Passive cooling and energy conservation design strategies of school buildings in hot, arid region: Riyadh, Saudi Arabia

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ABSTRACT

Due to the rapid growth of the country, prototype school buildings in Saudi Arabia were designed with little effort made towards the utilization of the natural resources to improve indoor conditions. Most of the existing school buildings in Riyadh, the capital city of the kingdom of Saudi Arabia, rely on mechanical equipment to cool interior spaces. As a result, these schools have become one of the major energy consumers during the peak time of the day. A huge amount of energy could be saved with better indoor air quality if school buildings were designed with respect to the local climate of Riyadh. An energy-efficient school will also create better learning and teaching environment, decrease the impact on the environment, cost less to operate and would be easier to maintain. This paper aims to emphasize the importance of using passive cooling and energy conservation design strategies in school buildings that are located in hot, dry climates such as the Riyadh region. Shading devices, landscape, ground cover, night ventilation, thermal mass, double glazing, thermal insulation, surface reflection, orientation and air infiltration will be investigated in this paper the aim being to modify the indoor condition of a school building. Each design strategy was individually applied to the ‘case study school’ and was evaluated using the thermal predictive model ‘HTB2’. Design strategies, mentioned above, were also integrated in the ‘basecase school’. Comparative evaluation of the thermal performance of the basecase and the modified case study school building design is also presented in this paper. The simulation results show that the modified design was able to significantly improve the indoor condition and reduce the cooling and heating loads of the existing school buildings.

1. INTRODUCTION

Riyadh, the capital city of Saudi Arabia, is one of the world’s fastest-growing cities. It has grown and expanded over a relatively short period of time, with the implementation of numerous construction and development projects as a result of spectacular economic improvement after the large-scale production of oil in the early 1960s (Al-Hemaidi, 2001). The education system and school buildings were a part of the national growth. In less than forty years the student enrolment rate for both boys and girls increased from 300,000 in 1965 to about 5 million in 2004. Numerous school building projects were built to provide educational spaces for students in all levels and types of education. The number of school buildings increased from 3,283 in 1970 to 30,414 in 2004, (The Ministry of Education, 2004). Major allocations of the government's general budget were given to the Ministry of Education to achieve qualitative and quantitative improvements in the education system and school buildings in Saudi Arabia. The decade between 1970 and 1980 in the Kingdom of Saudi Arabia witnessed massive and extraordinary improvements in school buildings when prototype school buildings were introduced to the country (The Ministry of Education, 1979; Al-Khwater, 2004).

Cost and time savings in school building construction were the central goals of the Deputy Ministry for Buildings and School Supplies, the department which is responsible for designing K-12 schools in the Ministry of Education.

As a result, they used prototypical school designs countrywide, regardless of the variation in climatic characteristics among the regions. Regrettably, most of the prototype school buildings do not accommodate the demands of the local climate of each region in Saudi Arabia (Al-Soliman, 1981; Khafaji, 1987). The designers of the prototype school buildings neglected the importance of environmental design strategies in their design and totally relied on mechanical equipment to cool, heat and light interior spaces (Al-Hemmiddi, 2002). A large amount of energy, as a result, is squandered and air pollution is increased. A significant amount of energy could be saved if there was enough awareness of environmental design principles in the early stages of the design processes (Salmon, 1999; Givoni, 1994).

2. AIM

The main aim of this paper is to maximize the potential of form and fabric of school buildings in order to provide good comfort conditions. With the purpose of achieving the main aim of this paper, a number of objectives were derived. The main objectives of this paper are as follows:

1 To identify, through a literature review, the environmental design strategies that could be used to modify the external environment with the aim of improving the condition of interior spaces of existing and future school buildings.

2 To carry out computer simulation experiments to evaluate the thermal performance of the existing prototype school building designs and to predict the effectiveness levels of various environmental design modifications when applied to the same design.

3. RESEARCH METHODOLOGY

The investigation of the research problem, justification, conclusions and findings has been achieved by literature review, on-site observation and advanced computer simulation tools. The theoretical foundation for this research has been obtained by a literature review related to climatic characteristics of Saudi Arabia, including the Riyadh region; educational systems; school building development; and environmental design strategies. Hourly climatic data, such as air temperatures, relative humidity and wind speed of Riyadh city were also collected from the Meteorology and Environmental Protection Administration in the Ministry of Defence and Aviation, Kingdom of Saudi Arabia. The contextual data has been gathered through on-site observation in a number of existing prototype school buildings in Riyadh city. This was followed by computer thermal predictions using the revised version of Heat Transfer through Building program 'HTB2' developed at the Welsh school of Architecture (Alexander, 1996) and ECOTECT, compiled by Square One research and the Welsh School of Architecture at Cardiff University (March, 2003).

4. SIMULATION PROCESSES

To achieve the objectives of the paper the Heat Transfer through Building program 'HTB2' and 'ECOTECT' were used to analyse, evaluate and demonstrate the thermal performance of the existing prototype school building. ECOTECT was used first in the simulation processes because it has the ability to identify the input files of a building by drawing a model of the building and it has the capability to export the input data to other simulation modeling programs and HTB2 is one of them. Afterwards, HTB2 was used to conduct all the simulation experiments. Simulation processes of the design modification went through two phases. The first phase was to apply a design strategy individually on the base-case model of the prototype school building. The second phase was to combine all selected design strategies in one model. Indoor air temperatures, cooling and heating loads were the criteria that were used to evaluate the thermal performance of each design strategy and the combined case.

