Effect of Galleries on the Thermal Performance of Buildings in the Gaza Strip

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Abstract- This study examines the effect of galleries design in a symmetrical street canyons on the thermal performance of buildings located in the Mediterranean climate of the Gaza Strip. It was carried out using two computer simulation tools, namely ECOTECT and IDA ICE. The gallery design parameters and street orientation were investigated to find out the extent to which they affect the external and internal thermal comfort. The study concluded that the thermal stress can affectively be mitigated if galleries are appropriately configured with relation to the solar orientation. The galleries on (E-W) oriented street are more protected from the sun than that on (N-S) oriented streets. About 39.4% of reduction in the incident solar radiation falling on (E-W) street occurs with increasing the gallery width to street width ratio (w/W) from 0.2 to 1.4. And about 22.8% of reduction occurs with increasing the gallery height to building height ratio (h/H) from 0.2 to 0.9. On the other hand, higher galleries effectively reduce the total requirement in the covered spaces, especially the upper floors. Therefore, more attention must be paid to the gallery dimensions in order to reduce energy consumption of buildings.

Index Terms— Galleries - Thermal performance – Energy – Orientation.

I INTRODUCTION

The street shape influences both indoor and outdoor environments, as the street consists of “shared” active facets between the building envelope and the open spaces. Thus, the street design is an important issue in the global approach for a passive urban design [1]. Different studies have dealt with the aspects of an urban street design. The use of galleries at street level as a shading device is usual and already known in ancient times [2]. Gallery is an element of bioclimatic architecture; it is an intermediate space or passage located on the ground floor (and/ or higher floors) in the southern façade. A glazed gallery in most old buildings enables the energy obtained to be used in cold seasons to support the building’s air conditioning system, and thus minimize energy consumption [3]. The effects of galleries on thermal comfort in urban street canyons are investigated by Toudert & Mayer (2007) [4] by means of numerical modeling by using the three-dimensional microclimate model ENVI-met 3.0. The results revealed that galleries have a strong effect on the heat gained by a human body and hence on the resulting thermal sensation. Consequently, a sensitive decrease of the area of thermal discomfort is achieved. Wang et al. (2014) [5] studied the thermal performance of a gallery in the hygrothermal environment using both measured and modelling data. The results for the simulations of the BMS system and purposely fitted monitoring instruments showed that the use of galleries can contribute effectively to reduce energy consumption. Generally, the thermal situation in the area of the galleries depends on the orientation of the street canyon along with the dimensions of the gallery i.e. height and width [6]. Thomas (2003) studied street galleries as an environmental approach to achieve sustainable urban design [7]. The study showed that strategies of asymmetrical street shape, together with using galleries and vegetation have an effective impact on outdoor comfort. Covered streets are common in a hot-dry climate in order to provide self-shading façades and protect pedestrian from undesirable solar radiation[8].

According to the previous studies and others, it is clear that the configurations of street galleries affect outdoor thermal comfort. However, the studies do not sufficiently pay attention to the impact of galleries and its orientation on the indoor thermal conditions, which may be part of the solutions to the problem of excessive energy consumption. Therefore, this study is an attempt to propose suggestions for improving the buildings environmental design and to find out the extent to which the solar and thermal performances of buildings are affected by the use of galleries. The study aims to find out the optimum street configurations with relation to galleries that ensure minimum use of energy to provide thermal comfort in buildings in the Mediterranean climate of Gaza.

Although there are many climatic factors that affect the thermal performance of buildings, this study focuses particularly on solar radiation. Other climatic factors, such as ventilation and humidity may be covered by other researches.

II STUDY TOOLS AND ASSUMPTIONS

A Simulation Tools

Two simulation tools, namely ECOTECT and IDA were used to carry out the investigations. The following are brief descriptions of the two computer programs:

ECOTECT is a software package with a unique approach for conceptual building design coupling an intuitive 3D design interface with a comprehensive set of environmental performance analysis functions and interactive information displays. ECOTECT provides its own fast and intuitive modelling interface for generating even the most complex building geometry [9]. ECOTECT visualize incident solar radiation on windows and surfaces over any period. Its displays the sun's position and path relative to the model at any date [10].

International Development Association - Indoor Climate and Energy program (**IDA ICE**) is a whole year detailed and dynamic multi-zone simulation application for the study of indoor climate of individual zones within a building as well as energy consumption of an entire building [11]. **IDA ICE** is an extension of the general IDA Simulation Environment. Weather data is supplied by weather data files, or is artificially created by a model for a given 24-hour period. Consideration of wind and temperature driven airflow can be taken by a bulk air flow model [12].

B Study Assumptions

Simulations were carried out during the summer and winter months. HVAC system was assumed to be fully air conditioned, lower band is 18.0° C and upper band is 26.0° C. The internal heat gain from occupancy, appliances and the ventilation heat gain were considered constant in the simulation, as the study concerns the incident solar radiation on the facades which overlooks the street and on the street ground. External walls have U-values of 2.25 W/m²*K in ECOTECT and 2.24 W/m²*K in IDA ICE. The roof U-values are 2.35 W/m²*K in ECOTECT and 2.35 W/m²*K in IDA ICE. Glazing U-values are 6 W/m²*K in ECOTECT and 5.8 W/m²*K in IDA ICE. These values were assumed to achieve the requirements of the U-values as recommended by the Palestinian code for energy efficient building [13].

