). When choosing a double-skin façade system; it is possible to determine the combinations of options such as selection of glass material, whether to use double or multi-glazed glasses, the position of louvers and if there are panels, the angle of these panels, sizes, locations, and number of openings which allow air movement such as vents and windows, and whether to use fans as active system components to accelerate or increase air movement with experimental studies or simulations.

Double-skin façades which are based on the principle of removing air heated in the cavity from the building during the cooling period and taking in the heated air in the cavity into the interior space have been investigated by many scientific studies to achieve good visual quality, acoustic quality, effective air movement, and thermal performance (Chen et al., 2019). A range of experiment set-ups can be developed to achieve and calculate air movement between the interior space and external environment by opening and closing four openings at the lower and upper levels at the internal and external envelope (or at structural element or building envelope) at different times as shown in Figure 2 (Jankovic and Goia, 2021).

Evaluations of the performance of double-skin façades made in different climatic regions worldwide help to nationalize the use of double-skin façades (Ghaffarianhoseini et al., 2016). A study conducted in China different sunspace departments which is one of the critical influence factors for attached sunspace is investigated and observed that 0.6 m depth is ideal in comparison with the 0.9 m, 1.2 m, and 1.5 m depths without considering the occupants' activity (Liu et al., 2022). A study in Japan on a two-story building with double-skin façades examined 5 different double-skin façade models which were developed by defining a range of openings and air movement systems and observed that with these models 20–30% energy gain was achieved during the heating period with the use of greenhouse effects and 10–15% energy gain during the cooling period with the use of chimney effect (Xu and Ojima, 2007). A study conducted in South Korea investigated

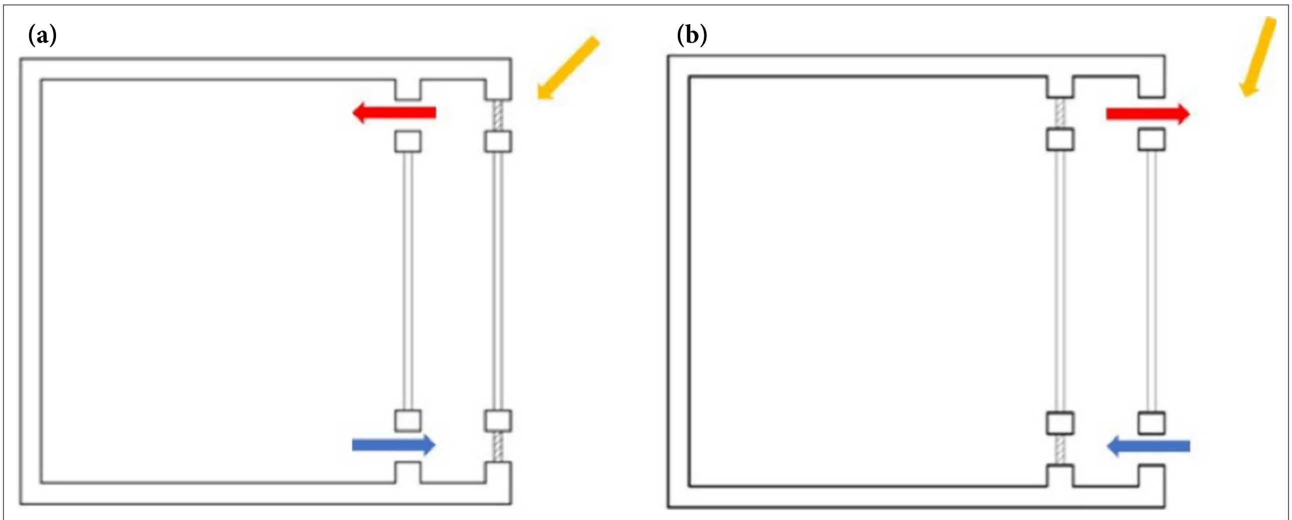

Figure 1. Schematic diagram of double-skin façade for winter **(a)** and summer **(b)** period daytime.

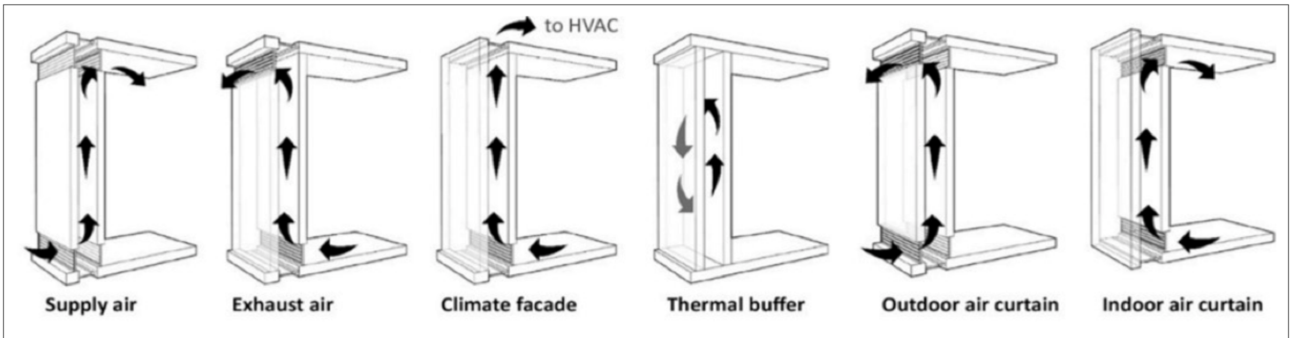

Figure 2. Double-skin façade air movement models [6] (Jankovic and Goia, 2021).

