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Toward sustainable school building design: A case study in hot and humid climate

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Abstract: There is a global concern about energy in buildings generally for two major reasons. The first one is to minimise the energy consumption in buildings, while the other is to provide thermally comfortable buildings with minimum energy usage. Most of the work carried out in buildings was in office as well as domestic sector. However, the limited publication was done in educational buildings generally. The significance of this research is to take into consideration the energy pattern in a school building in the Kingdom of Saudi Arabia. The research is going to use TAS EDSL computer modelling with its validation. TAS is one of the most commonly used software globally to predict energy building performance. In addition to that, the school will be visited for monitoring. Several types of advanced tools will be used to measure indoor air temperature, relative humidity and much more. This investigation shows that the utilisation of natural ventilation has a major impact on internal temperatures. It has lowered the minimum by 6°C and also lowered the maximum by 3°C. In addition to that, there is a noticeable influence on the top classroom which has its roof exposed to the outdoors. Such outcomes can serve the new vision of Saudi Arabia 2030 and aid to improve the reliance of its buildings on energy.

Subjects: Energy Efficiency; Geothermal Energy; Heating Ventilation & Air Conditioning

Keywords: building fabric; school buildings; natural ventilation; hot and humid climate; energy building

1. Introduction

Based on the new vision of the kingdom of Saudi Arabia which has been lunched in 2016. One of most important objectives of this vision is to reduce the relines of energy in buildings. One of the

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Dr Alwetaishi is the head of Civil Engineering Department at Taif University since 2016. In this article, he is dealing with a very complex architectural design to investigate the impact of shape on building energy performance.

PUBLIC INTEREST STATEMENT

In this study, the energy efficiency of prototype school design number 14 has been investigated in Saudi Arabia. The study used TAS EDSL tool which is considered as one of the most powerful and widely used software. It has involved a case study in the city of Jeddah which is a hot and humid region classification. The study suggested that this school design is not appropriate in this region due to large area of glazing which exceed 70% of total external wall in most of classrooms, hence, it is suggested that this area of glazing has to be minimized to prevent considerable of heat loss and gain.

most important advantages of a building is to provide a thermally comfortable environment for the users. Recently, there has been rise concern with respect to energy building performance by designers, engineers and other specialist within the subject. Generally speaking, there are many publications on domestic and office buildings. While building of education have received minor potential. In Saudi Arabia, the system of prototype school building design (PSBD) is approved which has resulted in the establishment of Fourteen schools in the country which are seen as the role model design schools. As a result, any misconception at the stage of design might be attributed of any issue.

In a study done in Saudi Arabia by Mohammed and Ismail (2015), the work has absorbed that when daylight is associated with artificial light, major cut down in the cooling was recorded. Furthermore, it was found that 14% of clear glass while 16% for double glazed low windows. Study carried out by Nik (2016) in a hot and humid climate of Malaysia, the research has accomplished that various elements are need to be studied such as window to wall ratio, material for the glassing system, shedding devices and high quality of building construction in order to obtain the ultimate design in buildings.

In terms of a work done in cold regions, a study carried out by Kimmo (2016) in the country of Sweden highlighted that heating demand was decreased by 5.6 to 25.3% in added glazed façade into a brick wall building. On the other hand, in a work done by Francesco (2016) in several climatic regions in Europe to investigate optimal window to wall ratio in office building. The research discover that although there is an optimal glazing to wall ratio in each climate, orientation was found the most important aspect especially in warmer regions. In addition, only south orientation in cold regions or in hot climates require restricted percentage of glazing ratio. On the other hand, Soojung (2016) findings submit that the energy demand increases as window to wall ratio does and that window position has the largest impact on load when glazing to wall ratio is higher than 20%. The work also emphasis that west-orientation is the worst among the rest. Research by Ryan (2015) report that the decision should not only be limited to glassing system features but wall type has to be taken into account as well.

New constructed buildings seem to be more energy efficient as it takes into account latest codes and regulations while older buildings seem to have less. In a study done by Sekki, Airaksinen, and Saari (2017) which investigates the effect of energy measurers on the values of energy efficiency indicators, the study shows that newer healthcare buildings were more energy efficient than schools buildings. In educational buildings in the UK, Barbhiya and Barbhiya (2013) has studied the thermal comfort. The study revealed that thermal comfort is not achieved in certain floors in the building during winter due to large glazing system which has the ability to access direct solar gain; however, heat loss can take place easily.

1.1. Impact of glazing system on energy internal condition in buildings

It is accepted that glazing system is the weakest part of the envelope within a building which is responsible for fundamental quantity of heat transfer, it is also considered as the fragile part in building construction, and therefore having a considerable influence on energy consumption (Roberto, Mazuroski, Abadie, & Mendes, 2011; Tsikaloudaki, Laskos, & Theodosiou, 2012). Abdullatif (2002) has also suggested that glazing system is attributed to the amount of heat transmittance, direct solar gain and thermal bridging through windows. Kamal, Greig, Alhomida, and Al-Jafari (2000) has reported in the case of heating, windows are responsible for about 10–25% of heat loss while and it is also responsible for excessive heat gain taking into account two major aspect which are glazing ratio and temperature swing between indoor and outdoor. To summaries the window system is of master importance in buildings to provide more thermally acceptable environment, hence, lower the energy consumption of buildings (Pal, Roy, & Neogi, 2009).

