The Potential of Thermal Insulation as an Energy-Efficient Design Strategy in the Gaza Strip

Omar S. Asfour[1], Emad Kandeel[2]

[1]*Associate Professor, Dept. of Architecture, IUG, Palestine, oasfour@iugaza.edu, o.asfour@hotmail.com*

[2]*Master Graduate, Dept. of Architecture, IUG, Palestine, kandeele2012@hotmail.com*

Abstract—global consumption of energy is increasing over time as a result of the continuous increase in population and urbanism. This includes energy consumed in buildings in both construction and operation stages, where significant amount of energy is consumed in heating and cooling. As a matter of fact, most buildings in the Gaza Strip are constructed without using thermal insulation. This resulted in an increasing reliance on mechanical means of cooling and heating in order to maintain thermal comfort of building occupants. Thus, this study carries out a numerical assessment of using thermal insulation as an energy-efficient design strategy considering the case of Gaza. This has been done though a computerised thermal modelling process of a typical residential building in Gaza. The study concluded that the good use of thermal insulation in walls and roofs can effectively reduce undesired heat gains and losses through building fabric, which help reducing human discomfort throughout the year by about 17%. In this regard, the use of air cavity as thermal insulation in a double wall has been found more effective and feasible than the use of polystyrene thermal insulation.

Index Terms—Thermal insulation; Thermal comfort; Energy; Residential buildings; Gaza.

I INTRODUCTION

The recent climatic changes are believed to be directly related to the increasing fossil fuels consumption. The role of buildings is fundamental here as 50% of global resources go into construction, and 45% of energy production is used in buildings [1]. Thus, buildings have a great potential in the field of energy savings through implementation of passive design techniques. In this context, there are several design approaches. For instance, it is firstly possible to reduce the rate of energy consumption to a reasonable level. It is also possible also to partially or fully replace the external energy sources by self reliance on energy.

Unfortunately, passive design techniques in buildings are not invested effectively. For example, Gaza is a highly-populated region that suffers from a severe shortage in conventional energy sources. However, it is possible to notice that increasing number of buildings in Gaza started to depend on air conditioning to maintain acceptable indoor conditions. This consumes a great deal of energy and pollutes the environment by noise and harmful emissions such as CO_2 and CFCs. One passive design techniques that could be used to limit this problem is thermal insulation.

Thermal behaviour of buildings is highly affected by the design of their envelope. This includes designing all external elements that are in contact with the external environment such as roofs, walls and windows. Thus, the use of thermal insulation helps reducing unwanted heat losses or heat gains. This limits heating and cooling loads, and provides healthy and comfortable indoor environment. There are numerous alternatives when it comes to choosing insulation materials. In general, insulation materials fall into three main categories [2]:

- Inorganic/Mineral: Products based on silicon and calcium such as glass and rock.
- Synthetic organic: Materials derived from organic feed stocks based on polymers.
- Natural organic: Vegetation-based materials like hemp and lamb's wool.

This requires good selection of building materials that have appropriate thermal properties. This includes thermal transmittance (U-Value), which measures how well a material allows heat to pass through. Thermal insulators are usually characterized by relatively low thermal transmittance. Thermal properties also include thermal lag, which is measured in hours. Thermal lag means the time taken for heat wave to pass from one side of building external element to the other side. Thermal insulators are usually characterized by relatively high thermal lag.

Several studies based on different methodologies and tools have been carried out to assess the effect of thermal insulation on buildings operational energy demand. The main aim of these studies is either to quantify the effect of thermal insulation in a specific climate or location, or to assess the efficiency of a specific material or building component as a thermal insulator. In this regard, Shi and Yang [3] discussed the importance of the integrated and comprehensive performance evaluation. This is to give more value to the conventional architectural design method based on space, form, and function, which needs also to be based on scientifically sound performance analysis. Ozel [4] investigated the optimum insulation thickness of building walls considering five different structure materials and the climatic conditions of Elazıg, Turkey. This is determined before and after the use of thermal insulation. Extruded and expanded polystyrene were examined in this regard using the yearly cooling and heating transmission loads as performance indicators. These are calculated using an implicit finite difference method under steady periodic conditions. Depending on the structure material and the insulation material, results showed that the optimum insulation thicknesses vary between 2 and 8.2 cm, and the payback periods vary between 1.32 and 10.33 years.