the basic condition where a double-skin façade was used as a buffer zone (Condition-1), a condition where there was a window to allow air transfer between the intermediate cavity and interior environment (Condition-2), and a condition where the air heated in the cavity was transferred to the HVAC system (Condition-3) and Condition-2 achieved 1% energy gain and Condition-3 achieved 41% energy gain compared to Condition-1 (Choi et al., 2012.). In another study on a multi-story building with a double-skin façade in South Korea 34 types of glass and intermediate cavity depths ranging from 8 to 148 cm were investigated and when optimization was done for all configurations a reduction of 5.62% in total energy consumption was observed (Jaewan et al., 2014). In a study conducted in China, the effect of a range of window openings on the temperature in the intermediate cavity and thus interior environment was assessed and compared to a single-skin façade, double-skin façade allowed 27.7–49.2% energy gain in the cooling period and 25.6–46% in the heating period (Kong et al., 2021). In another study done in China, optimizations of parameters such as interior wall window-wall ratio on the building, building orientation, wall structural elements, exterior façade glass type, and cavity shading element were assessed and double-skin façade was found to provide 17.2–28.7% energy gain compared to single-skin façade (Hancheng et al., 2021.) A study done in Holland on a high-rise building with double-skin façade reported that the building achieved 42% reduction in total energy consumption with its glass type, window-wall ratio, shading component, and high-performing envelope design that includes roof isolation (Raji et al., 2016.). When we look at energy consumption in Türkiye, we see that high volumes of fossil fuels are used and the total share of renewable energy sources in the total energy consumption is very low. In Türkiye, which has a high solar energy potential, the use of solar energy in passive systems in buildings will result in significant reduction in energy consumption and contribute to the country's economy.

Türkiye has a young population and school buildings constitute a major part of public buildings and energy consumption of these buildings is high. Fossil fuels are also the primary choice for school buildings. Since the number of education buildings is high and thus accounts for a significant part of a country's energy consumption, studying alternative methods that will reduce the energy consumption of education buildings is an important approach to develop sustainable energy use in the country (Mytafides et al., 2017). Especially in the regions where heating requirements are high heating energy costs can be reduced using indirect heat gain systems. In this study, a school building is chosen from the options of buildings that are not used for a whole year and do not require energy consumption mostly during the cooling period, and aimed to reduce energy consumption by installing a passive solar gain system in this building.

The efficiency that can be obtained with retrofitting buildings depends on multiple factors including the climate the building is in, the heating-cooling system in the building, materials used in the design and construction, and occupant profile. Therefore, measurement simulation and evaluation results of the same type of studies conducted in different climates and in different geographies in the world can be different.

Studies conducted by performing measurements in a range of climates allow us to understand and compare and classify retrofitting in a better fashion. At the same time, data obtained in measurements and experiments are required to find optimal solutions that can be implemented to improve ambient conditions in buildings with different functions. Estimating double-skin façade performance in buildings with different functions is quite difficult since it depends on the mutual effect of many variables. Although experimental data are the primary source, there are a limited number of studies in literature. Several simulation programs are used to understand the complicated behavior of double-skin façades (Hancheng et al., 2021). Therefore, studies that both use experimental studies and simulation programs are important since they allow comparison of measurements and calculations. Furthermore, although experimental studies are time-consuming and costly, it is the best way to reliably evaluate thermophysical conditions on advanced façade systems such as double-skin façade (Jankovic et al., 2022). Thus data obtained with experimental studies can be compared with the calculations made by simulation programs and this allows testing of new strategies that would be proposed to retrofit buildings. Therefore in this study, an elementary school building in Central Anatolia was evaluated by making measurements. Measurements were done for 6 days to analyze ambient temperature in two classrooms with the same volume and with south orientation in the elementary school building during the heating period (26/01–31/01). One of the classrooms was called the Test Classroom after installing a glass façade system and no change was done in the other classroom which was then called the Basic Classroom. Different experiment set-ups were developed by keeping windows and vents closed or open and ambient temperature was measured on the days when these experiment set-ups were analyzed.

METHOD

In this study, a glass façade was used in one of the classrooms with south orientation in an existing elementary school building to achieve double-skin façade and conditions were measured and evaluated for 6 days separately for the cooling and heating periods. The steps of the study are explained below.

Determining the Variables of the Building

In this study, measurements were done in a one-story elementary school building in Ereğli, Konya in the Central Anatolia region of Türkiye (37° 36' north latitude and 34° 31' east longitude), which has a temperate dry climate where the winter period is more dominant compared to summer period (Figure 3).

The building has four classrooms facing south, a school counselor's office facing west, a teachers' room, a classroom, and bathrooms facing north, and a classroom facing north and east. The Test Classroom in which a glass façade is installed and the Basic Classroom which acts as the control have only south-oriented external walls and have the same area and volume (Figure 4).