1.2. Window to wall ration

Window to wall ratio can have an obvious impact on energy saving with respect to total energy consumption. This depends on the type of glazing since glazing system has a great effect which is greater than hollow. Moreover, solar heat gain a well as heat transfer coefficient will rise influenced by the glazing to all ratio rise (Xing & Zhang, 2010). Adjusting the window area will lead to greater impact than adjusting the thickness of external wall (Bouchlaghem, 2010). Andrea, Giovanni, and Francesca (2011) has highlighted that it is not only about the size of window, but also orientation has a great influence. According to Lee, Jung, Park, and Yoon (2013), all windows in each direction should be minimised in all warm and hot regions.

1.3. Thermal transmittance through windows

Thermal transmittance is an important aspect in building energy performance. Tsikaloudaki (2012) findings indicate that in hot and warm climate regions, higher solar transmittance could lead to worse energy pattern. In contrast, it might be more beneficial in cold regions or cooler periods during the year. Tsikaloudaki (2012) suggested that the thermal coefficient should not be lower than 2.0 W/m^{2}K, However, all glazing area in school buildings in Saudi Arabia have a single clear glazing layer which is inefficient for reduction in heat exchange that take place in window system. Many types of materials which can be utilized in glazing system to enclose high energy performance, low-E glazed unit was found to be the most effective system (Cinzia, Linda, & Elisa, 2012; Msnuela, Anna, Salvatore, & Antonio, 2016; Nicola & Inger, 2016; Tavares, Gaspar, Martins, & Frontini, 2014). Seunghwan, Hakeun, Byung, Hyesim, and Donghyun (2013) has reported that the use of low-E glazed unit can acquire 15.2 to 19.9% in total energy consumption in South Korea, however, this relies on the specification of selected materials.

Similarly, Mohammed and Ismail (2015) has supported this opinion. His study done in hot area where the work has suggested 14% reduction in total energy building with the integration of daylight using double-system of clear glass whereas the reduction was about 16% using low-E windows. Low-E unit in hot region can has a significance impact in ameliorating energy performance with 82% of heat transmittance and a very low emissivity of only 8% (Msnuela et al., 2016). In addition to that Weilong, Lin, Jinqing, and Aotian (2016) has compared the semi-transparent photolytic (STPV) with a low-glazing unit. The study has revealed that STPV system has the ability to save up to 18% of the total electricity consumption per year in the city of Hong Kong.

In a cold region, city of Hong Kong, the south-west orientation was found the best for power generation derived from the STPV whereas south found the optimum of energy performance for passive heating. With respect to Mediterranean climate, Tavares et al. (2014) has investigated the performance of single, double-glazing and electro chromic system. The later system found to be more appropriate for west facing façade where south facing one shows no significance difference utilizing the same system. Aerogel unit was studied and investigated by Nicola and Inger (2016) and Xamán et al. (2017). The research highlights that Aerogel system is a functional system in reducing energy consumption emissions neglecting the total window to wall ratio. However, other research reveals that thermal performance is not all about material system used; it covers many features such as dimensional characteristics and material properties of whole system (Cinzia et al., 2012).

1.4. Factors affecting solar heat gain

There are three different methods for heat to travel via window assembly, conduction, convection and radiation. In addition, four important aspects affect the total heat gained by window system which is as follows: heat transmittance, reflectance, absorbance and emittance.

In terms of heat transmittance which is allocated to the amount of radiation that can truly pass through window assembly while reflectance indicate to the light which can be reflected on glazing surface. The latter is connected to glazing type, coating and angle of incidence. In order to evaluate the performance of glazing system, Solar Heat Gain (SC) can be used which is the standard to determine window ability. All specialist are now moving toward a new system called Solar Heat Gain

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Coefficient (SHGC) which refer to the portion of the entire energy that can actually enter the building via window. U-value is commonly used in solar heat gain related to energy performance. However, it is reported by many investigations that are insufficient for precise evaluation (Adrian & Joanna, 2015). On the other hand, Gunnlaug, Christian, and Svend (2016) is against this. Gunnlaug has considered U-value as an important approach to evaluate energy performance of windows in buildings.

2. Research methodology

Today's market is full of computer modelling simulation. TAS EDSL is one of the leading and widely used tools to predict energy performance of buildings. The software is very accurate as the validation of the tool was introduced previously. The building construction materials (BCM) will be investigated based on the current building design and fabrication. In addition to that several of BCM will be investigated; thermal insulation and thermal mass will be highlighted with the utilisation of natural ventilation. The paper will focus on indoor air temperature, relative humidity and solar heat gain as variables. One of the key points that make the validation of this research quite unique is the place of conducting the validation. It was done in a real case of the school design in the city of Jeddah with using a real outdoor air temperature monitored by data-logger. These data was also used in the computer modelling (TAS) in order to seek accuracy in calculating outputs. In addition, some advanced energy equipment will be used on the site in order to monitor the indoor environment of the school which will aid to raise more deep discussion.