C Location and Climate of the Gaza Strip

The Gaza Strip is a narrow strip of land in the west-southern part of Palestine extending along the Eastern Mediterranean beach [14]. It has a total area of about 365 km^2 [15]. It is located on Longitude 34° 26' east and Latitude 31° 10' north [16]. According to the Koppen system for climatic zoning, winter in the Gaza Strip area is rainy and mild while summer is hot and dry. The average daily mean temperature ranges from 25C◦ in summer to 13C◦ in winter [17]. The area of the Gaza strip includes generally two climatic zones. The first is located in the western part along the cost of the Mediterranean sea, which has semihumid Mediterranean climatic conditions. The main cities, which include about 97% of the inhabitants in the Gaza strip are located in this zone. The second zone is the semiarid loess plains located to the east of the Gaza strip, and considered an extension of Negev desert.

According to the application of Olgyay's bioclimatic chart for Gaza climatic conditions, , it is indicated that during summer months (June to September) ventilation is most recommend to minimize the adverse effect of humid and hot air and consequently achieve comfort. In winter, (December to March) solar radiation is advantageous to achieve comfort and minimse heating loads. In the rest of the year (April, May, October and November) the climatic conditions are within the comfort zone [16].

III THE FIRST CASE:

Effect of galleries design on the Incident Solar Radiation

A The Study Parameters

An urban canyon of H/W = 2, which was considered as an average profile between shallow and deep streets, with different gallery depths and heights were simulated, see figure 1. A segment of the street that consists of six buildings

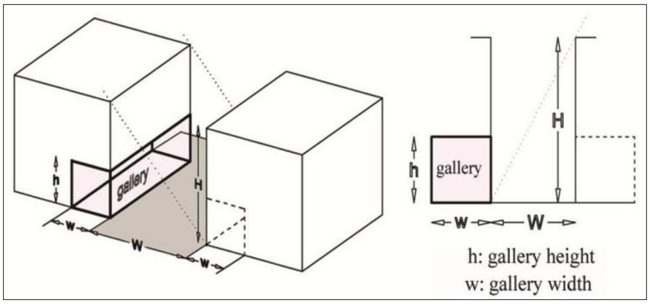


Figure 1 The gallery parameter.

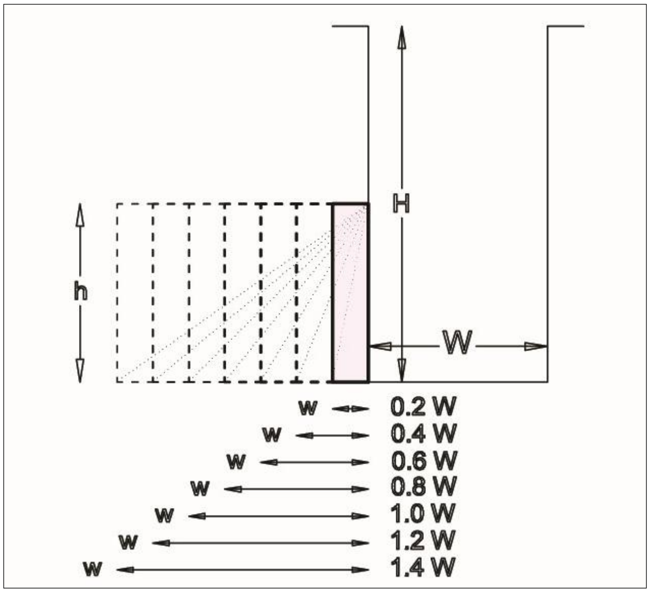


Figure 2 Gallery width to street width ratio simulated in the study

(three in each side) with a constant height of (20m) separated by the street width was considered as a representative of the whole street length. The setback distance between the adjacent buildings is taken to be 4m. The investigated gallery width to street width ratio (w/W) are 0.2, 0.4, 0.6, 0.8, 1.0, 1.2 and 1.4, see figure 2. In addition, a gallery canyon of (w/W) = 1.0 was simulated, taking into consideration a variable gallery heights. The investigated gallery height to building height ratio (h/H) are 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8 and 0.9, see figure 3. They were simulated at East – West and North – South orientations, see figure 4. The simulation results were expressed in terms of incident solar radiation on the facades of buildings overlooking the street and on the street ground (in KWh/m^2).