Physical characteristics of the case study

The case study is an identical two-story prototype school building that was built in the late seventies. It is a square shaped concrete building that consists of a courtyard surrounded by a four-meter wide corridor (Figs. 1-3). Table 1 summarizes the physical characteristics of the case study.

Table 1: Physical characteristics of the prototype school building.

Building form	Rectangular
Number of stories	Two
Total ground floor area	2332 m^2
Ceiling height	3300 mm
Glazed area	503 m^2
Type of glass	Single tint glass (12mm)
Interior walls construction	Hollow concrete block (200mm)
Interior walls finishing	Plaster (15 mm). White painting
Exterior walls construction	Hollow concrete block (200mm)
Roof construction	concrete slab (300 mm), cement screed (20 mm), tiles

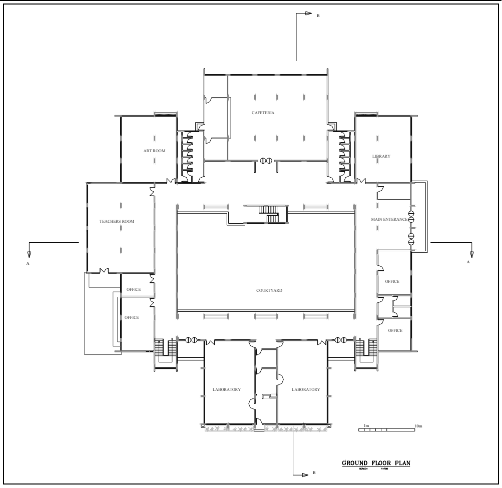

Figure 1: Ground floor of the prototype school building.

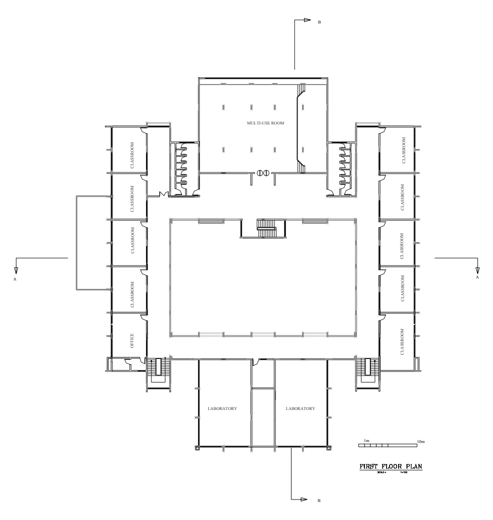

Figure 2: First floor of the prototype school building.

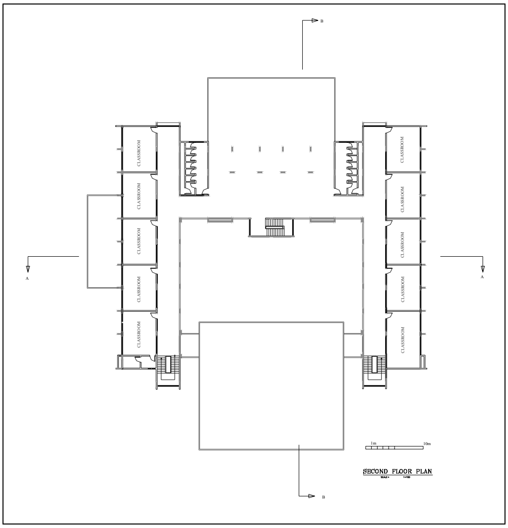

Figure 3: Second floor of the prototype school building.

5. DESIGN MODIFICATIONS

The benefit from environmental design strategies varies with climate, system type, system design and system size (Balcomb, 1992). Consequently, the intention of this paper is to investigate the effectiveness levels of a number of passive solar and energy conservation design strategies that were applied to the basecase of the prototype school building. Each strategy was individually applied to the basecase and was evaluated by the thermal predictive model ‘HTB2’. A group of selected design strategies were also integrated together in the combined case. Comparative evaluation of the overall thermal performance of the basecase and the modified school building design is also presented in this chapter. The comparison demonstrates the level of improvements achieved by applying these strategies to the basecase building design.

5.1 Window Shading

Transparent elements are the major cause of the high heat gain in school buildings in Riyadh especially during overheated periods of the year. Solar radiation can directly penetrate into a building through glazed areas as the weakest element in a building envelope. As a result, blocking the solar radiation before it reaches the opaque and transparent elements of a school building envelope is of great importance. Ignorance of the significance of shading devices during the early stages of school buildings design can increase the annual energy consumption, beside the negative effect on the indoor environment in terms of high temperatures and direct solar radiation. Placing proper over-hang and side-fins shading devices on the windows and/or vegetation can provide shade for the windows. Shading devices can be installed in a school building with reasonable cost and can remarkably improve its thermal performance.

In the prototype school building, it was found that all windows have the same type and dimensions of shading devices regardless of their location and orientation. Even though Saudi Arabia has five different climatic zones, the Ministry of Education also uses typical type and dimensions of shading devices in various climatic characteristics. Shading elements would be more effective if they were designed for the local climate of each region and for each façade of a building.