It is essential to proof in technical and professional way the capability and accuracy of the computer tool; otherwise the outcomes derived from such tool will not be reliable. Three data-loggers (Figure 1) were set in three locations in the studied school (Figure 1) in order to record indoor temperature along with relative humidity. Moreover, one date-logger was set outside the school to record actual outdoor temperature. The derived outdoor temperature later on was replaced with the estimated data in the database of TAS files. The impact of this was very obvious on the accuracy appear in Figure 2. The result of the validation indicate that TAS EDSL tool is a very accurate approach to predict energy building performance if outdoor temperature was accurately recorded and replaced with the estimated data in the database files of the program (Figure 3).

3. Dry bulb temperature and solar heat gain of Al Noor's selected classrooms in both winter and summer

TAS outcomes calculation of indoor air temperatures indicate that the top floor classroom (1_2) was responsible for 2–3°C in comparison to the other classrooms which are not exposed to outdoor through the roof. This supports the observation of monitored data in chapter 6. Based on the experiment of the impact of orientation in Al Ameer School, it was observed that there is a great influence from south orientation on internal conditions, especially with a larger area of windows. As all the selected classrooms here are south-facing, a high amount of solar radiation is predicted in all of the classrooms.

Regarding solar gain in the selected classrooms, as much as 1,000 W solar gain was transmitted and subsequently released inward in classrooms 2_2 and 3_2 which are located on the first and top floors,

Figure 1. Data-logger used for validation of TAS EDSL using actual outdoor temperature.

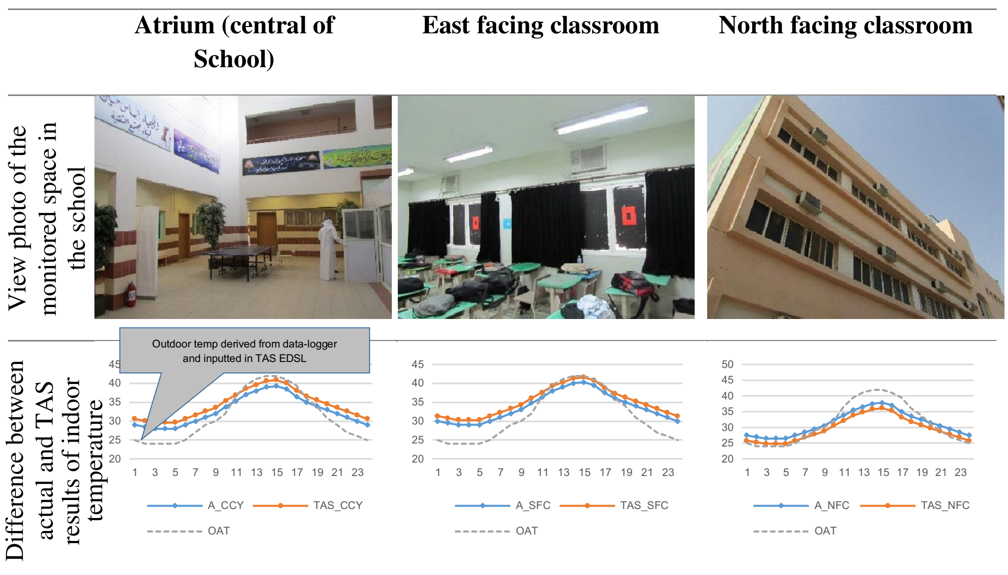


Figure 2. Locations in Al Noor School selected for validation in the city of Jeddah.

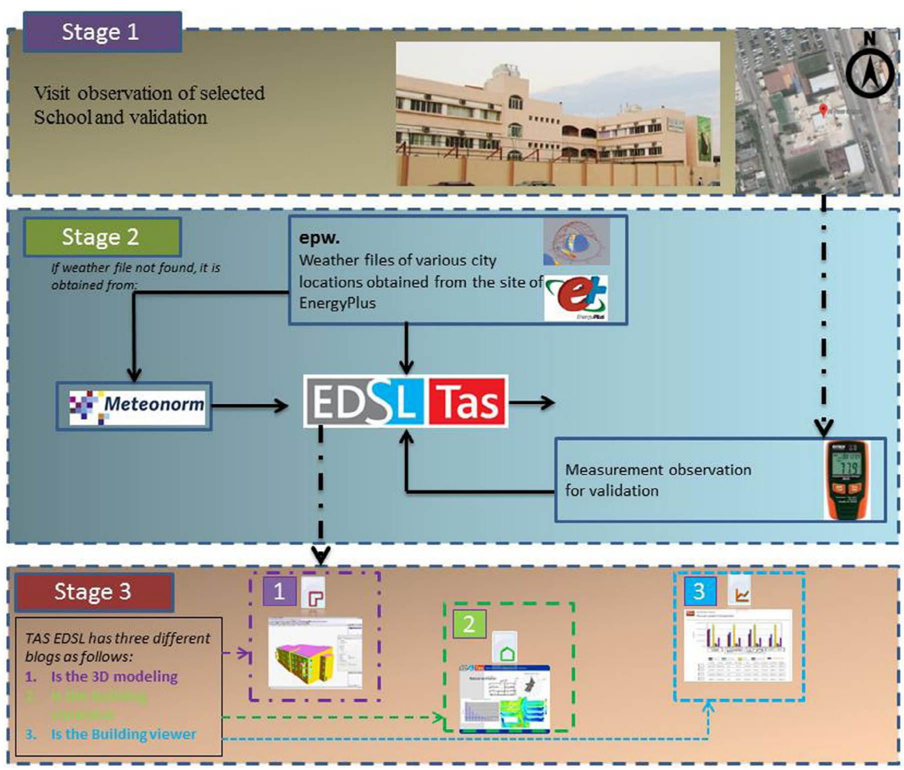


Figure 3. Flow chart of the method of the research.