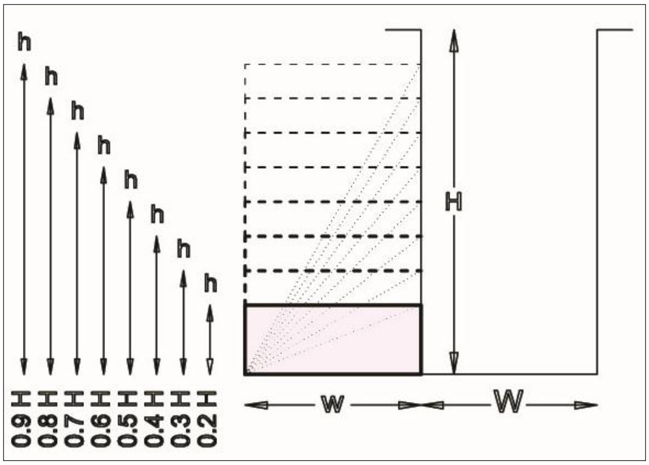
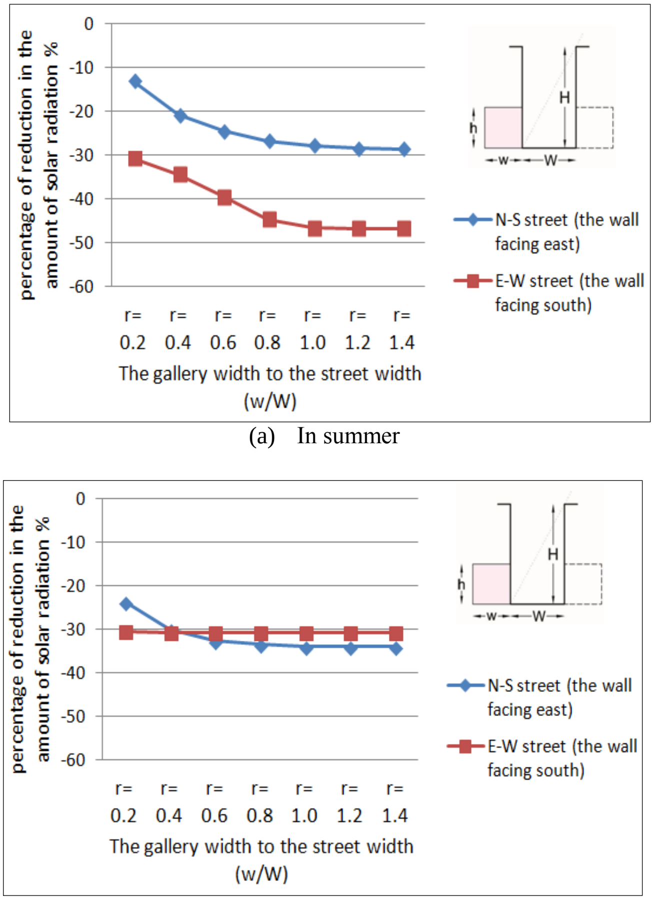


Figure 3 Gallery height to building height ratio considered in the study



(a) In summer

(b) In winter

Figure 4 Incident solar radiation on façades overlooking (N-S) and (E-W) street as a result of varying the galleries width by ECOTECT

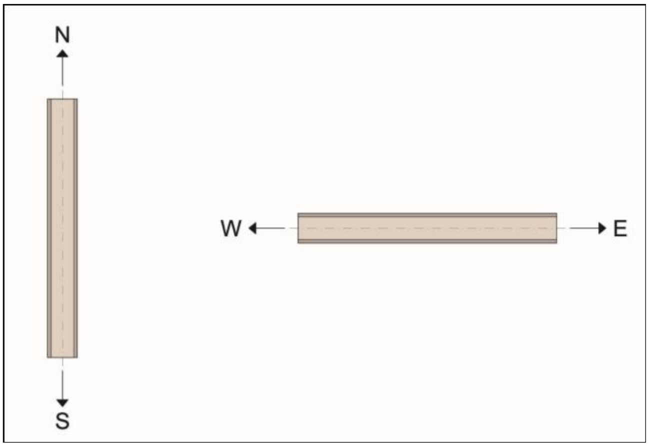
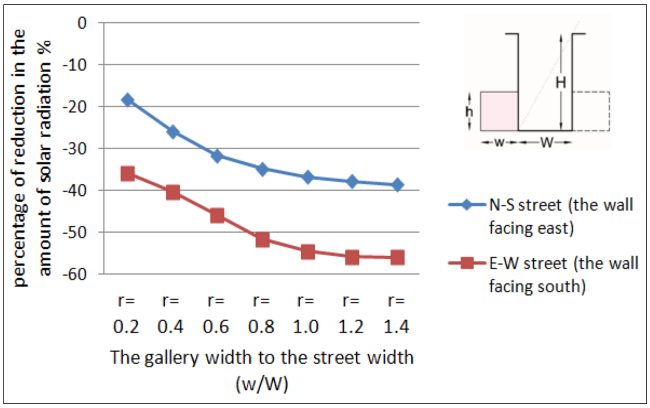