The first step in the simulation processes in this strategy was carrying out extensive simulation runs and tests on one classroom to demonstrate and ensure selection of the appropriate type and dimensions of shading devices for the Riyadh climate and the windows design in the prototype school building. Over-hang, vertical fins and a combination of both of them with different dimensions were applied on the two windows of the classroom with different orientation. The best performance was achieved by applying a combination of over-hang and side-fins on all facades. It was found also that 1m projection with 0.05m distance from the surface on north and south facing windows and 1.5m projection with 0.05m distance from the surface on east and west facing windows proved a good design of shading devices. They show an optimum performance and were able to improve the interior environment and reduce the direct solar radiation received by glazed areas. Therefore, the same dimensions and design of the shading devices mentioned above were applied on the basecase windows.

5.2 Roof Shading

The roof receives a large amount of solar radiation and is the main source of heat gain in buildings especially in hot, dry climates (Meyer, 1982). One third of the heat gain and losses in a building occurs through roofs (Chalfoun, 1999). Consequently, beside thermal insulation, roofs should be protected from intense solar radiation during the day. A ventilated double roof layer is an effective design strategy in hot, dry climates to minimise heat gain. Roofs can be shaded by an additional layer of roof that can be constructed by appropriate materials such as lightweight concrete, coupled with thermal insulation. The second layer can be built upon the main roof with one meter distance from the external surface of the main roof. The air space in between the two layers is for air circulation to eliminate the heat.

5.3 Landscape

All surfaces and elements of a building envelope receive intense direct solar radiation especially in Riyadh, which is located in a desert climate. Vegetation is a passive solar design strategy that plays a major role in the built environment. Beside the aesthetic and beauty, trees can provide shade for exterior surfaces of a building envelope and can modify the microclimate of its site. Using plants, creepers and grassy ground cover in a hot, dry climate is a simple and effective method that contributes to cool interior spaces and minimises the amount of heat gain. Unfortunately, prototype school buildings in Saudi Arabia, and in Riyadh in particular, lack the vegetation and landscape elements in surrounding area of the buildings and in courtyards. The surrounding area and courtyards of the prototype school buildings are paved with concrete tiles and are entirely exposed to direct sunrays. The surfaces of the materials used in the courtyards and outside the buildings absorb and reflect solar radiation during the day and release heat during the night. As a result, all the exterior walls and windows of the prototype school buildings receive most of the direct and reflected solar radiation. Placing trees and changing the ground surface in the surrounding area of a school building and in the courtyard can minimize solar radiation by a significant amount.

Deciduous trees are assumed to be placed in the surrounding area of the basecase. Due to the uncertainty of the amount of shade and evaporation rate that a tree can provide for a certain surface and area, shading masks of wall screen were used in the simulation processes. Apart from the window, all walls towards the courtyard and exterior environment were shaded. Windows were excluded because they already have shading elements and applying screen wall on windows seems not to be practical since the daylight is an important factor that cannot be neglected in educational buildings. In addition, ground cover of the area adjacent to the building envelope was replaced with grass. Grass reflects only about 0.20 per cent of solar radiation into a building compared with concrete pavement in the basecase that reflects about 0.40 per cent.

In reality vegetation as a design strategy is more efficient than wall screen shading devices, because trees can reduce the surrounded air temperatures by shading the ground and by evaporative cooling. Air temperatures can be significantly decreased by the evaporative process of the moisture that plants produce especially in a hot, dry climate. However, the results of the simulation, will give an estimation of the performance of shading the building and the courtyard's surfaces.

5.4 Night Ventilation (Nocturnal Cooling)

Heat is normally absorbed and stored during the day by building structure elements and it is released back into spaces in the second half of the day. Warm air would build up by heat gain from interior surfaces during the night and hence increases air temperatures the next day. As a result, night ventilation is needed to flush the heat out. Normally, there is a large swing in air temperature between day and night in the climate of Riyadh. During the night, commonly, the air temperatures drops dramatically by 10 to 22° C. Night ventilation in this case can utilize the fluctuation in air temperatures to cool the school building envelope and bring fresh air into building spaces.

It was noticeable that the minimum air temperatures inside the case studies of the prototype school buildings were higher than the exterior environment. This was due to structural materials, window size and the absence of night ventilation. The prototype school building has very large glazed areas and has relatively high mass construction. Solar radiation in this case is absorbed by walls, floor and roof during the day and was released back in a form of heat into spaces during night. If the windows were opened during the night and early hours of the morning, the construction of a prototype school building would be cooled and the heat would be eliminated. Night ventilation was used from 00:00 to 9:00 am during overheated periods of the year.

5.5 Thermal Mass

A high thermal mass structure has the ability to absorb and store heat during the day and save it for night. Thermal mass materials can also reduce the fluctuations in indoor air temperatures. The capability of the thermal mass materials, therefore, will cope with the local climate in Riyadh in all seasons. In winter, for example, thermal mass envelope absorbs heat by direct solar radiation during the day and uses the heat to warm up the interior spaces during the night. In summer seasons, thermal mass is also a useful strategy to protect the envelope from the harsh environment in Riyadh. However, it should be shaded during the day and cooled at night.