Fang *et al.* [5] investigated the effect of building envelope insulation on cooling energy consumption in China summer using two types of experimental chambers. These chambers were constructed to evaluate the effects of external wall insulation on energy consumption and the indoor thermal environment. Air conditioning power consumption was recorded using a power meter. Results showed that the indoor thermal environment of the insulated chamber was less affected by the outdoor environment when compared to the basic chamber. In this regard, the insulated chamber offered a saving up to 23.5% in air conditioning energy consumption during the summer time. Shoubi *et al.* [6] carried out a study to assess various combinations of materials that help reducing energy demand in buildings. This has been done with reference to the bungalow house type, and the tropical climatic conditions prevailing in Malaysia. Ecotect software has been used to estimate the annual amount of energy consumption in the baseline and improved designs. Results indicated that the use of alternative insulation materials in the building envelope, such as double-brick walls, could reduce this consumption by about 28%.

One important study in this regard is the Palestinian Code of Low-Energy Buildings According to this Code, the maximum total U-value should be 1.8-2.2 W/m^2.K for ceilings and floors, and 2.5 W/m^2.K for walls [7]. The Code also offers several design options for building envelope, where thermal insulation is used. However, these options are not numerically justified. Thus, the use of thermal insulation as an energy-efficient design strategy in Gaza and its effect on thermal comfort will be numerically examined in the following modelling study.

II METHEDOLOGY

In this study, computer simulation of several cases has been implemented. In this regard, Ecotect 5.5 program has been used as a thermal simulation tool. Ecotect is user-friendly software that is widely used for thermal modelling of buildings. It has a CAD interface and several thermal analysis tools that allow assessing buildings thermal performance during the design stage. Thermal performance modeling has been carried out firstly for the reference case as a benchmark, and then for the thermally-insulated cases. All factors, except thermal insulation of building walls and final roof, have been assumed fixed to ensure a fare comparison that shows the effect of this insulation. Discomfort status, measured in degree hours, has been used as an indicator of the thermal performance. This is because improving thermal comfort of building users should be the ultimate aim of the design.

The prototype that has been chosen is a five-storey residential building that represents a common residential building type in Gaza. This type is common as a response to the extended family culture and increasing price of urban land. Moreover, most electricity consumption in Gaza (about 70%) goes to the domestic sector [8]. This means that a great deal of energy could be saved here as a result of implementing passive design strategies. Each floor of the modelling case accommodates four flats with different orientations. Simplicity of building design has been observed, and a sufficient area of 160m^2 has been provided to accommodate six members, which reflects the average Palestinian family size [9]. Each flat consists of three bedrooms, a living room, a dining room, two toilets and a kitchen. The apartments are vertically linked with common staircase.

As shown in Figure 1, the building has been three-dimensionally modelled. Its long axis has been oriented north-

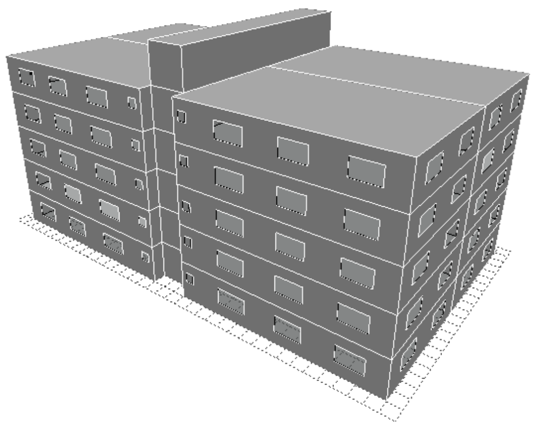

Figure 1 Three Dimensional View of the Modelling Case

south, which reduces its exposure to the southern sun. Ecotect reads any building as thermal (or non-thermal) zones, which should be observed in the modelling process. Thus, each flat of the twenty flats in the building has been assumed as a single thermal zone, where the internal partitions are neglected due to their relatively low thermal mass. This has resulted in ten thermal zones, which are named according to their height. For example, the ground floor includes four flats as follows: GF-a, GF-b, GF-c, and GF-d, and so on.