This is a one-story masonry building built with 3.5 m floor height and 40 cm sub-basement level. The thickness of the external walls of the existing classroom is 60 cm and the wall components consist of external plaster, stone masonry wall, and internal plaster. The thickness of the internal walls of existing classrooms is 55 cm and the wall components consist of external plaster, stone masonry wall, and internal plaster. The thickness of cavity external walls is 23 cm and the wall components consist of external plaster, brick wall, and internal plaster. No thermal insulation material is used in the walls. The structural members of the elementary school building and the glass façade integrated into the south façade are shown in Table 1.

The second glass façade was applied on the south façade of one of the selected classrooms and no change was done in the other classroom and temperature measurements were done simultaneously in both classrooms.

The installed applied on the external façade of the Test Classroom is 720 cm in length, 352 cm in height including 40 cm sub-basement, and 60 cm in width. There are 6 windows in the 60*60 cm modular system built on the glass façade and 3 of these windows are in the upper section and 3 at the lower section of the façade. There are 3 ea 20*40 cm vents on the lower section of the wall facing the cavity and 6 ea 20*20 vents on the windows on the upper section of the wall (Figure 5). The second glass façade applied on the south façade of the school building is shown in Figure 6.

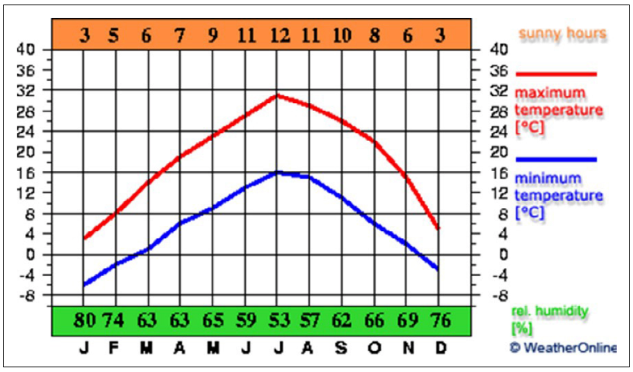

Figure 3. Climate conditions for Ereğli (WeatherOnline, n.d.).

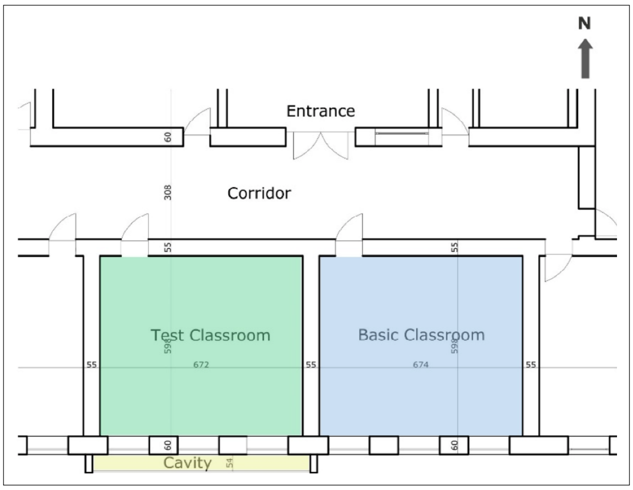

Figure 4. Plan of the test classroom in which glass façade is installed and basic classroom.

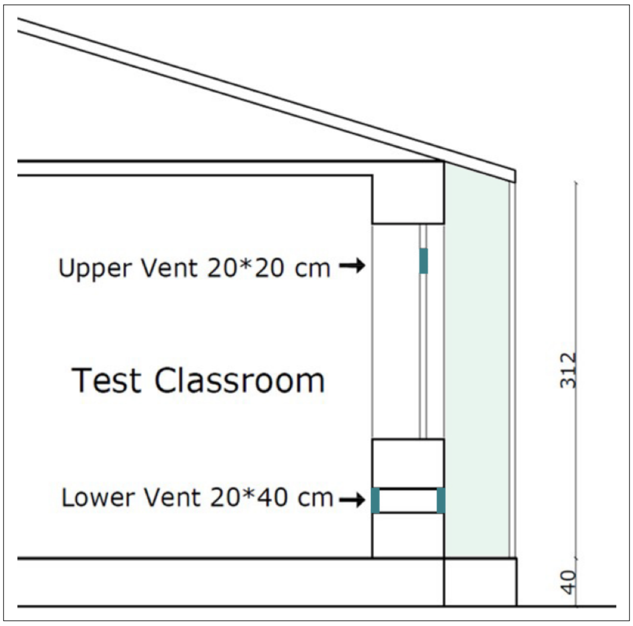

Figure 5. Cross-section.

Figure 6. Applied second glass façade.