The envelope of the existing prototype school building was upgraded to a high mass building. The existing materials were not changed because there was no significant difference in thermal performance between the materials used in the existing basecase building and other high mass materials. However, the thickness of the materials did show difference. The thickness of exterior walls was increased from 0.20m to 0.30m and the thickness of the slap was increase from 0.30m to 0.40.m.

5.6 Thermal Mass Combined With Night Ventilation

The same material and thickness of the thermal mass structure were used in this simulation test. However, night ventilation was added into the input files from 00:00 to 9:00 am every day in the selected spaces during summer months.

5.7 Double Glazed Windows

Double-glazing can reduce the U-value of glazed areas of a building. Low U-value of transparent elements can reduce the heat gain and loss by conduction and radiation through glass (Building Research Establishment, 1993). All the single-glazed windows in the basecase of the prototype school building were replaced with double-glaze with 0.12m spacing between the two-glassed layers.

5.8 Thermal Insulation

Installing thermal insulation in new buildings in Saudi Arabia, including school buildings, became compulsory due to the high levels of energy consumption through the built environment. Thermal insulation can significantly increase the thermal resistance of a building envelope and hence buffer the interior spaces from the outside environment. Unfortunately, thermal insulation was not used in the prototype school buildings that were built in 1970-1980 due to the absence of building regulations at that time.

Polystyrene insulation material with 0.05m and 0.10m thicknesses were applied in walls and roof respectively. Polystyrene was chosen because it has been successfully used in Saudi Arabia, being reasonably priced and having good thermal resistance (Mechanical Engineer Department, 2003). In addition it has been used by the Ministry of Education in new school buildings.

5.9 Thermal Insulation Combined With Night Ventilation

The same insulation materials and thickness coupled with night ventilation in between 00:00 am to 9:00 am were used in this test.

5.10 Surface Reflectance

Solar radiation can be transformed in three different ways. It can be absorbed, transmitted and/or reflected (Watson and Labs, 1983). Reflectance is the ratio of light reflected by a surface from the amount of incoming radiation depending upon the angle of incidence and material (Chalfoun, 1999). The effectiveness level of reflectance factor as a function of colour of exterior surfaces on interior conditions of the prototype school building was investigated in this paper. Materials with dark colour absorb a large quantity of solar radiation and hence increase indoor air temperatures. In addition, polished plane surfaces reflect solar radiation less than rough surfaces. As a result, light or white paint colours with rough finishing should be used in exterior surfaces, especially in Riyadh, which is characterized by a hot, dry climate. Fortunately, the exterior surfaces of the case study were painted with light, grey, beige or green colours. However, white colour can, theoretically, reflect more radiation than those colours mentioned above. This subsection of the simulation will test this assumption.

During the modeling of the school building by ECOTECT, the exterior finishing colours of walls and roof of the geometry model were chosen to match the colours of the existing case studies. It was found that walls and roof have absorption factor of about 0.20 and 0.17 per cent respectively. The percentage of the exterior surfaces absorption factors mentioned above were decreased to 0.10 per cent, representing white finishing colour. It was also increased to 0.80 per cent representing dark colour that can reflect only twenty percent of the solar radiation.

5.11 Combined Case

All the selected passive solar and energy conservation design strategies, mentioned above, were combined in one case. The main purpose of the combination is to asses the improvements that design strategies can make in the thermal performance, cooling and heating loads if they are integrated and applied together to the basecase.

The combination case consists of window shading, roof shading, landscape, night ventilation, thermal mass, double glazed windows, white finishing colour and thermal insulation. However, some of these strategies were not used during winter, such as night ventilation and shading by vegetation. Infiltration, as an effective passive solar design strategy was investigated separately through the combined case. Figures 4-8 show comparison in indoor air temperature of the selected spaces between the basecase and the combined case.

Cooling and Heating Loads

The following charts show a comparison in cooling and heating loads of the selected spaces between the basecase and the combined case of the prototype school building (Figs. 9 and 10).

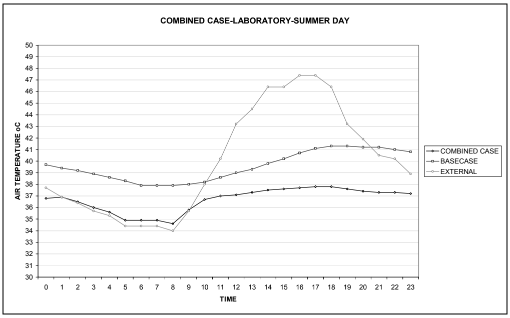

Figure 4: Thermal performance of combined design strategies in the laboratory (summer day).

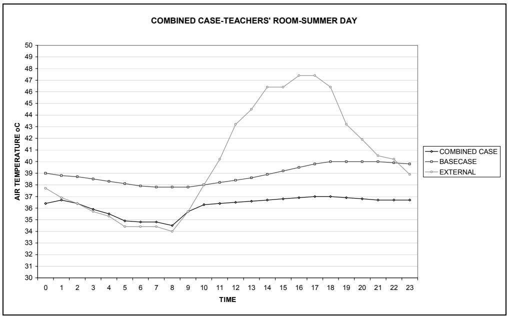

Figure 5: Thermal performance of combined design strategies in the teachers' room (summer day).