Figure 6 The two main street orientations considered in the study

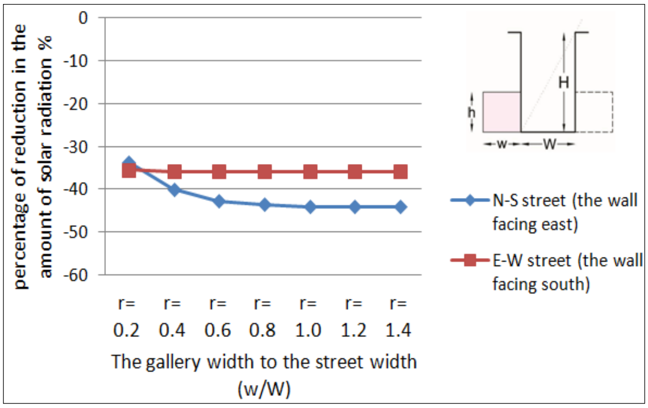
B Results

The first case study is concerned with the impact of galleries width on the solar radiation received on the facade of the central building, during the summer and winter months. Figure 5 presents percentages of reduction in incident solar radiation on the wall facing east in (N-S) street and the wall facing south in (E-W) street. The results indicate that the incident solar radiation decreases with increasing the gallery width to the street width ratio (w/W). The shallowest gallery with (w/W=0.2) receives the largest amount of solar radiation, whereas, the least amount is received in the deepest gallery with (w/W=1.4). Increasing the galleries width from 0.2W to 1.4W in the summer months can decrease the incident solar radiation on the wall facing east, which overlooks the north-south oriented street axis in ECOTECT by about 13.1%, 20.83%, 24.57%, 26.75%, 27.8%, 28.5% and 28.6%, whereas the percentages of decrease equal about 23.6%, 30.0%, 32.7%, 33.48%, 34.04%, 34.04% and 34.04% in the winter months at the correspondent width ratios respectively. This indicates that the deepest gallery with (w/W=1.4) is the most advisable in summer, since it is the most protected from undesirable solar radiation. In winter, the opposite is true, as the shallowest gallery with (w/W=0.2) would be the most recommended to receive maximum solar radiation when it is welcome. So, it is recommended to pay more attention to the ratio of gallery width to the street width to be closer to the intermediate ratio to attract a large amount of solar radiation in the winter and less amount of radiation in the summer.

The same trend can be observed in the results of IDA ICE program for the same cases, although there are slight differences in the quantitative amounts of solar radiation, figure 6. About 18.15%, 25.83%, 31.57%, 34.75%, 36.85, 37.91% and 38.6% of decreasing in the solar radiation for the same ratios in the summer months, whereas about 33.88%, 40.25%, 42.42%, 43.48%, 44.04%, 44.05% and 44.05% in the winter months, see figures 6. The discrepancy in the results of ECOTECT and IDA ICE can be referred to the different calculation algorithms and slight variations in the specifications of building materials. Overall, the general agreement between the results of the two programs indicates a high reliability and confirms the validity of the simulation outcomes.



(a) In summer

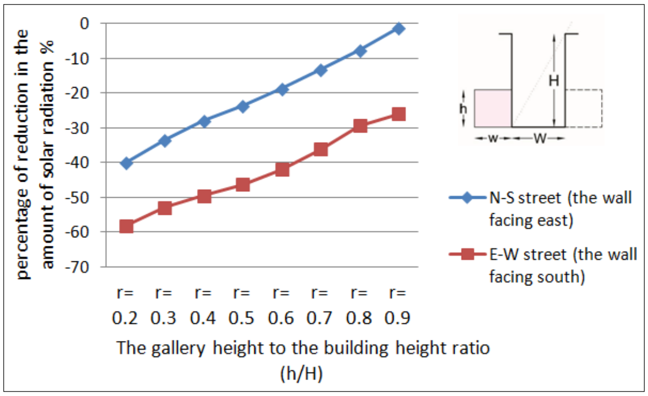


(b) In winter

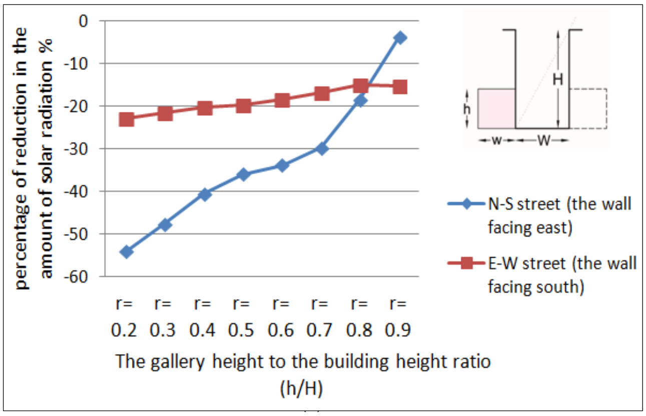
Figure 6 Incident solar radiation on façades overlooking (N-S) and (E-W) streets as a result of varying the galleries width by IDA ICE

With respect to the street orientation, figure 5, reveals that changing the street orientation from N-S (90°) to E-W (0°) in the summer months results in an average decrease in the solar radiation received on the buildings façades by about 30.78%, 34.37%, 39.55%, 44.73%, 46.64%, 46.74% and 46.74% at the correspondent width ratios respectively. However, an average decrease in the solar radiation of IDA ICE results are 35.78%, 40.37%, 45.95%, 51.73%, 54.64, 55.94 and 56.64% respectively, see figures 6. This means that the building façades with galleries overlooking (E-W) streets orientation are more shaded than that overlooking N–S street. In contrast, the effect of galleries in the east-west oriented street axis in the winter period is not remarkable. This is attributable to the low altitude position of the sun in the winter periods and the lack of solar radiation intensity. Hence, E-W streets are warmer than N-S streets especially in winter. Accordingly, E-W orientation of streets seems to be the most desirable for both summer and winter months.