Table 1. Structural Materials of the School Building

Structural Elements	Material	Thickness (m)
Glass Façade Floor	Reinforced Concrete	0.40
Glass Façade Window (Aluminium joinery)	Tempered double glazed glass	0.006+0.012+0.006
External wall	Cement plaster	0.02
	Brick wall	0.19
	Cement plaster	0.02
Cavity	Cavity Air	0.54
Glass Façade Ceiling	Tile roof covering	0.03
	Water insulation Roof board	0.003
	Weatherboard	0.025
	Rafter	0.10
	Aluminium composite panel	0.007
Existing Classroom floor	Blockage	0.30
	Lean concrete	0.10
	Floating screed	0.05
	Adhesive mortar	0.02
	Tile	0.007
Existing Classroom Window (PVC joinery)	Double glazed glass	0.003+0.012+0.003
Existing Classroom External Wall (facing the cavity)	Cement plaster	0.02
	Stone wall	0.56
	Cement plaster	0.02
Existing Classroom interior wall	Cement plaster	0.02
	Stone wall	0.51
	Cement plaster	0.02
Existing Classroom Ceiling	Tile roof cover	0.03
	Water insulation	0.003
	Weatherboard	0.025
	Rafter	0.10
	Reinforced Concrete Floor	0.10
	Cement plaster	0.02

Determining Measurement Variables

Measurement devices were placed in mesh boxes that do not obstruct air movement to prevent elementary school students from accessing the devices and ensure uninterrupted and correct measurement (Figure 7a). Wood mesh boxes were built so that the measurement device in the external environment is not affected by solar radiation and wind and the measurement device in the cavity is not affected by solar radiation (Figure 7b). The systems in the Konya–Ereğli meteorology office were examined to build mesh boxes to make measurements in the external environment and their heights compared to road elevation and sizes were determined according to expert opinion and then mesh boxes were built.

One ambient temperature device was placed in the external environment, one in the Test Classroom and one in the Basic Classroom and one was installed in the cavity. The ambient temperature device in the cavity was located right in the middle of the cavity height. Devices were installed 2 m above the ground hanging right in the middle of the classroom for the safety of the students (Figure 7a). The temperature measurement device was fixed right in the middle of the 30*30 box at a height of 2 m from the road in the external environment. When deciding about the location of the temperature measurement device, it was important to find a location that was as far away from trees and high buildings as possible in an open field.

Figure 7. Ambient temperature measurement device locations **(a)** Test classroom **(b)** Cavity.

The ambient temperature measurement device used in the field is the Extech RHT10 Humidity and Temperature USB Datalogger. The device measures temperatures between (−40) and 70°C and the error margin is ± 1°C between (−10) and 40°C; ±2°C between (−40) and (−10) ±2°C between 40 and 70°C. Measurement frequency was between 2 and 24 s (Teledyne Flir, n.d). The device used to measure air movement speed was DELTA Ohm HD 2103.2 datalogger and AP741S1 hot-wire. The devices measured air movement speed in the range of 0.1–40 m/s and the error margin is ±0.02 m/s for air movement speeds in (0.0–0.99) m/s range and ±0.04 m/s for (1.0–9.99) m/s range and ±0.04 m/s for (10.0–40) m/s range (Delta OHM, 2017).

Determining Experiment Set-ups

Experiment set-ups included keeping vents and windows open or closed during the day and at night depending on the requirements of the heating period.

Six experiment set-ups were created for the period of 26/01–31/01 (heating period.) Since the school was closed due to winter break, all radiators in the Test Classroom and Basic Classroom were turned off. Radiators in the adjacent classrooms and corridors were turned on and doors opening to the corridor of the classrooms not included in the experiment were always open. Windows and classroom doors of the Basic Classroom were kept closed all day. The door to the Test Classroom was closed and experiment set-ups were developed according to open or close status of windows, vents, and curtains. Windows and vents were kept open to let the heated air in the cavity into the Test Classroom during the day and closed to prevent heat loss at night. Glass façade windows were always closed. Under certain conditions, curtains were used on the external surface of the glass façade to prevent heat loss from the glass façade during nighttime. Experiment set-ups and conditions are shown in Figure 8.

It was not possible to change the condition at 00:00 h when determining measurement conditions in all experiment set-ups. Therefore experiment set-ups were changed at the hours shown in Figure 8 every day.

FINDINGS

Measurements in the study were done for 6 consecutive days during the heating period. This 6-day period was between January 26 and January 31.

26–31 January (Heating Period) Ambient Temperature Measurement Results

Based on the measurements done between 26/01 and 31/01, changes in the interior space and external environment temperatures and solar radiation values are shown in Figure 9. Since solar radiation was not measured in the field, the values were obtained from the Ulukışla meteorology office which measures solar radiation and is at the closest location to the experiment building. Ambient temperature measurement values in the Test Classroom and Basic Classroom are shown in Table 2.

As seen in Figure 9, the Test Classroom ambient temperature was measured higher than the Basic Classroom ambient temperature on ESU-1, ESU-2, ESU-3, ESU-4, ESU-5, and ESU-6. Solar radiation values are 550–600 kWh/m² in ESU-1 and ESU-4 measurements and 250–300 kWh/m² in ESU-3, ESU-5, and ESU-6 measurements. Since solar radiation values were low as shown in Figure 9, cavity temperatures were measured around 10°C lower during daytime in ESU-3 and ESU-6 measurements compared to other experiment set-ups. It is possible to evaluate experiment set-ups by classifying them into two groups: ESU-1, ESU-2, ESU-4, and ESU-5 in which solar radiation values were higher and ESU-3 and ESU-6 in which solar radiation values were lower. In all experiment set-ups, warm air in the cavity rises and moves to the interior space through the upper opening on the classroom façade and cooler air enters in through the opening at the lowest level on the classroom façade. Accordingly, it is possible to comment that the temperature in the interior space is a function of the warm airspeed and rate of moving in the room, the area of entry and exit openings, and the difference in the height of these openings. Based on these principles, the performance of different experiment set-ups is evaluated as shown below.