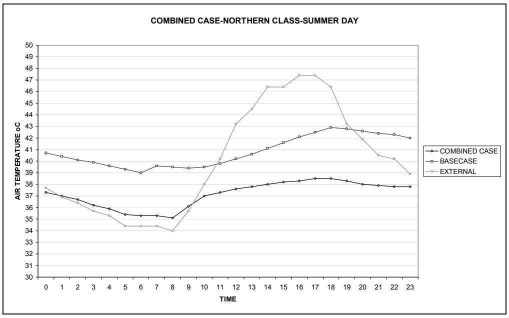

Figure 6: Thermal performance of combined design strategies in the northern classroom (summer day).

5.12 *Infiltration (Air Sealing)*

Infiltration is the uncontrolled means of ventilation and is measured in units of air changes per hour (ACH). Infiltration is a major factor that directly influences indoor conditions of a building. In hot dry climates, infiltration should be minimized to protect the interior spaces from the harsh outside environment. Due to the absence of annual maintenance of school buildings envelope, infiltration accounts as a major cause

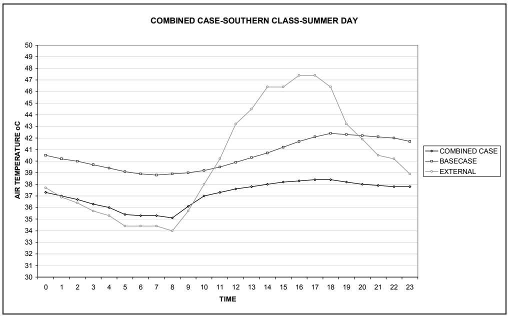

Figure 7: Thermal performance of combined design strategies in the southern classroom (summer day).

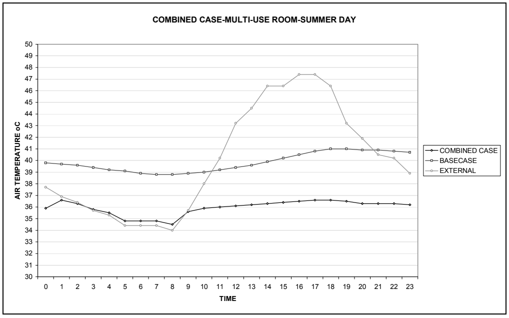

Figure 8: Thermal performance of combined design strategies in the multi-use room (summer day).

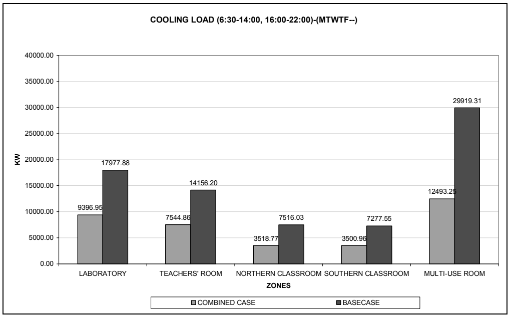

Figure 9: Comparison in cooling load between the base-case and the modified case.

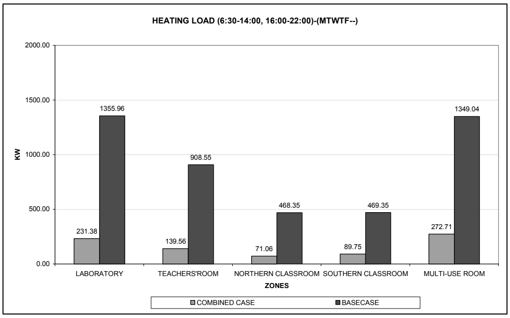

Figure 10: Comparison in heating load between the base-case and the modified case.

of the high heat gain and loss in the prototype school buildings in Riyadh. The findings of the experiments that were done by the author in the case studies of the prototype school building state that an average of infiltration in classrooms was 3.00 Air Change per Hour. The thermal performance of the basecase with 3 (ACH) was compared with the combined case that is assumed to be an airtight building with 0.5 (ACH).

Cooling and Heating Loads with Infiltration

Minimizing air infiltration can also save energy that is used to cool school buildings. The following charts demonstrate a comparison in cooling and heating loads in between the basecase and the combined case (Figs. 11 and 12).

5.13 Occupancy Pattern

Density of occupation also has a significant effect on indoor environment, especially in educational buildings. Occupants are a major source of internal heat gain in school buildings. They can significantly increase the indoor air temperatures and indoor pollutant, especially if there is no adequate ventilation. People produce carbon dioxide naturally by breathing as a result of natural human metabolic processes. Due to the shortage in quantity of school buildings and the high number of enrolment rate of students, classrooms in the existing prototype school building are densely occupied. The average number of students in each classroom is about forty. They are a major source of interior heat gain and have a direct effect on the indoor condition and the cooling loads.

Forty occupants were added to the selected spaces of the basecase and the combined case (Fig. 13). The hourly rate of heat production by students in a typical school environment varies with activity between 70 watts and 100 watts. In the simulation test 70 watts were used as a minimum heat that a student produces into a space. The second phase of this investigation is to reduce the number of the occupants in the combined case from 40 to 30 people (Fig. 14).