Figure 7, shows the impact of galleries height on the solar radiation received on the building façades. It is clear that the incident solar radiation increases with increasing the gallery height to the building height ratio (h/H) from 0.2 to 0.9, in both summer and winter. Increasing the galleries height from 0.2H to 0.9H in the summer month can decrease the incident solar radiation on the wall facing east, which overlooks the north-south oriented street axis by about 39.88%, 33.49%, 28.1%, 23.8%, 18.67%, 13.31%, 7.63% and 1.22%, whereas decrease the radiation on the façade in the winter months by about 54.26%, 47.78%, 40.6%, 36.04%, 33.98%, 29.78%, 18.54% and 3.84%. This indicates that, the amount of solar radiation falling on facades can be reduced effectively by using deeper and lower galleries. Hence, attention is drawn here on the relevance of galleries dimensions to the thermal comfort in buildings and within galleries.



(a) In Summer



(b) In winter

Figure 7 Incident solar radiation on façades overlooking (N-S) and (E-W) street as a result of varying the galleries height by ECOTECT

With regard to the impact of orientation along with the gallery height, figure 7, reveals that changing the street orientation from N-S (90°) to E-W (0°) in the summer months results in an average decrease in the solar radiation received on the buildings façades by about 58.22%, 52.99%, 49.61%, 46.44%, 42.08%, 36.17%, 29.49% and 25.99% at the correspondent width ratios respectively. In addition to decrease solar radiation in the winter months by about 22.82%, 21.61%, 20.41%, 19.83%, 18.57%, 16.78%, 15.03% and 15.19%.

Accordingly, galleries design in southern façade overlooking E-W oriented streets is more effective than the eastern or western façade overlooking streets with north-south orientation, since they allow an acceptable degree of protection from the undesirable solar radiation in summer, and in the same time, allow a reasonable amount of solar radiation to hit the buildings facades in winter.

It should be noted that the galleries design also affects the amount of incident solar radiation falling on the street ground. East-West street orientation with different gallery dimensions were simulated to assess their impact on the amount of radiation falling on the street ground in the summer months. Figure 8, shows that the incident solar radiation received on the street horizontal space decreases with the increasing the gallery width to street width ratio. The shallowest gallery with (w/W) = 0.2, achieves the highest amount of solar ration. In contrast, the deepest gallery, with (w/W=1.4), achieves the best thermal behavior due to its high degree of protection from the sun rays. On the other hand, The highest gallery with (h/H) = 0.9 , achieves the highest amount of solar ration, whereas the lowest gallery, with (h/H=0.2), achieves the best thermal behavior because of the short period of exposure to the sun, see figure 9. Thus, the thermal situation in streets with galleries is better than that in streets that are completely irradiated. Thus, galleries are considered a good way to protect pedestrian spaces.

It is worthy of note that, the dimension of the gallery in combination with the street orientation are decisive. This emphases the need to be configured properly to ensure optimum solar performance for buildings and outdoor spaces.

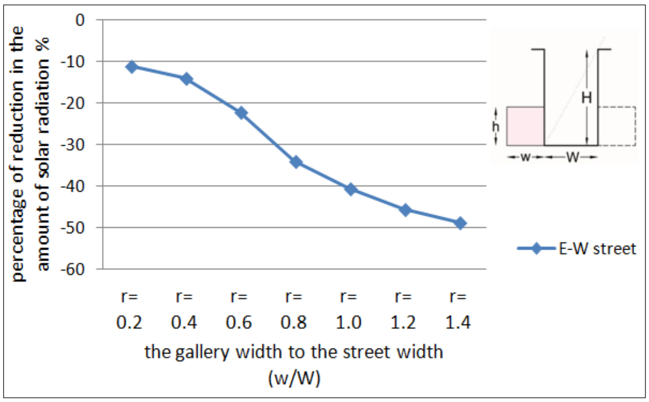


Figure 8 Incident solar radiation on (E-W) street as a result of varying the galleries width by ECOTECT