respectively, leaving the ground floor class with less than 800 W. This is attributed to the sun's path, which has limitations in reaching the ground floor outer surface due to self-shading. However, in summer classroom 2_2 had the highest amount of solar gain. In fact, it is quite complex to clarify which nearby object has resulted in such shade. Thus there is no doubt that there is going to be certain differences for the elevation of the selected classrooms in winter and summer. In a comparison between in the access of solar gain between this school and the previous one, it can be noted that the Al Noor School has more access of solar heat gain than in Al Ameer School due to window to wall ratio. This has resulted in a considerable amount of solar heat gain which could be as high as 300 W (Figures 4 and 5).

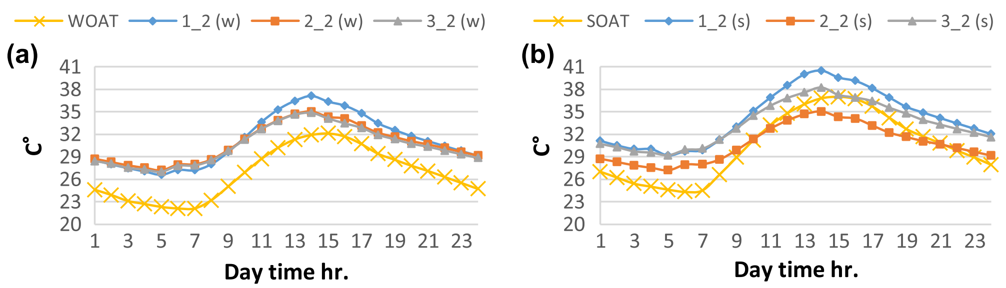


Figure 4. Air temperature distribution in both winter (a) and summer (b) in Al Noor School.

Notes: WOAT = Winter outdoor air temperature (actual, monitored) and SOAT = Summer outdoor air temperature (actual, monitored).

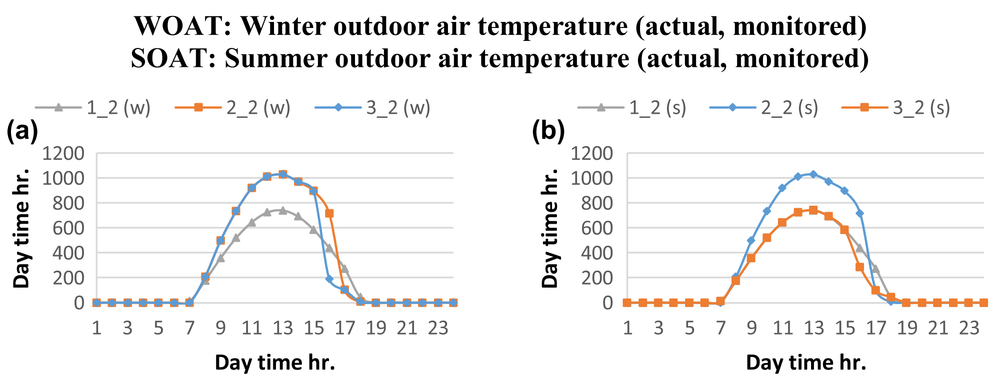


Figure 5. Solar heat gain distribution in both winter (a) and summer (b) in Al Noor School.

4. Heat conduction through walls, floors and roofs (Al Noor School)

The influence of roof heat conduction (RHC) is obvious and dominating in both winter and summer for the top classroom (1_2) as it can be seen in Table 1. This will conceivably have its implementations on heat conduction. As a result, an increase of heat gain derived from the ceiling inward will take place. In terms of floor heat conduction for each classroom in both summer and winter (FHC), there was not any indication of heat gain variations. The amount of heat conducted was quite stabled at about −500 W, which shows there is little continuous heat gain conducted inside the zones (classrooms). It can be admitted that the impact of the floor on the heat conduction is minor. In contrast, the leverage of the roof is enormous in comparison.

With regard to external wall heat conduction (EWHC), its influence is second after RHC. Furthermore, as has been discussed before, the impact of EWHC in winter is greater than in summer due to temperature difference in between indoor and outdoor which lead to larger flux of heat conduction. The

Table 1. Max and min heat conduction (loss and gain) of Al Noor School in both winter and summer, (W)

	Roofs		External walls		Floors	
Winter						
	Max loss	Max gain	Max loss	Max gain	Max loss	Max gain
1_2	4,880.7	−8,198.2	1,758.1	−1,972.1	257.7	−573.7
2_2	888.8	−2,141.9	1,381.3	−1,972.1	197.02	−538.9
3_2	357.6	−2,141.9	1,308.3	−1,972.1		
Summer						
	Max loss	Max gain	Max loss	Max gain	Max loss	Max gain
1_2	3,883.5	−5,783.3	704.8	−876.8	238.8	−540.2
2_2	602.66	−1,764.6	589.2	−876.8	223.23	−540.2
3_2	347.3	−1,764.6	503.1	−876.8		

amount of heat conduction through the fabric is quite similar between the classrooms during time intervals, considering the different levels that they have, particularly, in the pattern of heat gain during the day. These fluctuations were quite restricted in summer since the influence of solar radiation on external walls is limited. It can be said that heat conduction through the ceiling is abundant compared with the other two surfaces, after that external walls rank second. Floors have quite a small influence on heat conditions. In addition to that there was a more noticeable increase in the effect of solar radiation on heat conduction in winter than in summer.