III MODELLING CASES SETUP

A Building Materials

Ecotect thermally reads building components according to their type. This includes floors, walls, roofs, ceilings, windows, etc. For each element several options related to building materials are available. These materials, along with their thermal properties, are available in the program material library. This includes: U-value, Solar Absorption, and Thermal Lag. The most common construction system in the residential buildings of Gaza is the structural system (reinforced concrete foundations, columns, and ceilings). In this study, building materials are defined to match the most common ones in Gaza. This is intended to explore thermal performance of the reference building, and decide whether it needs some improvement or not. As mentioned above, Ecotect material library offers a wide range of building materials. However, additional materials have been created in this study to meet the common building materials in Gaza. Thermal properties of these additional materials have been obtained using the thermal properties calculator integrated in Ecotect, and the Palestinian Code of Energy Efficient Buildings [7].

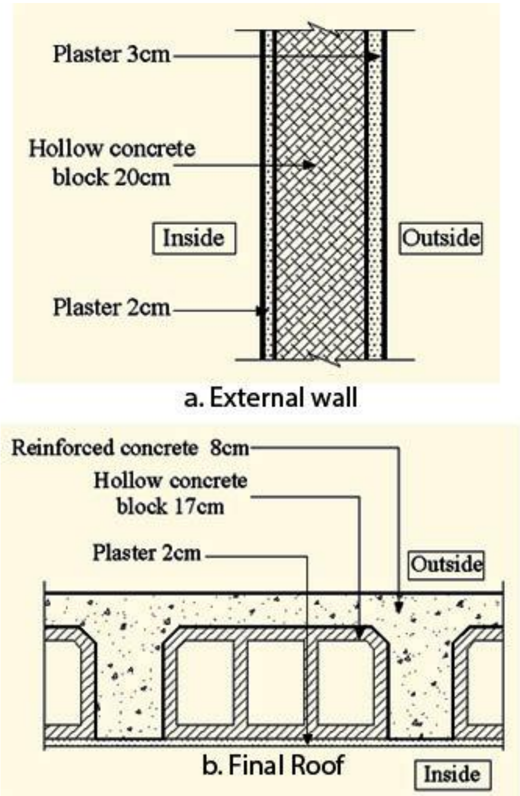

Figure 2 Main Building Materials Used in the Reference Modelling Case

The following is a description of the several materials used in the reference modelling case. These materials are also illustrated in Figure 2.

1. External walls

Most commonly, walls in Gaza are made of hollow concrete blocks and thin layers of cement plastering applied to the internal and external walls. A typical section of external walls shows 20 cm hollow concrete blocks, with 1-1.5 cm of internal plaster and 2-3 cm of external plaster. Thermal properties of this element are as follows: U-value: 2.3 W/m^{2}K, admittance: 4.4 W/m^{2}K, decrement factor: 0.3, time lag: 7.4 hrs.

2. Ceiling

The typical ceiling section shows three parts: 8 cm layer of reinforce concrete, 17cm layer of hollow concrete blocks, and 1 cm layer of plastering. In Ecotect, the internal floors between flats are assumed the same but with these layers in reversed manner. Thermal properties of this element are as follows: U-value: 2.6 W/m^{2}K, admittance: 4.9 W/m^{2}K, decrement factor: 0.4, time lag: 6.8 hrs.

3. Glazing

Windows are important parts of the building envelope since they provide both lighting and ventilation. A typical single-glazed window with aluminium frame is assumed here. Thermal properties of this element are as follows: U-value: 5.5 W/m^{2}K, admittance: 5.5 W/m^{2}K, solar heat gain coefficient: 0.9.

B Zone Thermal Settings

The second step after defining building materials is to define thermal settings of each thermal zone. This includes the following:

1. Estimation of internal heat gains

Internal heat gains in any thermal zone may be a result of its occupants, lighting or appliances used in it. Heat gains due to lighting and appliances are called the Sensible Gains. As for occupants, six occupants are assumed in each zone to reflect the average Palestinian family size [9]. Occupants are assumed in "sedentary" mode. Thus, the total heat gain due to occupants is 70W * 6 person = 420W. It is important to note that it is only required in Ecotect to specify the number of occupants, which helps the software to calculate the resulting heat gain.