- It was observed that since the temperature in the cavity was quite higher than the temperature in the Test Classroom in ESU-1 measurements and air entry and exit openings were at the same height, it was not enough for the warm air in the cavity to move to the interior space increasing the temperature difference between the Test Classroom and Basic Classroom. The highest and the lowest temperature differences in the alternative ESU-1 was 2.2°C and 0.3°C respectively.
- In ESU-2 measurements, although the middle window with the biggest surface area was closed, the effect of having lower and upper vents open, in other words having the distance between the intermediate cavity and air movement vents at the maximum (110 cm) on the interior space can

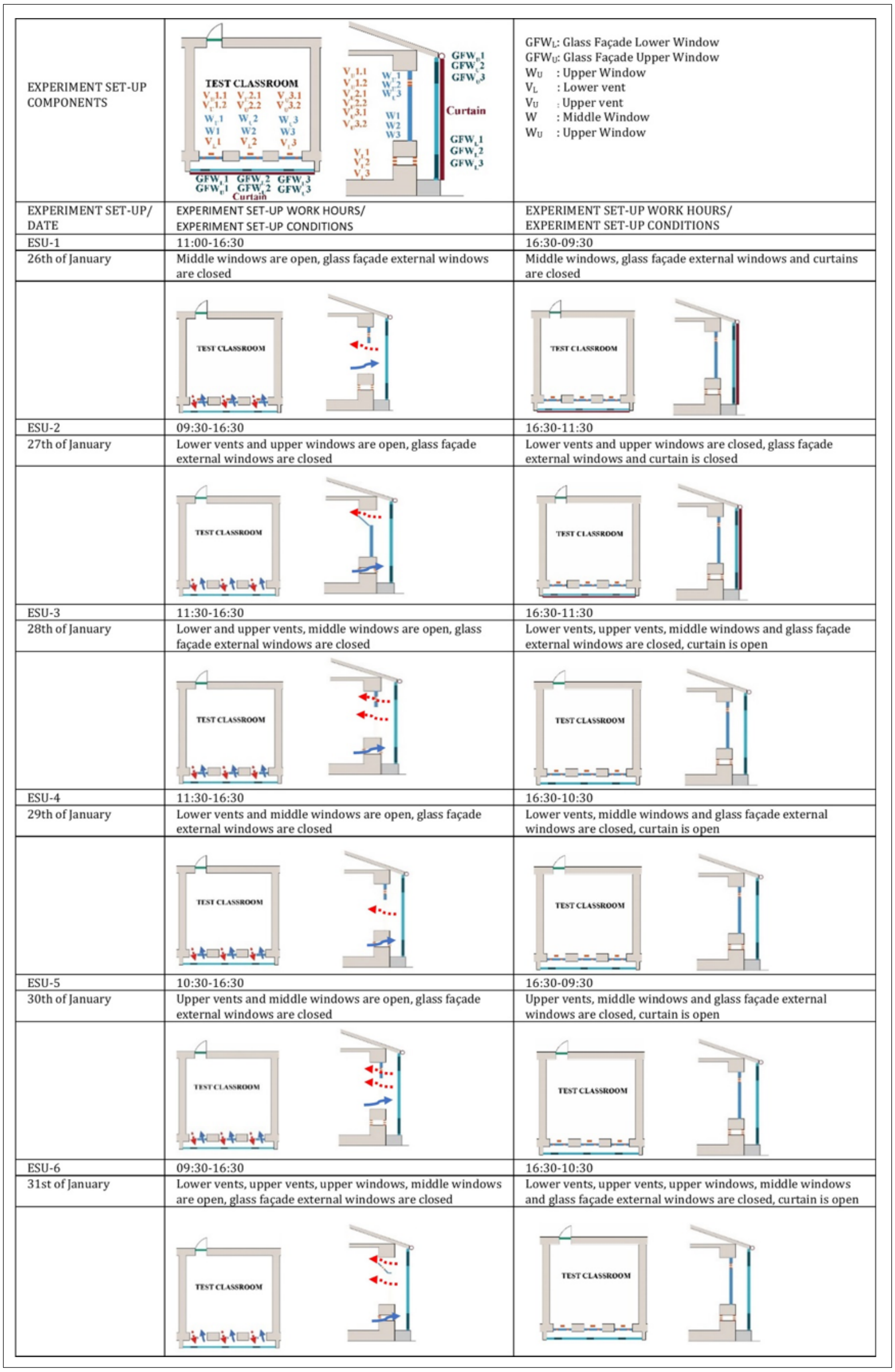

Figure 8. Experiment set-ups and conditions used on 26–31 January (heating period).

be seen. As this distance increases, warm air movement in the intermediate cavity increases and accelerates, and therefore the best results in the temperature difference between the Test Classroom and Basic Classroom were in ESU-2 after ESU-4 and ESU-5. In the alternative ESU-2, the temperature difference between the Test Classroom and Basic Classroom was 2.5°C.