5. Impact of level of classroom on indoor environment

In this school (Figures 6 and 7), the main variable is the variation in levels (ground, first and top floor), where all the classrooms are facing south. The use of AC systems in the classrooms makes it quite complex to analyse the internal condition properly. Thus, utilising the absence of it during the experiment and out of school times might aid in the discussion and analysis. Regarding the winter results for the microclimate of the selected classrooms, the top floor (1_2) has a higher IAT by 2 °C at 11am compared with the other two classrooms. This indicates the effect of heat conducted by the roof which is exposed to the outdoors. Similarly, globe temperature in the top classroom is the only zone where a gradual increase was recorded throughout the day, whereas in the other two a gradual decrease was reported. This might be due to radiation source of heat through the external wall including the window system. With regard to FIST, it was relatively higher in the ground floor class (3_2), which is expected as ground heat is the main source in this situation. On the other hand, it is at lowest figures in classroom (2_2) which is located in first floor (no outer exposure).

RIST was higher in classroom 1_2 which is located in top floor, and the source of heat is obvious. However, there are some uncontrolled variations between the classrooms in some variables such as RIST; this has a correlation with the circulated cool air generated by the AC. Consequently, unexpected figures may be found. For instance, although the IATs of classrooms 2_2 and 3_2 are similar, the RIST was not. The only effect factor here is the influence of the AC system which varies in efficiency and duration of operation. As far as the summer results are concerned, it has to be highlighted first that the OAT on the day of conducting 1_2 was considerably lower than 2_2 and 3_2. In addition to that it was partly cloudy day which will have an effect on solar radiation. However, taking into account all of these surrounding conditions, the top zone (1_2) remains the highest IAT. The IAT of this classroom peaked at 31°C when OAT peaked at 36°C, while the IAT of classroom 3_2 peaked at 33.8°C when OAT reached 40°C. The cloud covered sky on the day of the 1_2 experiment has the ability to lower GT by a couple of degrees. Based on the previous discussion it can be noted that there is a larger influence on the top floor, which has its roof exposed to outdoors than on the ground floor, which has its floor exposed to outdoors. This influence may lead to temperature differences of 2 to 3°C in both winter and summer. Figure 8 indicate that South orientation can raise IAT by roughly 1.5 to 2°C when comparing it with north-facing classroom.

Figure 6. Locations of classrooms monitored in the school, on vertical level (same location).

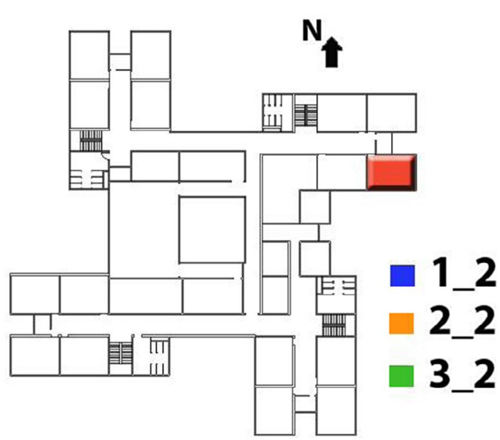
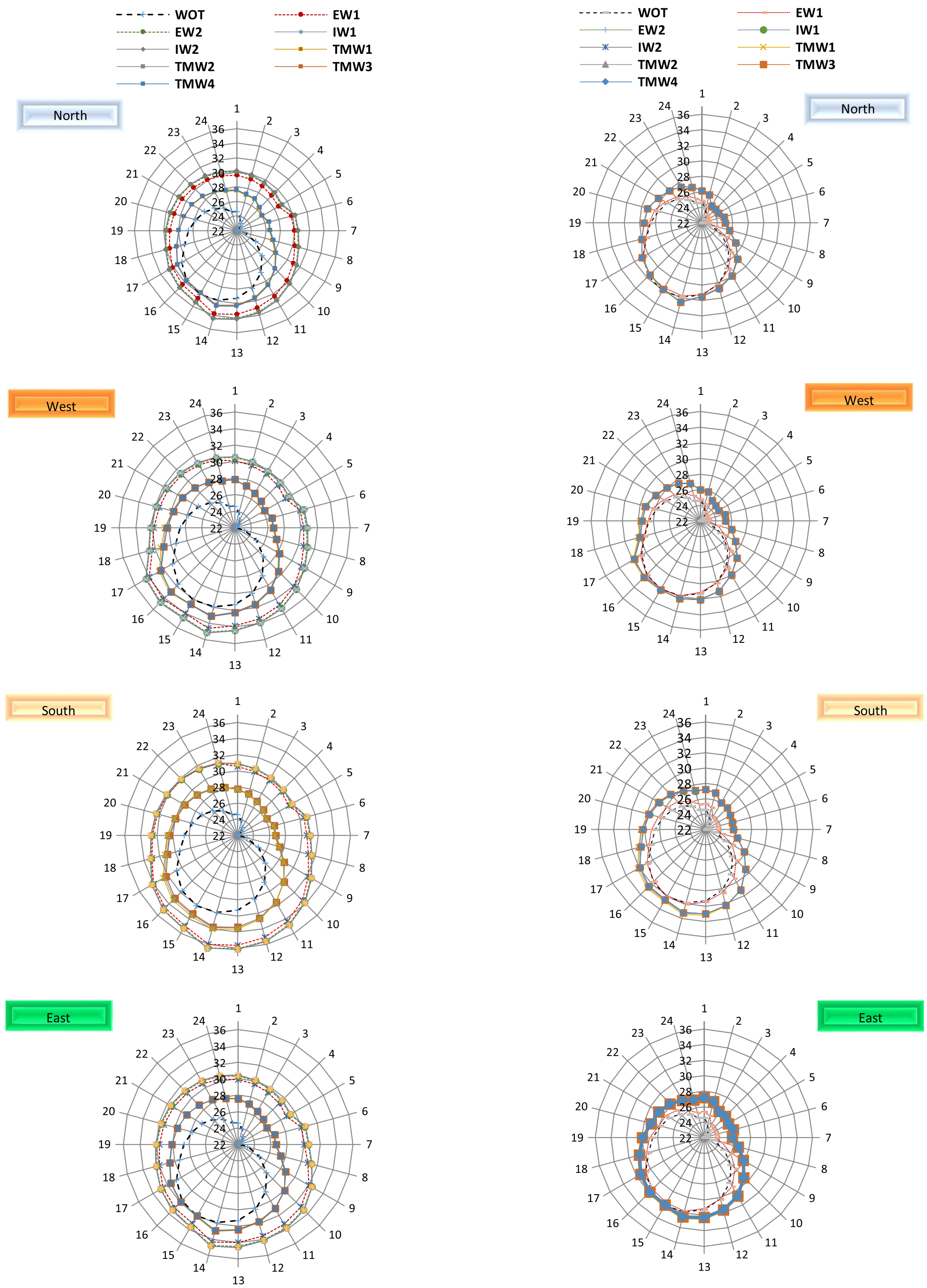