6. DISCUSSION

The simulation results of the investigation show significant improvements in the thermal performance of the modified case. The design

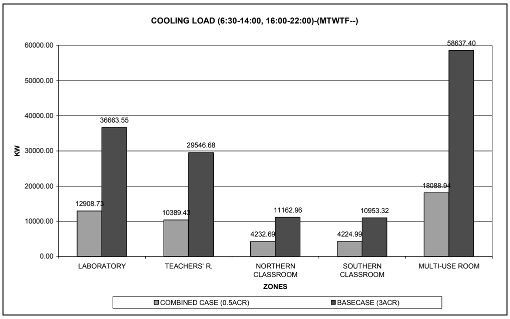

Figure 11: Comparison in cooling load between the basecase and the modified case (with infiltration).

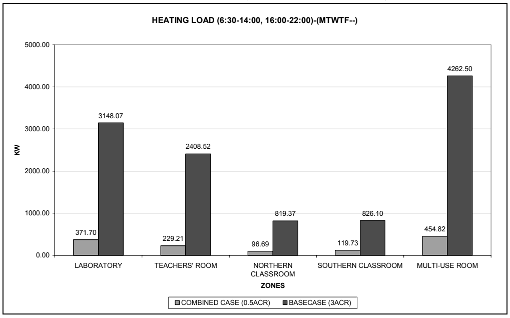

Figure 12: Comparison in heating load between the basecase and the modified case (with infiltration).

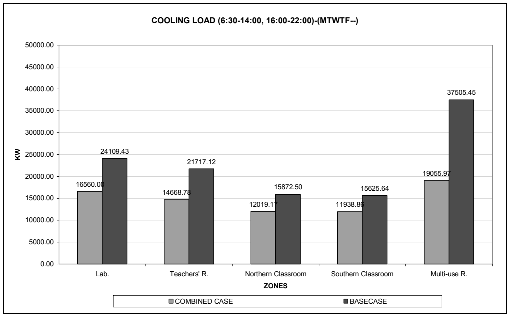

Figure 13: Cooling loads of the bascase and combined case with occupants (40 people).

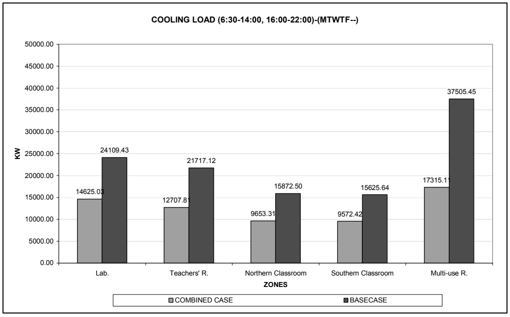

Figure 14: Cooling loads of the basecase and combined case with occupants (30 people).

strategies were also able to save significant amounts of heating and cooling loads of the basecase building. It was found that maximum air temperatures of the northern and southern classrooms were reduced by 4.4ºC and 4ºC respectively. The average maximum and minimum air temperatures of the basecase were also reduced by 3.9ºC and 3.7ºC respectfully while the average air temperature was also reduced by 3.3ºC during summer. The selected passive solar and energy conservation design strategies were also significantly effective during wintertime. It was found that the average maximum and minimum air temperatures were increased by 3.6ºC and 6.1ºC in the combined case. In addition, the design modifications significantly reduce the average cooling and heating loads of the basecase building by 52.5 per cent and 82.3 per cent respectively.

Based on the previous investigation, passive and energy conservation design strategies vary in their effectiveness. It was found that thermal insulation with night ventilation, high thermal mass with night ventilation, and wall shading coupled with grassy ground cover are the most effective design strategies in summertime. It was also found that thermal insulation and thermal mass structure were very effective design strategies during wintertime. In addition, minimizing the infiltration rate has a significant effect on the interior condition during both summer and winter. There were noticeable improvements in the thermal performance, cooling and heating loads of the basecase when the air infiltration was reduced from 3 ACH in the basecase to 0.5 ACH in the combined case. The average maximum and minimum air temperature was reduced by 4.6ºC and 1.8ºC respectively during summer and they were increased by 1.5ºC and 7.3ºC respectively during the winter day. Furthermore, the cooling and heating loads of the basecase were reduced by 66 per cent and 88.9 per cent respectively in the combined case of the prototype school building.

Occupants also impact on the cooling load of a school building. People are a major source of internal heat gain and they reduce the effectiveness of other design strategies that modify a school buildings envelope. Reducing the occupants' density in a classroom will have a significant influence on indoor conditions. For example, the reduction in the cooling load of the basecase was increased from 35.3 per cent to 44.4 per cent by decreasing the number of occupants in the combined case from forty to thirty.

The main findings of the modelling experiments of the design strategies are as follows:

1. It was clear that the existing shading devices of the prototype school building are not appropriate for the local climate of Riyadh. It was found that a combination of over-hang and side-fins was significantly able to improve the thermal performance of indoor spaces especially those which are facing north, east and west. The average indoor air temperatures of the selected spaces were reduced by 0.4ºC during summertime, by 0.7ºC during spring/autumn. Yet, shading devices in the multi-use room, that is facing west, reduced the indoor air temperatures by 1.8ºC. This emphasizes the insufficiency of placing large glazed areas on the west façade because it is not an easy task to protect them during summer and winter at the same time, unless movable exterior shading devices are used. It was found also that the existing overhang on the south façade of the case study can perform well and there is no need to replace it with a new shading device. Moreover, it is highly recommended to place a number of vertical fins in each window of the east and west facades. To maximise the potential of the vertical fins they should be orientated to the south-east in the east windows and oriented to the north-west in the west windows. By placing and orienting them in the way mentioned above they will be able to block the solar radiation during early morning and the late afternoon in summer, spring and autumn. However, movable shading devices, especially vertical fins, will give better performance since the heat may be pleasant during some days in the spring and/or autumn.
2. The roof is a major source of heat gain in buildings located in hot, arid regions. An additional lightweight layer of the roof helped to minimize the solar radiation received by the roof. However, the reduction in air temperature achieved by shading the roof was varied among spaces. The effectiveness of this design strategy is mainly based on the area of the roof and the orientation of the space. Regarding orientation factor, it was

found that shading the roof of spaces that are facing south, such as southern classroom and teachers' room was not significant because south aspects receive most of the solar radiation through the walls. On the other hand, there was significant reduction in indoor air temperatures in spaces facing north, east and west. Regarding the influence of roof area, it was found that the highest reduction in indoor air temperatures was found in the multi-use room because it has a large roof area and is oriented to the west. The maximum air temperatures in the multi-use room and the northern classroom were reduced by 0.8ºC and 0.5 respectively. Space in between the two roof layers should be naturally ventilated to eliminate heat.

3. It was found that landscape combined with grass ground cover can remarkably improve the indoor condition. The simplest method to minimize both direct and reflected solar radiation that fall on a building envelope is to place vegetation such as deciduous trees which have the ability to keep their leaves during summer when shade is required and lose them during winter when solar radiation is needed. Grass should also be used as ground cover around a school building to reduce the reflected solar radiation onto walls and windows.
4. Desert climate is characterized by large variations in air temperatures between day and night. Night ventilation (nocturnal Cooling) as a design strategy shows good improvement of the indoor air temperatures. The results of the modelling experiments ensure the importance of night ventilation to improve the thermal performance of the case studies during over heated periods of the year, especially if it was combined with thermal mass structure and thermal insulation.
5. Thermal insulation and high thermal mass show significant improvement and they were able to improve the thermal performance of the case study. Exterior walls should be constructed with at least 0.30 m concrete block to increase the heat capacity of the building envelope. Thermal insulation should also be installed close to the outer surface of walls and roof to reduce the transformation of heat before it reached the inner surface. Simulation results made it evident that Polystyrene with 0.05 m and 0.10 m thicknesses are recommended for walls and roof respectively. The combination of high heat capacity material that has the ability to store heat and low heat conductivity material that has the ability to resist or to insulate against heat flow would promote the thermal performance of a school building. However, thermal insulation and high mass structure cannot be effective if they were used as separate design strategies. In airtight buildings with large glazed areas, thermal insulation and thermal mass structure alone can increase the indoor air temperatures during overheated periods of the year. Thermal insulation and high mass materials will store heat that has penetrated into indoor spaces through glazed areas and been absorbed by the indoor surfaces. During the overheated period of the year when the exterior condition is cooler than interior spaces during the night, the heat will be released into the indoor spaces and increase its air temperature. As a result, night ventilation should be involved with thermal insulation and high mass design strategies to eliminate the heat inside spaces during night in summertime.
6. Double glazed windows were not as effective as other design strategies that were applied on the basecase. Double glazed windows would probably be more effective if the indoor spaces were air conditioned. However, this assumption needs to be investigated in further work.
7. Colour of the exterior surfaces has a significant influence on the amount of heat gain through a building envelope. White or light coloured surfaces absorb less solar radiation than those painted with dark colours. Even though the existing finishing colours of a prototype school building are light green and beige, the thermal performance of the basecase was improved with white finishing colouring. The simulation results of the case study show significant reduction in indoor air temperature by replacing the exterior surface absorption factor from 0.20 to 0.10 per cent and there was a remarkable rise in indoor air temperatures by increasing the absorption factor to 0.80 per cent, which represents the dark colours.

The charts in Figs. 15-22 summarize the results of the modelling experiments.

7. CONCLUSION

This paper has described the investigation of the thermal performance of a number of passive solar and energy design strategies in the case study of a prototype school building in the hot, dry climate of Riyadh. The main aim of this paper is to emphasize the significance of the environmental and energy conservation design strategies in energy conscious school buildings design. Several passive solar and energy conservation design strategies were selected to improve the thermal performance of the case study. HTB2 modelling program was used to do the modelling experiments of each design strategy and the modified prototype school building that combined all the selected design strategies. The obtained results show that the combined case, that adopted the selected passive solar and energy conservation design strategies, was able to significantly improve indoor conditions and reduce the cooling and heating loads of the basecase. The findings of this chapter are not only limited to the case study of the prototype school buildings. They can be applied to any school building design in Riyadh and/or other regions that have similar climatic conditions.

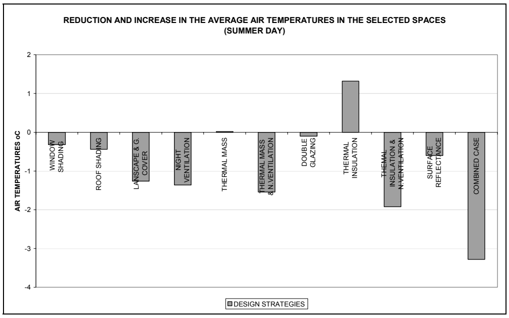

Figure 15: Variation in effectiveness levels of the design strategy to increase or decrease indoor air temperatures of the basecase during summertime.