- The height difference between air entry exit vents in the alternatives ESU-4 and ESU-5 were 110 cm and 90 cm, respectively. Since the height difference between air

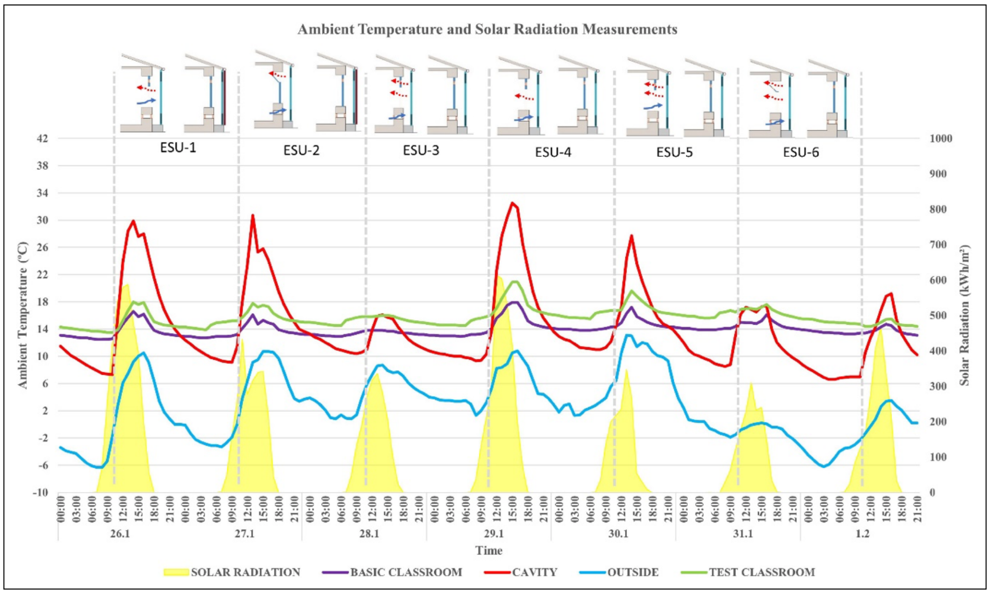

Figure 9. Ambient temperature and solar radiation measurement values on 26/01–31/01.

entry and exit openings was bigger and solar radiation values were higher, the temperature difference between the Test Classroom and Basic Classroom was maintained 1 h longer in ESU-4 (2 h) compared to ESU-5.

- At the same time in the alternative ESU-4, since the warm air in the cavity entered into the interior space through the middle window which was the biggest opening, this shows that this alternative has a high performance because the interior space temperature was high and interior air temperature value (20°C) which is used in the calculations for education buildings according to the TSE 825 could be maintained for 2 h although no active heating system was used. With this, the speed and volume of the transfer of warm air in the cavity to the interior space increased and the temperature difference between the Test Classroom and Basic Classroom also increased. When we look at the ESU-4 and ESU-5 measurements, the Test Classroom temperature was 3°C higher than the Basic Classroom temperature in the measurements done at 15:00 and 16:00 in ESU-4 and at 15:00 in ESU-5. This 3°C temperature difference is the highest temperature difference measured in 6 experiment set-ups (Table 2).
- In the experiment set-ups ESU-3 and ESU-6, entry and exhaust vents had similar areas and were at similar heights. However, upper vent in ESU-3 and upper window in ESU-6 which has a bigger area were used as upper opening. Having approximately the same temperature values in the Test Classroom and cavity in ESU-3 and ESU-6 resulted in less air movement between these two spaces. However, since solar radiation values in the external environment were low in both experiment set-ups, cavity temperature was very close to the values measured in the Test Classroom and at the same time lower than other experiment set-ups. As shown in Table 2, at 15:00 h when the temperature in the cavity was less than the Test Classroom temperature, since the upper vent in ESU-3 has a smaller area than the upper window in ESU-6, air movement from the Test Classroom which was warmer to the cavity was less and temperature difference between the Test Classroom and Basic Classroom in ESU-3 (2.3°C) was higher compared to ESU-6 (2.0°C.)
- Furthermore, the temperature in the Test Classroom was higher than that in the Basic room even in the ESU-6 measurements in which the exterior environment temperature dropped below zero during the day, which can be explained by the fact that the Test Classroom is adjacent to the cavity instead of the exterior environment. Although less air movement was present since the Test Classroom and cavity temperatures were very close with the use of the openings mentioned in the experiment set-ups, the cavity acted as a buffer zone so the temperature in the Test Classroom was higher than that the temperature in the Basic room.
- When ESU-3 and ESU-6 measurements in which solar radiation values were lower were examined, the highest temperature difference was 2.3°C at 15:00 (28/01) and 08:00, 09:00, and 10:00 (29/01) in ESU-3 where measurement results were higher in the Test Classroom than those in the Basic Classroom (Table 2). Table 2 shows 24 h interior air temperature values and temperature differences between the Test Classroom and Basic Classroom with different experiment set-ups.