Figure 7. Winter outdoor and indoor temperature of selected classrooms in the school of Al Noor with various samples of external walls including current, insulated and thermal mass, the simulation has been carried out twice (one with the use of natural ventilation, and the other without).

Notes: WOT = is the winter outdoor temperature, CW = the current walls of the selected schools, IW = the proposed insulated walls and TMW = the proposed thermal mass walls.



6. Improving of building envelope

Regarding the selection of thermal insulation materials, the same main layers and order has been used along all of the proposed external walls and roofs in order to ensure the impact of layer type and thickness when it comes to comparison. Moreover, only one type of insulation has been applied to be compared with as no sign of difference has been obtained when more types have been tested (see the graph below), the type of insulation is extruded polystyrene which is mainly used not only on all new versions of schools in Saudi, but also in all buildings that belong to the government. TAS

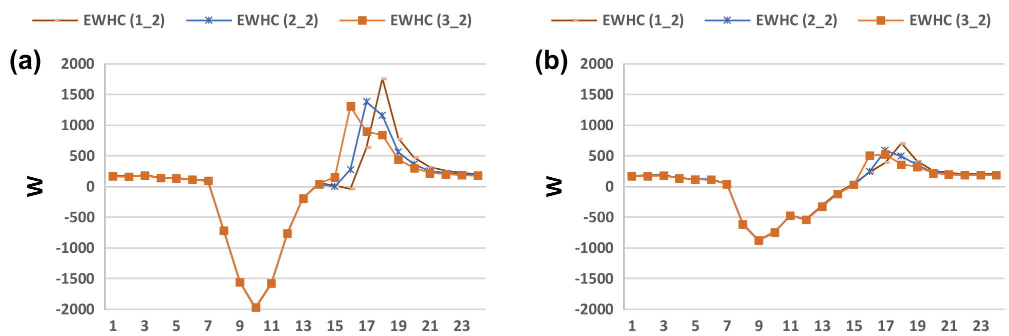


Figure 8. Heat conduction via external walls in Al Ameer School in both winter (a) and summer (b).

also will be used to test the impact of a number of proposed external walls, roofs and floors on the indoor air temperature, heat conduction, solar heat gain and cooling load (Table 2).

7. Existing wall of the selected schools

In terms of the excising walls of Al Ameer, Al Noor and Bader Schools they have two different types of external walls. The first one which is EW1 is applied on Bader's external walls whereas EW2 is applied on Al Ameer and Al Noor. EW1 wall has a single layer which consists only of 250 mm clay brick. On the other hand, after 2,000 the ministry of education has unified and developed construction materials of the external wall which has included 50 mm of thermal insulation. The U value of the old external wall has improved from 1.317 to 0.383 W/m²·°C. However, the result obtained will be completely unexpected.

As far as the proposed construction layers are concerned, the two main factors affecting the heat transfer between indoors and outdoors are the thermal insulation and thermal mass, where the first has the ability to slow down heat traveling in between the two sides of the wall, and the later has the ability to store heat for a longer time and then release it later on.