To specify the Sensible Gains, heat gains due to lighting and appliances should be estimated. As for lighting, it is estimated in residential buildings that heat gains due to energy efficient lighting is about 11W/m^2 [10]. As for appliances, Table 1 shows an assumption of the appliances that are usually used in residential buildings in addition to their operation times. The total heat emission due to these electric equipment is 620 W. Given that each thermal zone (or apartment) floor area is 160 m^2, heat gain due to equipment is about 4W/m^2.

Thus, Sensible Heat Gains in the thermal zone settings should be defined as: heat gains due to lighting + heat gains due to appliances = 11 + 4 = 15 W/m^2.

TABLE 1
Heat Emission Due to Appliances [11], Adapted by Authors

Equipment	No.	Watts	Operation time	Total (W)
Refrigerator	1	60	75%	45
Washing machine	1	1000	10%	100
Oven	1	2000	5%	100
Microwave	1	2000	5%	100
Kettle	1	2000	5%	100
TV.	1	150	50%	75
P.C.	1	200	50%	100
Total (W)				**620**

TABLE 2
Average Monthly Temperature in Al-Arish, Egypt, and Gaza, Palestine [12]

Average Monthly Temperature (Al-Arish) (ºC)											
1	**2**	**3**	**3**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
13	14	16	18	21	24	25	26	25	22	20	16
Average Monthly Temperature (Gaza) (ºC)											
1	**2**	**3**	**3**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
13	14	15	18	20	23	25	26	25	22	19	15

2. Estimation of ventilation rate

HVAC system for all zones is assumed natural ventilation. A ventilation rate of 18 litres of fresh air every second is required for every person in the case of residential buildings [11]. As number of persons in every zone is 6, this means that the required volumetric air change rate is 108 l/sec, which equals $108*10^3*3600$ cm^3/h, i.e. 388.8 m^3/h.

Given that volume of the zone is $160m^2 * 3m = 480\ m^3$, the required air change per hour is = 388.8/480 = 0.81 Ach/h, or 1 Ach/h approximately. In Ecotect program, this value represents the average uncontrolled air leakage (infiltration) in typical construction. This can provides sufficient ventilation rate in winter when windows are closed. In summer, the software assumes that windows are opened to provide natural ventilation whenever external conditions are thermally acceptable.

3. Schedules management

Schedules feature is used in Ecotect to control some variables in the thermal settings of zones. For example, it can be used to switch off the lights overnight, which reduces the resulting sensible heat. In this study, two schedules are assumed:

- The occupancy schedule: this assumes full occupancy from 12 am to 8 am, 30% from 8 am to 2 pm (the working time), and 70% from 2 pm to 12 am. This is in weekdays. In weekends, 70% occupancy is assumed from 2 pm to 12 am, and a full occupancy is assumed for the rest of the day.
- The sensible gains schedule: this assumes 70% of the reference value of sensible gains (15 W/m^2) from 8 am to 8 pm, and 30% for the rest of the day, i.e. overnight.

C Climatic Data

To carry out any thermal analysis using Ecotect, it is essential to specify the city in which the building is located. To do so, the climatic data file of this city should be downloaded from the program directory. In fact, there are limited climate data files to download while using the program. As there is no climatic data file for Gaza, it is possible to rely on Al-Arish climatic data file due to the similarity between these two cities. Al-Arish is a coastal city in Egypt that is close to Gaza. Both cities are located on latitude 31 N. Table 2 compares temperature averages for both cities.

It is possible now to start thermal analysis of the building, giving that thermal insulation is not used yet. Due to the limited size of the study, thermal analysis will be limited to two zones (flats): zone Second-a (i.e. flat "a" in the second floor), and zone Fourth-a (i.e. flat "a" in the top floor). Both zones are south-westerly, which represents high exposure to sun, where thermal insulation may be required. Moreover, zone Fourth-a is located in the top floor and receives additional solar radiation through the roof, where thermal insulation may be required as well.

IV Modelling Study Results

A Thermal Behaviour of Reference Case

Ecotect offers several thermal performance analysis features and indicators. This includes:

- The hourly temperature profile.
- The hourly heat gains and losses.
- The monthly loads/ discomfort.