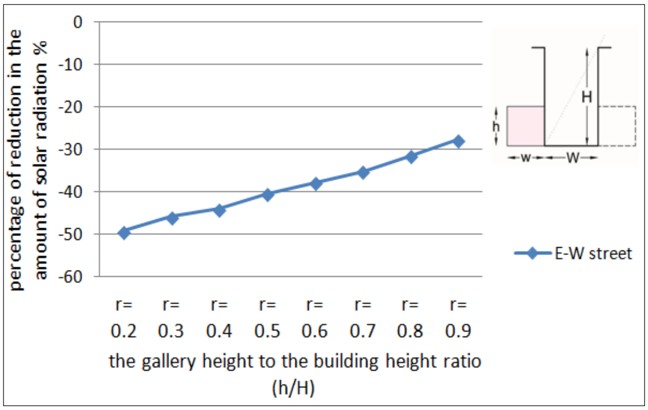


Figure 9 Incident solar radiation on (E-W) street as a result of varying the galleries height by ECOTECT

IV The Second Case:

Effect of Galleries design on the Thermal Performance of Buildings

A The Study Parameters

The thermal performance of the central building in the examined segment of the street was investigated taking into consideration various gallery depths and heights. The examined buildings were assumed to have 5 stories, in addition to the ground level, with a constant height of 20m. The percentage of windows to wall area was taken to be 10%, and the setbacks between adjacent buildings are 4m. These configurations represent the most common case of multi-story buildings in Gaza [18]. The investigated gallery widths are 0.5m, 1.0m, 1.5m and 2.0m, see figure 10.

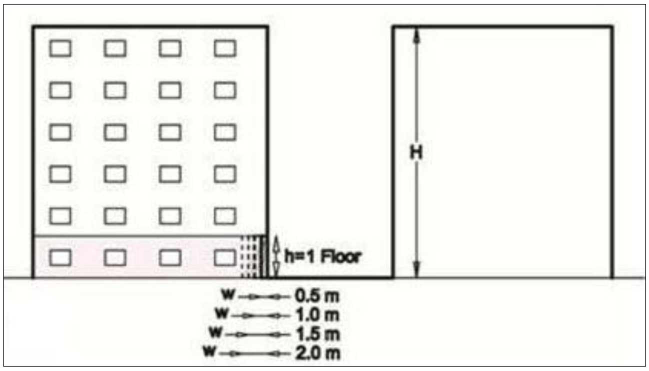


Figure 7 Gallery widths simulated in the study

In addition, a gallery width equals to 2.0m were simulated, taking into consideration a variable gallery heights. The investigated gallery heights are 1 floor (3.3m), 2 floors, 3 floors, 4 floors and 5 floors, see figure 11. The simulation results were expressed in terms of the heating and cooling energy (in KWH/m³) required to achieve comfort.

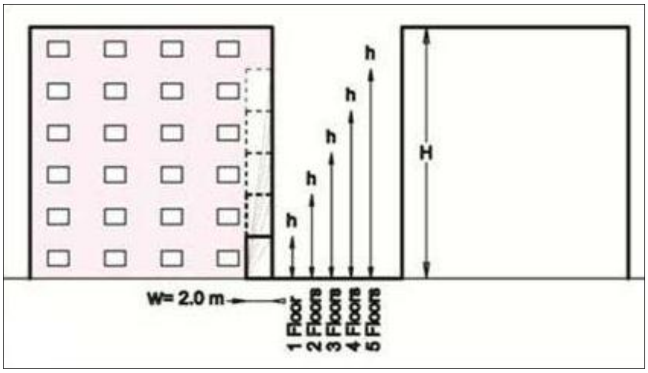


Figure 8 Gallery heights considered in the study

B Results

The first examined case is concerned with the impact of gallery width on the cooling and heating loads in the ground floor of the building facing west in (N-S) oriented street. Figure 12, shows that the cooling energy decreases as the gallery width increases, This is attributable to the effectiveness of horizontal shading of the deeper galleries. It is worthy of note that the minimum amount of cooling energy is required by ground floor at the deepest gallery (2.0m), and then decreases gradually with approaching the gallery width to 1m. Increasing the gallery width from 0.5m to 2.0m in the summer results in an decrease of 3.92% in the energy required to achieve comfort. In contrast, increasing the gallery width from 0.5m to 2.0m in winter, increases the heating energy by about 2.0%. So, the shallower the gallery is, the more desirable will be for reducing the heating energy required to achieve comfort in winter.

It should be noted that changing the orientation angle of N-S street to be along E-W axis results in a decrease of about 6.32% in the energy required by the ground floor. Accordingly, buildings with galleries overlooking E-W oriented streets is the most preferable throughout the year, since it requires the minimum amount of energy to provide thermal comfort.