In terms of non-ventilated internal classrooms in winter (Figure 9), thermal mass Proposed walls had better IAT with drop of 1.5 to 2°C. The possible explanation for this is that thermal insulation slows down the air from travelling inward whereas thermal mass construction has the capability to store heat and then released it afterwards. Consequently at night, when the outdoor temperature is lower than indoors, more heat exchange is taking place with the thermal mass wall which subsequently will be transmitted inside over the night. Furthermore, it can be noted that the thermal mass proposed walls had a lower indoor temperature swing by 2°C in comparison with the proposed thermal insulated external walls.

The significance between each proposed group has to be highlighted. It can be seen that the difference between each group is quite negligible, to the extent that they overlap each other. This revealed that modifying the thickness of each variable material such as thermal insulation or thermal

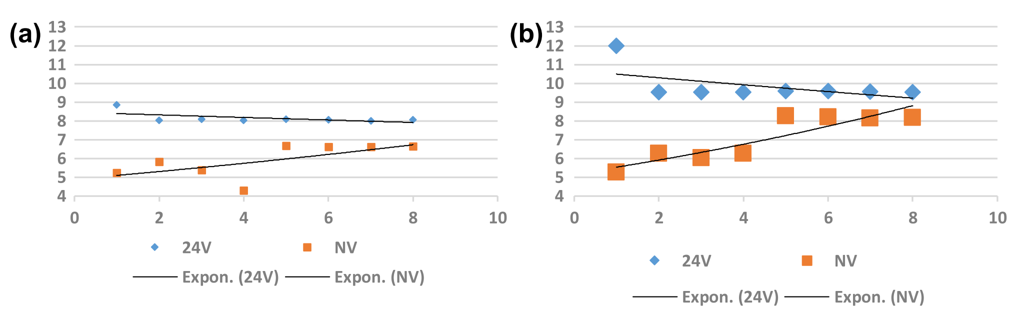


Figure 9. Temperature swings in north-facing classroom in winter (a) and summer (b) with respect of each applied eternal wall.

Table 2. Characteristics of existing, proposed insulated group and proposed thermal mass group

	Wall code	Description	Thickness (mm)	*U*-value w/ $m^2 \cdot {}^{\circ}C$	Conductivity $w/m^2 \cdot {}^{\circ}C$
Excising walls	EW1 "used in Bader school"	• External paint • External rendering • Clay brick • Internal plaster • Internal paint	15 250 12	1.317	2.004
	EW2 "used in Al Ameer and Al Noor schools"	• External paint • External rendering • Clay brick • External polystyrene • Concrete block • Internal plaster	15 250 50 150 15	0.383	0.425
Insulated walls	IW1	• External paint • External rendering • Clay brick • Extruded polystyrene • Concrete block • Internal plaster	15 250 100 15	0.242	0.259
	IW2	• External paint • External rendering • Clay brick • Extruded polystyrene • Concrete block • Internal plaster • Paint	15 250 150 150	0.177	0.168
Thermal mass walls	TMW1	• External paint • External rendering • Solid concrete • Internal plaster • Internal paint	15 100 12	1097	1.534
	TMW2	• External paint • External rendering • Solid concrete • Internal plaster • Internal paint	15 150 12	0.861	1.109
	TMW3	• External paint • External rendering • Solid concrete • Internal plaster • Internal paint	15 250 12	0.602	0.713
	TMW4	• External paint • External rendering • Solid concrete • Internal plaster • Internal paint	15 400 12	0.415	0.465

mass has by far less effect that choosing the right materials in hot and humid climate. Orientation, to a certain extent had its impact on internal conditions. There was about a 2°C rise in between south and north with the use of thermal insulation, while this gap was only about 1°C with the use of thermal mass. Moreover, the more the external wall is exposed to direct sunlight, the more the temperature swing is likely to vary for a particular material. This investigation also declared that the use of insulation has to have utilisation of night ventilation to cool the internal conditions otherwise thermal insulation will likewise prevent the outdoor cooler air from cooling in the building.

8. Twenty four hours natural ventilated classrooms in winter

On the other hand, in the case of 24 h natural ventilation the situation has been reversed (Figure 9). Exceptionally, the single layer external wall which was used in Bader School had the lowest indoor temperature at night compared with all current and proposed external walls including thermal insulation and thermal mass walls. The high U-value and thermal conductivity of this type of wall (single) aids to preserve the inner environment in contact with outer conditions. This has resulted in a strong correlation in terms of the temperature indoors and outdoors throughout the day. However, it has to be considered that in this type of wall, cooling the internal environment will require an extra amount of energy consumption, as heat loss will take place due to the high conductivity and poor u-value.

A similar view has been replicated in summer, only with higher temperatures for both indoor and outdoor. The relationship between IAT and cooling load might be distinct, for this reason an evaluation of cooling load has to be addressed to figure out any alterations.

9. Temperature swing as a result of examined external wall for both 24hr natural ventilation and without natural ventilation

In terms of north-facing, in general there is no significance difference between all the tested groups in the temperature swing in both summer and winter as it can be seen in Figures 10 and 11. However, the thermal mass group had more appealing of temperature swing than the other two. Moreover, the EW1 wall had the highest temperature swing in both seasons. This is because of the absence of thermal insulation which makes it easier for the heat to be transferred between indoor and outdoor. In a study done by Alwetaishi and Balabel (in press) and Alwetaishi (in press) where two PSBD were analysed in term of effectiveness of natural ventilation, the work found that natural ventilation benefits include: improving indoor air temperature and providing thermal comfort for the users.