1. The hourly temperature profile

This displays internal and external temperature profiles together for a selected day and thermal zone. This facilitates comparing both profiles and understanding building thermal behaviour. Temperature values have been obtained for the average hottest day to represent summer conditions, and for the average coldest day to represent winter conditions. Figure 3 shows the average summer and winter temperature profiles for zones Second-a and Fourth-a.

In summer, Figure 3 shows that zone Fourth-a has a higher internal temperature compared to zone Second-a mainly in the afternoon period. This can be a result of the solar radiation acting on the roof of zone Fourth-a. Another observation is that internal temperature in both zones has less swing compared to the external one, which presents the effect of building envelope in modifying the external temperature

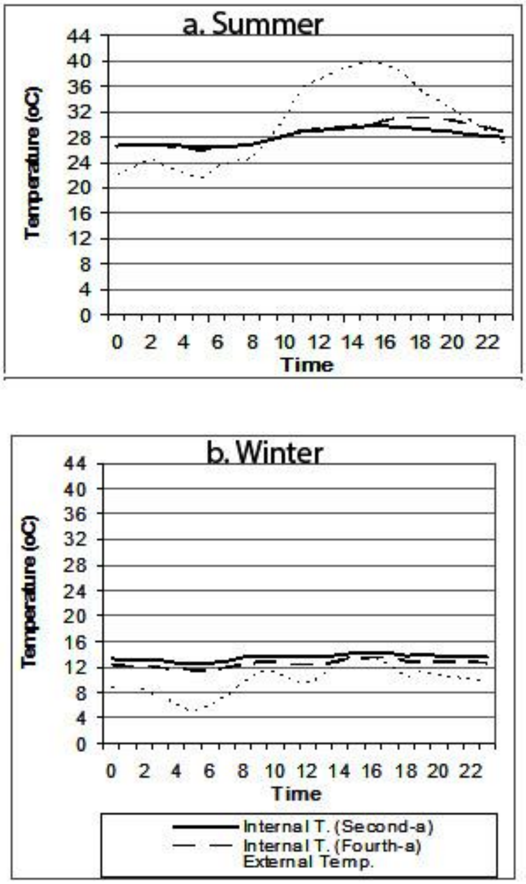

Figure 3 Hourly Temperature Profiles for Zones Second-a and Fourth-a in the Average Hottest and Coldest Days

passively. Thermal comfort limits have been defined in Ecotect from 18 to 26ºC. As shown in Figure 3, both zones are above the lower limit, but exceeds the upper one starting from the noon time when external temperature reaches 36.8ºC.

In winter, Figure 3 shows that both zones are outside the comfort range (18-26ºC) with no significant swing. However, zone Fourth-a has lower internal temperature compared to zone Second-a during the whole day. This can be a result of heat loss through the roof of zone Fourth-a.

2. The hourly heat gain and losses

This displays magnitudes of the several heat flow paths acting on the examined thermal zone in a specified day. This is displayed in Watts, and includes several heat flow paths like fabric, zonal, and solar heat gains or losses. This is useful to understand what is going on inside a building as a result of changing its building materials, ventilation system, or windows orientation for example.

Table 3 shows the hourly heat gains and losses for zones Second-a and Fourth-a in the average hottest and coldest days. In summer, it is clear that zone Fourth-a gains more heat through building fabric as it has more exposed surface area (241m^2 compared to 81m^2 in zone Second-a). Fabric heat gains in zone Fourth-a (63253Wh) are higher by about four times when compared to zone Second-a (15501Wh).

TABLE 3

Estimated Hourly Gains and Losses for Zones Second-a and Fourth-a in the Average Hottest and Coldest Days

Summer Gains (Wh)						
	Zone: Second-a					
Heat Path	**HVAC**	**Fabric**	**Solar**	**Vent.**	**Internal**	**Zonal**
Total (Wh)	0	15501	2821	55690	36648	-37
	Zone: Fourth-a					
Heat Path	HVAC	Fabric	Solar	Vent.	Internal	Zonal
Total (Wh)	0	63253	2821	55690	36648	-1917
Winter Gains (Wh)						
	Zone: Second-a					
Heat Path	**HVAC**	**Fabric**	**Solar**	**Vent.**	**Internal**	**Zonal**
Total (Wh)	0	-21745	504	-83351	38580	250
	Zone: Fourth-a					
Heat Path	HVAC	Fabric	Solar	Vent.	Internal	Zonal
Total (Wh)	0	-47372	504	-83351	38580	3942

Solar heat gains are the same as there is no difference between both zones in terms windows area and orientation. Ventilation gains are significant, where gains occur as a result of the hot air leakage into the space. The zonal gains or losses depend on the internal temperature of the adjacent zones. Heat should move from the hotter zones to the colder ones. It is clear that zone Fourth-a loses more heat (-1917Wh) to the adjacent zones compared to zone Second-a (-37Wh). Similar observations can be noticed in the winter, but in a reversed manner. However, zone Fourth-a gains some heat (3942Wh) from the underneath zones as it is colder than them.