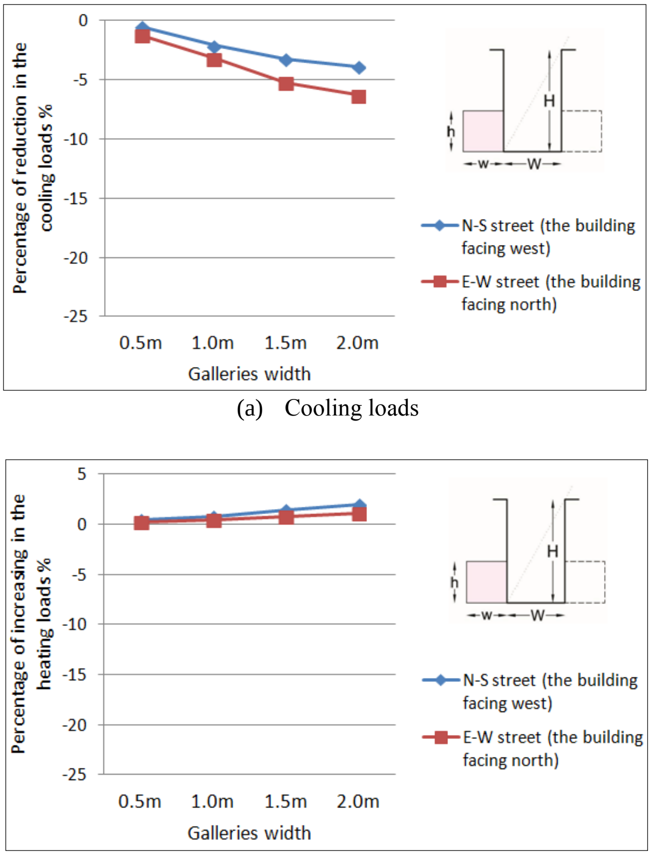


Figure 9 Required energy to achieve comfort in the building facing west in a (N-S) street and the building facing south in a (E-W) street as a result of varying the gallery width

Figure 13, shows the effect of a gallery width on the total heating and cooling energy required throughout the year. It is clear that the trend of the total energy is the same as that of the cooling energy, explained in figure 12(a). This is referred to the significant effect of the gallery's deepness on reducing the required energy to achieve the best thermal comfort. Hence, it is advisable to increase the width of gallery to achieve maximum area of shading, and consequently reduce the energy required to achieve thermal comfort.

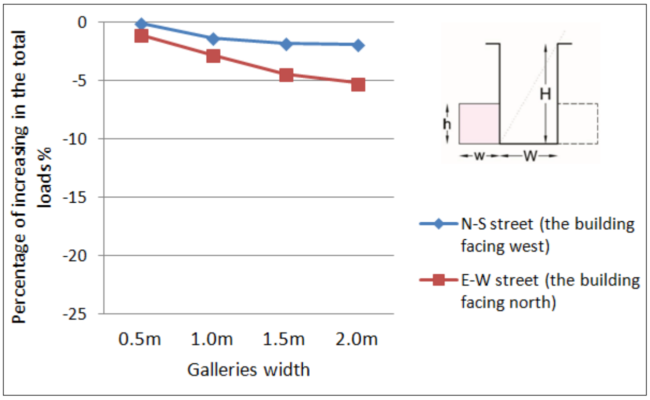
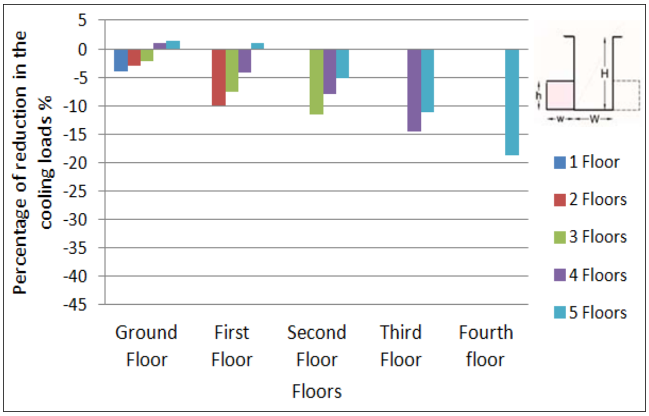


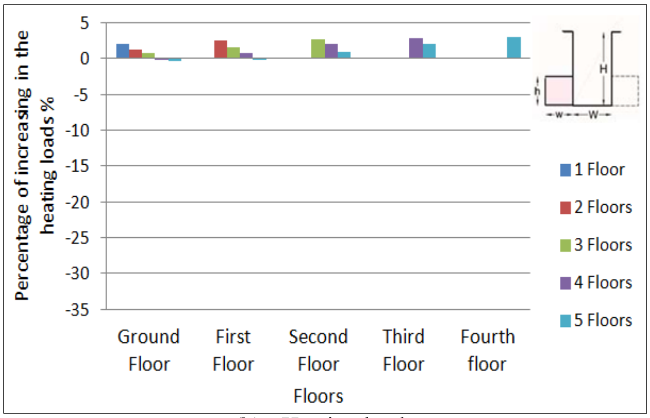
Figure 13 Total energy required to achieve comfort in the examined building as a result of varying the galleries width by IDA ICE.

The second examined case is concerned with the impact of the gallery height on the cooling and heating loads. The thermal performance of all floors, which includes the gallery in the examined building was analysed to find out the extent to which each floor will be affected by changing the gallery height. The results indicate that the reduction in the cooling loads in summer is noticeable in higher floors, which are located directly under the gallery, whereas the heating loads in winter is slightly increased, see figure 14.