Table 2. 26 January-31 January (heating period) Test Classroom and Basic Classroom Ambient Temperature Measurement Values

	Ambient Temperatures Measured in Basic Classroom and Test Classroom For Different Experiment Set-Ups (°C)			
	ESU-1			
Hour	**Date**	**Basic Classroom**	**Test Classroom**	**Temperature Difference (TC-BC)**
10:00	26th of January			
11:00		13.6	13.9	0.3
12:00		14.7	15.2	0.5
13:00		15.7	16.7	1.0
14:00		16.6	18.0	1.4
15:00		15.8	17.6	1.8
16:00		16.2	17.9	1.7
17:00		14.9	16.4	1.5
18:00		13.8	15.1	1.3
19:00		13.5	14.8	1.3
20:00		13.3	14.6	1.3
21:00		13.2	14.5	1.3
22:00		13.1	14.4	1.3
23:00		13.0	14.3	1.3
00:00	27th of January	12.9	14.3	1.4
01:00		12.9	14.2	1.3
02:00		12.8	14.1	1.3
03:00		12.7	14.0	1.3
04:00		12.7	13.9	1.2
05:00		12.8	14.6	1.8
06:00		12.9	14.9	2.0
07:00		12.9	15.0	2.1
08:00		12.9	15.1	2.2
09:00		13.0	15.2	2.2
10:00		13.2	15.2	2.0
11:00				
	ESU-2			
Hour	**Date**	**Basic Classroom**	**Test Classroom**	**Temperature Difference (TC-BC)**
10:00	27th of January			
11:00		14.1	15.7	1.6
12:00		15.0	16.5	1.5
13:00		16.1	17.8	1.7
14:00		14.7	17.2	2.5
15:00		15.3	17.5	2.2
16:00		14.9	17.3	2.4
17:00		14.7	16.3	1.6
18:00		13.9	15.8	1.9

Table 2. 26 January-31 January (heating period) Test Classroom and Basic Classroom Ambient Temperature Measurement Values (Cont.)

	ESU-2			
Hour	**Date**	**Basic Classroom**	**Test Classroom**	**Temperature Difference (TC-BC)**
19:00		13.7	15.5	1.8
20:00		13.5	15.3	1.8
21:00		13.4	15.2	1.8
22:00		13.3	15.1	1.8
23:00		13.2	15.0	1.8
00:00	28th of January	13.2	15.0	1.8
01:00		13.2	14.9	1.7
02:00		13.1	14.8	1.7
03:00		13.0	14.7	1.7
04:00		13.0	14.6	1.6
05:00		12.9	14.5	1.6
06:00		12.9	14.5	1.6
07:00		13.1	15.3	2.2
08:00		13.2	15.5	2.3
09:00		13.4	15.7	2.3
10:00		13.6	15.8	2.2
11:00		13.8	15.8	2.0
	ESU-3			
Hour	**Date**	**Basic Classroom**	**Test Classroom**	**Temperature Difference (TC-BC)**
10:00	28th of January			
11:00				
12:00		13.8	15.8	2.0
13:00		13.8	15.9	2.1
14:00		13.8	16.0	2.2
15:00		13.7	16.0	2.3
16:00		13.7	15.9	2.2
17:00		13.5	15.6	2.1
18:00		13.4	15.4	2.0
19:00		13.4	15.2	1.8
20:00		13.3	15.1	1.8
21:00		13.2	15.0	1.8
22:00		13.2	14.9	1.7
23:00		13.1	14.8	1.7
00:00	29th of January	13.1	14.7	1.6
01:00		13.0	14.6	1.6
02:00		13.0	14.6	1.6
03:00		13.0	14.6	1.6
04:00		13.0	14.6	1.6
05:00		12.9	14.5	1.6

Table 2. 26 January-31 January (heating period) Test Classroom and Basic Classroom Ambient Temperature Measurement Values (Cont.)

	ESU-3			
Hour	**Date**	**Basic Classroom**	**Test Classroom**	**Temperature Difference (TC-BC)**
06:00		13.0	14.5	1.5
07:00		13.2	15.2	2.0
08:00		13.2	15.5	2.3
09:00		13.3	15.6	2.3
10:00		13.5	15.8	2.3
11:00		14.1	16.1	2.0

	ESU-4			
Hour	**Date**	**Basic Classroom**	**Test Classroom**	**Temperature Difference (TC-BC)**
10:00	29th of January			
11:00				
12:00		15.6	17.1	1.5
13:00		16.3	18.5	2.2
14:00		17.5	19.8	2.3
15:00		17.9	20.9	3.0
16:00		17.9	20.9	3.0
17:00		16.8	19.6	2.8
18:00		15.2	17.5	2.3
19:00		14.7	16.9	2.2
20:00		14.5	16.6	2.1
21:00		14.3	16.4	2.1
22:00		14.2	16.2	2.0
23:00		14.1	16.1	2.0
00:00	30th of January	14.0	16.0	2.0
01:00		14.0	15.8	1.8
02:00		14.0	15.7	1.7
03:00		13.9	15.7	1.8
04:00		13.8	15.6	1.8
05:00		13.8	15.6	1.8
06:00		13.8	15.5	1.7
07:00		13.9	16.3	2.4
08:00		14.0	16.5	2.5
09:00		14.1	16.6	2.5
10:00		14.3	16.7	2.4
11:00				

	ESU-5			
Hour	**Date**	**Basic Classroom**	**Test Classroom**	**Temperature Difference (TC-BC)**
10:00	30th of January			
11:00		14.4	16.7	2.3
12:00		14.9	16.8	1.9
13:00		16.3	18.3	2.0

Table 2. 26 January-31 January (heating period) Test Classroom and Basic Classroom Ambient Temperature Measurement Values (Cont.)