3. The monthly discomfort degree hours

If a thermal zone is naturally ventilated, Ecotect can perform a thermal comfort assessment with reference to the occupants inside the space. This considers the amount of time the internal temperature of this zone spends outside the specified comfort conditions. In addition, thermal discomfort in Ecotect can be estimated using degree hours, which measures thermal discomfort by the number of degrees spent outside the comfort band.

Figure 4 shows the discomfort intervals measured in degree-hour for each month in the year. This is given for zones Second-a (the wide bars) and Fourth-a (the narrow ones), given that comfort lower limit is 18ºC and comfort upper limit is 26ºC, and that upper columns indicate the "too hot" state, while bottom ones indicate the "too cool" state. It clear that there is a significant amount of discomfort recorded in both zones in both summer and winter. However, the problem is more significant in summer for zone Second-a, and in winter for zone Fourth-a. The previous analysis shows that the proposed building requires some improvements to improve its thermal performance. One option is to examine the

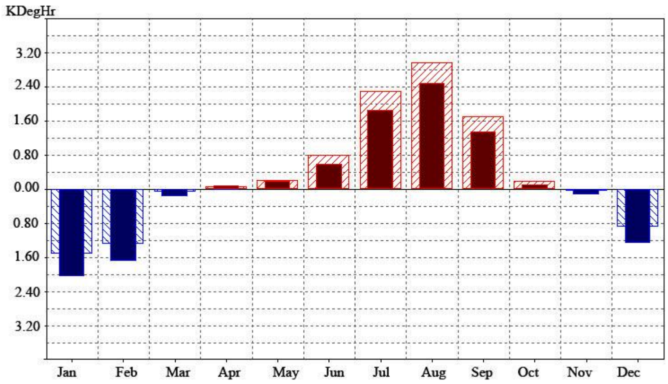

Figure 4 Measured Monthly Discomfort Degree Hours for Zones Second-a (the Wide Columns) and Fourth-A (the Narrow Ones)

effect of thermal insulation, which is the main passive design strategy targeted in this study. This is because thermal insulation usually protects the building from the undesired climatic conditions, and reduces its need for heating and cooling. This will be done for the external walls of zone Second-a, and for the external walls and the roof of zone Fourth-a as discussed below.

B Thermal behaviour of the thermally-insulated case

Two thermal insulators recommended by the Palestinian Code of Energy Efficient Buildings [7] are examined here:

- Wall Insulation-A: This is a 35cm double wall with a middle air cavity and cement plastering at both sides. Thermal properties of this insulated wall are: U-value: 1.5 W/m^{2}K, admittance: 5.6 W/m^{2}K, decrement factor: 0.13, time lag: 7.4hrs.
- Wall Insulation-B: Similar to the above one but polystyrene insulation in the middle instead of the air gap. Thermal properties of this insulated wall are: U-value: 0.4 W/m^{2}K, admittance: 5.6W/m^{2}K, decrement factor: 0.2, time lag: 12hrs.

1. Effect of thermal insulation on Zone "Second-a"

The use of both Insulation-A and Insulation-B will be examined for zone Second-a here. Building material of the external walls in the whole building has been changed to these two insulated walls. The hourly heat gains and losses could be a useful tool to demonstrate the effect of thermal insulation as it displays heat movement through building fabric. Table 4 shows the resulting heat gains and losses through building fabric. Results obtained shows that the use of thermal insulation has successfully reduced heat gains or losses through building fabric. However, Wall Insulation-B (polystyrene in a 35cm double wall) seems to be more effective when compared to Wall Insulation-A (air cavity in a 35cm double wall).