However, the covered spaces also face periods of low stress. This is due to the exposure of the lower floors facades and the ground surface to direct solar beams as well as the outgoing heat from the ground in the case of the higher galleries. For more clarity, the gallery height equals to 4 and 5



(a) Cooling loads



(b) Heating loads

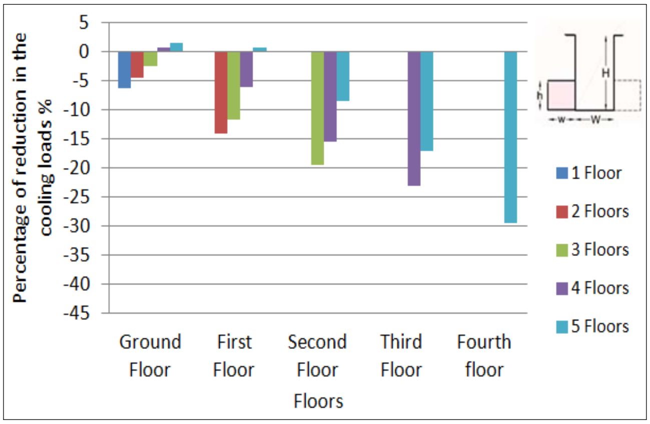
Figure 10 Required energy to achieve comfort in the building facing west in (N-S) street as a result of varying the galleries height by IDA ICE.

floors can increase the cooling loads by about 1.05% and 1.53% respectively in the ground floor.

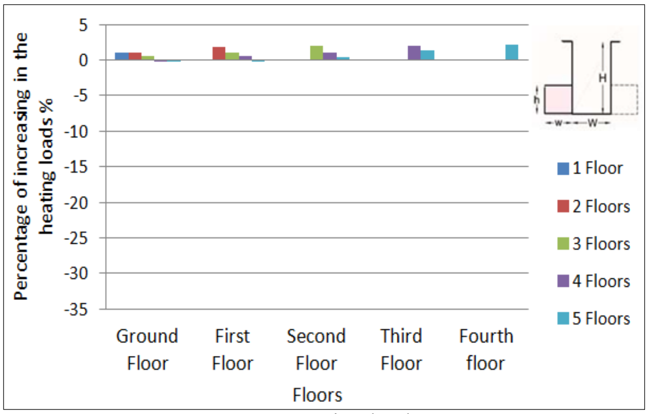
Therefore, the upper floors, which are exposed to intense solar radiation should be carefully provided with appropriate galleries to ensure minimum penetration of solar radiation, and consequently less energy requirement.

Figure 15, shows that changing the street orientation from N-S to E-W, decreases the required cooling load in the summer period by about 6.32% in the ground floor in the case of the gallery height equal to 1 floor, by about 14.08% in the first floor in the case of the gallery height equal to 2 floors, by about 19.24% in the second floor in the case of the gallery height equals to 3 floors, by about 23.48% in the third floor in the case of the gallery height equals to 4 floors and by about 29.57% in the fourth floor in the case of the gallery height equals to 5 floors.

It is also shown that the increase in heating loads in (E-W) street is less than the increase in (N-S) street, which confirms that the galleries on an (E-W) street are well protected and the extent of discomfort is very limited. So it is concluded that East- West oriented street axis with galleries effectively reduces the bad effect of undesirable radiation falling on the southern apartments and thus mitigate the thermal stress, especially in the summer at the same time keeps the desirable heat in the winter.



(a) Cooling loads



(b) Heating loads

Figure 15 Required energy to achieve comfort loads in the building facing north in (E-W) street as a result of varying the galleries height by IDA ICE.

V CONCLUSION

This study discussed the impact of gallery design on the incident solar radiation and thermal performance of buildings. The study emphasized that using galleries is useful for reducing thermal stress. This is due to the effectiveness of their horizontal shading which reduced undesirable intense solar radiation. It was concluded that deeper and lower galleries can play an important role in reducing the incident solar radiation, especially on the walls facing south which are the most important to shade. It was found that the deepest gallery with width ratios (w/W) =1.4 can reduce undesirable radiation falling on the façade by about 28.6% and 46.74 for N-S and E-W oriented streets respectively. Moreover about 22.8% of reduction occurs with increasing the gallery height to building height ratio (h/H) from 0.2 to 0.9.

It was found that orienting the gallery axis along E-W direction is advisable to ensure the short duration of exposure to the sun rays in summer and the long duration in winter. The deeper the gallery is, the less the energy will be required to achieve thermal comfort throughout the year. The optimum galleries width in the lower floors for both east-west and north-south oriented street is 2.0m, as it offers a reduction in energy consumption per cubic meters by about 6.3% and 3.92% respectively. It is recommended to use high galleries to protect the upper floor' facades from the intense solar radiation, taking into consideration that lower floors are usually shaded by opposite buildings. The use of galleries as a horizontal shading device will be advisable to achieve indoor thermal comfort with minimum use of energy during the year.

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