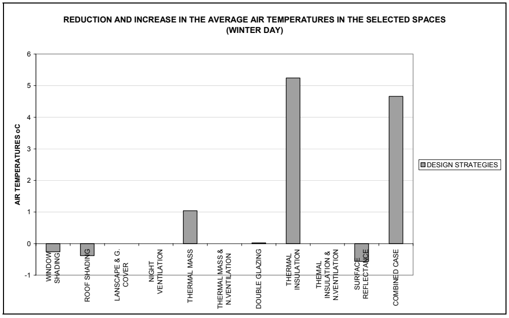

Figure 16: Variation in the effectiveness levels of the design strategy to increase or decrease indoor air temperatures of the basecase during wintertime.

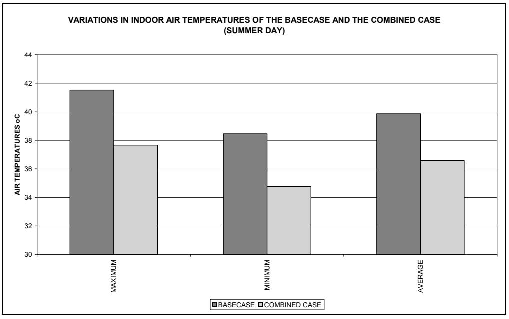

Figure 17: Comparison in the mean of the maximum, minimum and average indoor air temperatures between the basecase and the combined case during a summer day.

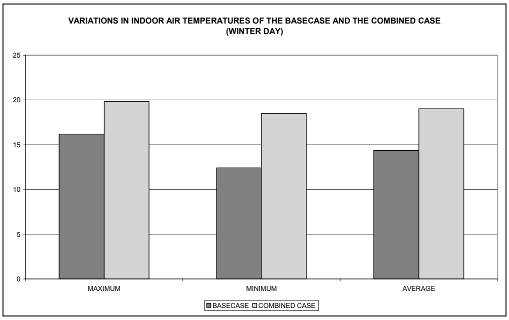

Figure 18: Comparison in the mean of the maximum, minimum and average indoor air temperatures between the basecase and the combined case during a winter day.

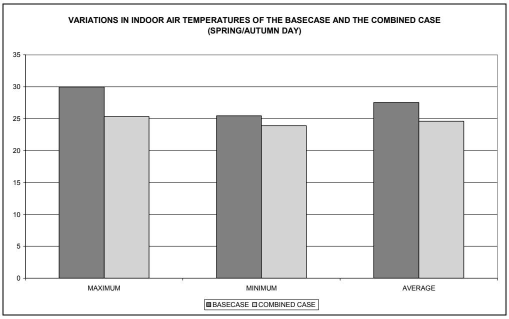

Figure 19: Comparison in the mean of the maximum, minimum and average indoor air temperatures between the basecase and the combined case during a spring/autumn day.

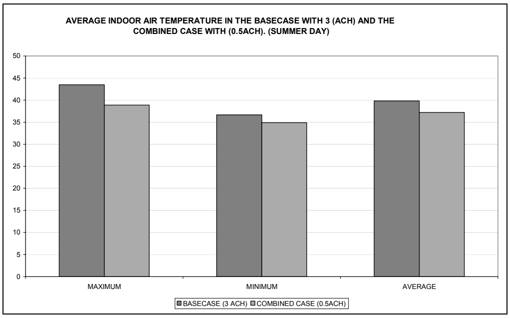

Figure 20: Comparison in the mean of the maximum, minimum and average indoor air temperatures between the basecase with 3 (ACH) and the combined case with 0.5 (ACH) during a summer day.

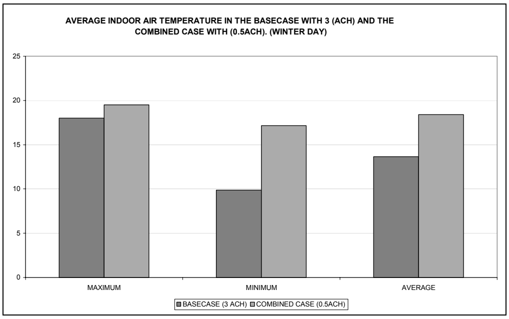

Figure 21: Comparison in the mean of the maximum, minimum and average indoor air temperatures between the basecase with 3 (ACH) and the combined case with 0.5 (ACH) during a winter day.

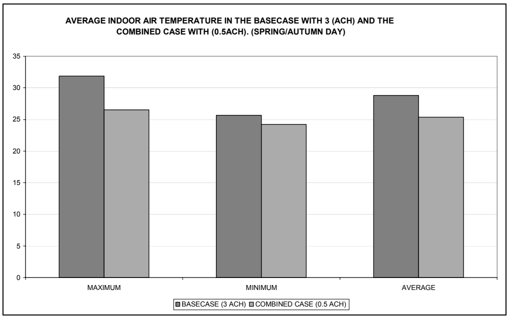

Figure 22: Comparison in the mean of maximum, minimum and average indoor air temperatures between the basecase with 3 (ACH) and the combined case with 0.5 (ACH) during a spring/autumn day.

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