However, a look at the resulting thermal comfort conditions, presented in Table 5, reveals that these conditions have improved in the cold months but not in the hot ones. As for the "Too Cool" case, thermal discomfort has been reduced by 6% and 24% as a result of using Wall Insulation-A

TABLE 4

Estimated Heat Gains and Losses Through Building Fabric in Zone Second-a for the Average Hottest and Coldest Days, Before and After Using Thermal Insulation

Type / Gains/Losses	Wall Insulation-A		
	Before Insulation	**After Insulation**	**Diff.**
Summer Gains (Wh)	15501	10411	-33%
Winter Losses (Wh)	-21745	-16542	-24%
Type / Gains/Losses	**Wall Insulation-B**		
	Before Insulation	**After Insulation**	**Diff.**
Summer Gains (Wh)	15501	9692	-38%
Winter Losses (Wh)	-21745	-15408	-29%

TABLE 5

Total Annual Thermal Discomfort Degree Hours in Zone Second-a Before and After The Use of Thermal Insulation

Type (Deg. Hrs.)	Wall Insulation-A		
	Before Insulation	**After Insulation**	**Diff.**
Too Hot	8249	8749.6	+6
Too Cool	3809.3	3589.5	-6
Type (Deg. Hrs.)	**Wall Insulation-B**		
	Before Insulation	**After Insulation**	**Diff.**
Too Hot	8249	10066.3	+22
Too Cool	3809.3	2895.3	-24

and Wall Insulation-B, respectively. As for the "Too Hot" case, thermal discomfort has increased by 6% and 225% as a result of using Wall Insulation-A and Wall Insulation-B, respectively. This indicates that despite the positive effect of thermal insulation in protecting the building from the undesired hot weather in summer, it seems that it prevented internal gains from leaving the space which causes some overheating and increases thermal discomfort.

Thus, thermal insulation has a positive effect in the cold months but not in the hot ones. This confirms the need of adopting a comprehensive passive design strategy in which several passive techniques are integrated to improve thermal performance over the year. This includes:

- Reducing internal heat gains.
- Using shading devices and energy-efficient windows.
- Using high thermal mass in internal partitions.
- Using night-time ventilation.

One strategy will be examined here, which is the use of night-time ventilation in the relatively hot months (April to September). This strategy aims to cool the building fabric over night by increasing ventilation rate during night-time.

Thus, the building becomes able to absorb more internal heat gain during the day time. To do so, a ventilation schedule has been assumed. That schedule assumed an infiltration rate of 1 Ach/hr during winter and day-time in summer, and an infiltration rate of 2 Ach/hr during over night in summer. This practically means that windows will be slightly opened overnight when external air temperature is low.

The effect of night-time ventilation on thermal discomfort is presented in Table 6. It shows that night-time strategy, along with thermal insulation, helped improving thermal performance of the building. This strategy reduced total discomfort degree hours by 18% for both Wall Insulation-A and Wall Insulation-B. However, Wall Insulation-A is more effective in summer, which has the priority in thermal design of buildings located in hot climates.

TABLE 6

Total Annual Discomfort Degree Hours for Zone Second-a Before and After the Use of Night-Time Ventilation Beside Thermal Insulation

Type (Deg. Hrs.)	Wall Insulation-A		
	Before Insulation & Night Vent.	After Insulation & Night Vent.	Diff.
Too Hot	8249	6598.4	-20
Too Cool	3809.3	3251.8	-15
Total	12058.3	9850.2	-18
Type (Deg. Hrs.)	Wall Insulation-B		
	Before Insulation & Night Vent.	After Insulation & Night Vent.	Diff.
Too Hot	8249	7363.9	-11
Too Cool	3809.3	2519.6	-34
Total	12058.3	9883.5	-18

2. Effect of thermal insulation on Zone "Fourth-a"

Thermal insulation in this zone is similar to zone Second-a but with additional thermal insulation used in the top roof. An insulated roof section recommended by the Palestinian Code of Energy Efficient Buildings [7] will be examined here (see Figure 5). This roof is a 25cm ribbed concrete roof covered with 5cm of thermal insulation (polystyrene), 5cm of foam concrete, 2cm of moisture insulation, 2.5cm of sand, and 1cm of tiles, respectively from bottom to top. Thermal properties of this insulated roof are: U-value: 0.73 W/m^{2}K, admittance: 5.3 W/m^{2}K, decrement factor: 0.1, time lag: 11hrs. This means that the insulated roof has lower U-Value (0.73 compared to 2.6 W/m^{2}K), and higher thermal lag (11 compared to 6.8 hrs).