	ESU-5			
Hour	**Date**	**Basic Classroom**	**Test Classroom**	**Temperature Difference (TC-BC)**
14:00		17.2	19.6	2.4
15:00		15.8	18.8	3.0
16:00		15.4	18.1	2.7
17:00		15.0	17.5	2.5
18:00		14.7	17.0	2.3
19:00		14.5	16.6	2.1
20:00		14.4	16.4	2.0
21:00		14.3	16.3	2.0
22:00		14.3	16.2	1.9
23:00		14.2	16.1	1.9
00:00	31st of January	14.1	16.0	1.9
01:00		14.1	15.9	1.8
02:00		14.0	15.9	1.9
03:00		13.9	15.7	1.8
04:00		13.9	15.6	1.7
05:00		13.9	15.6	1.7
06:00		13.9	15.7	1.8
07:00		14.0	16.4	2.4
08:00		14.1	16.5	2.4
09:00		14.1	16.7	2.6
10:00				
11:00				

	ESU-6			
Hour	**Date**	**Basic Classroom**	**Test Classroom**	**Temperature Difference (TC-BC)**
10:00	31st of January	14.4	16.5	2.1
11:00		15.0	16.9	1.9
12:00		14.9	17.0	2.1
13:00		14.9	17.0	2.1
14:00		14.8	16.9	2.1
15:00		15.2	17.2	2.0
16:00		16.1	17.6	1.5
17:00		15.3	16.9	1.6
18:00		14.8	16.5	1.7
19:00		14.4	16.2	1.8
20:00		14.2	16.0	1.8
21:00		14.1	15.8	1.7
22:00		14.0	15.6	1.6
23:00		13.9	15.5	1.6

Table 2. 26 January-31 January (heating period) Test Classroom and Basic Classroom Ambient Temperature Measurement Values (Cont.)

	ESU-6			
Hour	**Date**	**Basic Classroom**	**Test Classroom**	**Temperature Difference (TC-BC)**
00:00	1st of February	13.8	15.5	1.7
01:00		13.7	15.4	1.7
02:00		13.6	15.2	1.6
03:00		13.5	15.1	1.6
04:00		13.5	15.0	1.5
05:00		13.4	15.0	1.6
06:00		13.4	14.9	1.5
07:00		13.3	14.9	1.6
08:00		13.3	14.8	1.5
09:00		13.3	14.8	1.5
10:00		13.4	14.7	1.3
11:00				

CONCLUSION

The purpose of this study is to examine the performance of a double-skin façade system installed on a one story elementary school building in the temperate-dry climatic region by comparing ambient temperatures measured in different experiment set-ups in the heating period. The classroom where no change was made was called the Basic Classroom and the classroom where the glass façade was installed on the south façade was called the Test Classroom and the space between the glass façade and the Test Classroom was called the cavity. In the measurements done for 6 experiment set-ups between 26/01 and 31/01 in the heating period;

- Test Classroom ambient temperature values were minimum 0.3 and maximum 3.0°C higher than Basic Classroom ambient temperature values.
- Depending also on the solar radiation, when the experiment set-ups ESU-1, ESU-2, ESU-4, and ESU-5 in which intermediate cavity temperature was higher and the experiment set-ups ESU-3 and ESU-6 in which solar radiation values were lower were compared, the best result was achieved in the alternative ESU-4. As a result of having high cavity air temperature as well as 110 cm height difference between air entry and exit openings in the cavity and Test Classroom (the highest difference among the alternatives that have one large opening [middle window-lower vent, middle window upper vent/upper window]), higher temperatures were achieved in the Test Classroom compared to the other alternatives.
- In the alternatives ESU-3 and ESU-6 with almost similar opening properties in which solar radiation was lower, air movement was reduced because cavity and Test Classroom temperatures were very similar.
- When we look at the cavity and Test Classroom temperatures, temperatures were 15.7°C–16.0°C, respectively at 15:00 in ESU-3 and 16.5°C–16.9°C, respectively, at 14:00 in ESU-6 and since cavity temperature was lower than the temperature in the Test Classroom, there was a heat transfer from the Test Classroom to the cavity.
- Less upper vent area in the alternative ESU-3 resulted in less heat loss in the Test Classroom. Although there was less air movement since the Test Classroom and cavity temperatures were the same, intermediate cavity acted as a buffer zone so the temperature in the Test Classroom was higher than that in the Basic Room even in the ESU-6 measurements in which exterior environment temperature dropped below zero during the day.
- In this study, no equipment that allows air transfer such as fans that consumes energy was used in the set-ups used as passive systems and warm air in the cavity was planned to be transferred to the Test Classroom to increase the temperature thereby natural convection. As shown in Figure 9, the difference between cavity and Test Classroom temperatures measured in ESU-1, ESU-2, and ESU-4 was 8.9–12.9°C. In these experiment set-ups where the temperature difference between the intermediate cavity and Test Classroom is high, if a fan powered by solar energy which will increase transfer of warm air in the intermediate cavity to the Test Classroom is used, it will be possible to increase the temperature difference between the Test Classroom and Basic Classroom.

Following this study in which only measurement results were evaluated, the goal is to focus work on improving system performances by comparing measurement results with simulation calculation values and developing improvement suggestions for the size and location of vents and windows. In addition, with the help of the data obtained from this study, future studies can be carried out to improve the thermal performance of the building envelope and the results can be extended.

ETHICS: There are no ethical issues with the publication of this manuscript.

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