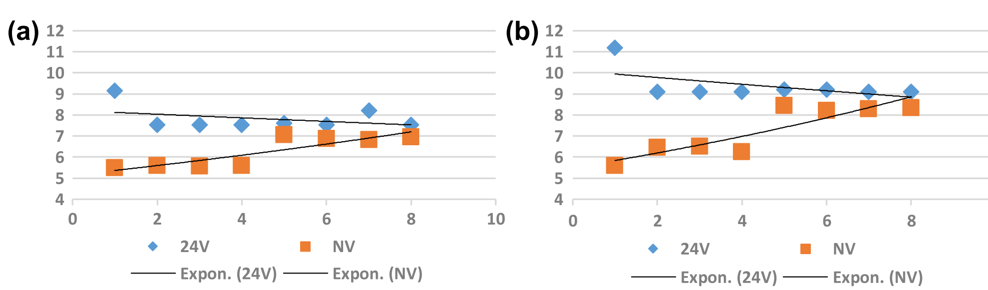


Figure 10. Temperature swings in east-facing classroom in winter (a) and summer (b) with respect of each applied eternal wall.

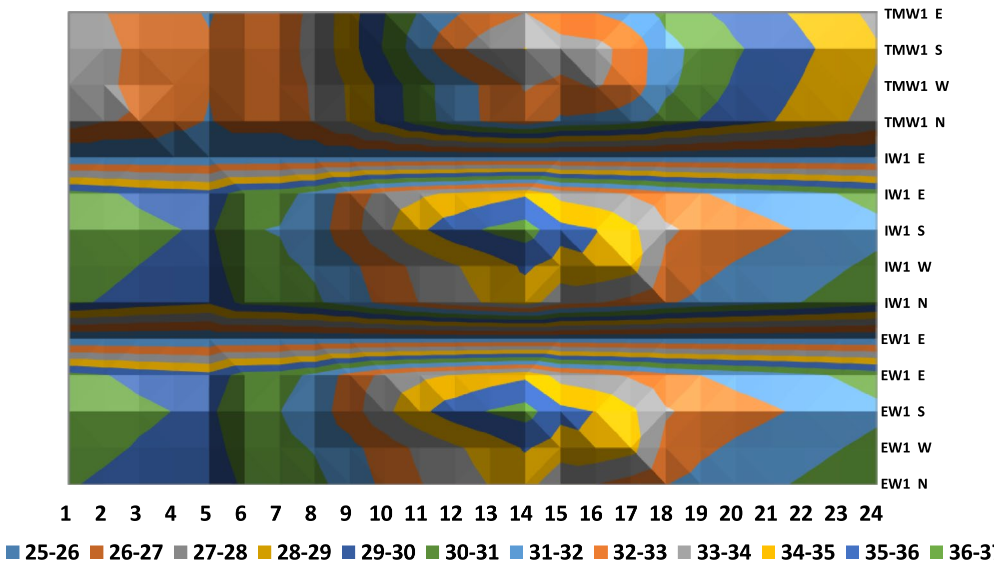


Figure 11. Impact of each construction material group on IAT in each direction in winter (without mean of natural ventilation, C°).

10. Conclusion

This study investigates the energy performance of PSBD number 14 in Saudi Arabia using TAS EDSL. In terms of floor heat conduction for each classroom in both summer and winter, there was not any indication of heat gain variables. The amount of heat conducted was quite stable at about (−500 W), which shows that there is a little continuous heat gain conducted inside the zones. It can be admitted that the impact of the floor on heat conduction is minor. In contrast, the roof/ceiling is enormous in comparison. With regard to EWHC, its influence ranks second after the impact of RHC. It can be said that heat conduction through the ceiling is abundant compared with other two surfaces, after then comes the external wall in the second position. Floors have a quite small influence on heat condition. In addition to that there was a noticeable increase in the effect of solar radiation on heat conduction in winter than in summer.

In terms of non-ventilated classrooms in winter, thermal mass proposed walls had better IAT with a drop of 1.5 to 2°C. Furthermore, it also has a lower temperature swing by 2°C. In terms of the significance of thickness of each group of material it is quite negligible to the extent that they overlap each other. This revealed that modifying the thickness of each variable material such as thermal insulation or thermal mass has by far less effect than choosing the right materials in hot and humid climate. Orientation to a certain extent had its impact on internal condition. There was about 2°C rise in between south and north with the use of thermal insulation while this gap was only 1°C with the use of thermal mass. In the case of natural ventilation the situation has been reversed. Exceptionally, the single layer external wall which was used in Bader School has the lowest indoor temperature at night compared to all current and proposed external walls including thermal insulation and thermal mass walls. However, in this type of walls, cooling the internal environment will require an extra amount of energy consumption as heat loss will take place due to the high factor of conductivity. This investigation shows that the utilisation of natural ventilation has a major impact on internal temperatures. It has lowered the minimum by 6°C and also lowered the maximum by 3°C which is considerable and have an effect on users' thermal sensation. It can be divulged that in hot and humid climates utilisation of natural ventilation with thermal mass that has thickness of at least 15 cm can provide more thermally acceptable indoor condition than the use of thermal insulation. There is a noticeable influence on the top classroom which has its roof exposed to the outdoors. This may cause a rise of 2–3°C in winter and summer. On the other hand, there is no significant impact of heat conducted through the ground floors on IAT.

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