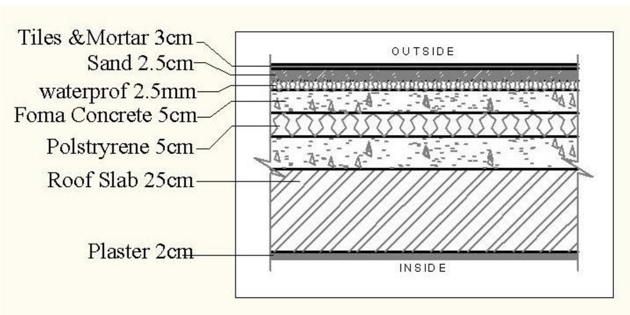

Figure 5 The Proposed Insulated Roof Section

The previous analysis showed that thermal insulation works more effectively when integrated with the night-time ventilation. It also showed that Wall Insulation-A offers better insulation in summer. Thus, these two findings will be considered here. Figure 6 and Table 7 show the total annual discomfort measured in degree-hour for zone Fourth-a. This is shown for three scenarios:

- Before using thermal insulation in the walls and the roof.
- After using the insulation (Wall Insulation-A).
- After using thermal insulation along with night-time ventilation.

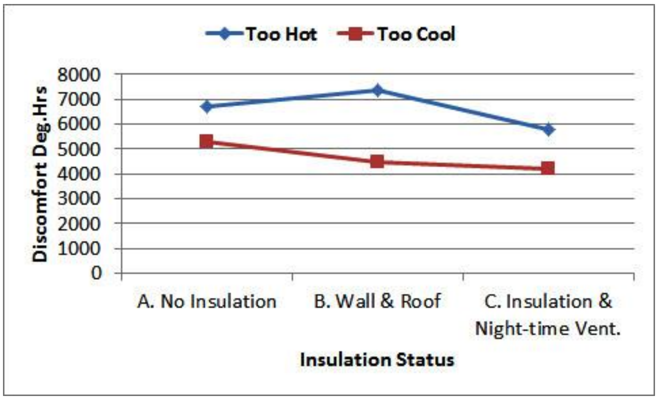

Figure 6 Monthly Discomfort Degree Hours for Zone Fourth-a Before and after Insulating the Walls and the Roof

TABLE 7

Monthly Discomfort Degree Hours for Zone Fourth-a Before and after Insulating the Walls and the Roof

Status (Deg.Hrs.)	A. No Insulation	B. Wall & Roof Ins.	Diff. (A&B)	C. Ins. & Night-time Vent.	Diff. (A&C)
Too Hot	6700.5	7382.7	+10	5785.1	-14
Too Cool	5293.4	4469	-16	4219.3	-20
Total	11993.9	11851.7	-1	10004.4	-17

It seems that findings here are consistent with the ones obtained in the case of zone Second-a. The positive effect of using thermal insulation can be noticed in winter as it could reduce thermal discomfort by about 16%. However, it causes some overheating in summer. This can be overcome using nigh-time ventilation, where total discomfort has been reduced by 17%.

V ENERGYSAVINGS AND PAYBACK PERIOD

To estimate the amount of energy that would be saved as a result of using thermal insulation, the monthly space load graph in Ecotect can be used as an approximation method. This graph displays the total heating and cooling loads required to maintain thermal comfort in a specified thermal zone. To do so, the building is assumed air conditioned when the internal temperature is higher or lower the thermal comfort limits (18-26ºC). The fact that the building is air conditioned implies two changes in the zonal thermal settings:

- Natural ventilation rate will be set to the minimum, assumed 1.0 Ach/hr of air infiltration, as windows are closed.
- Night-time ventilation will not be used as windows are closed to allow for air conditioning.

Table 8 shows the expected energy savings as a result of using thermal insulation for zones Second-a and Fourth-a. Both wall insulation types assumed in this study (Wall Insulation-A, and Wall Insulation-B) have been considered, in addition to the roof insulation in the case of zone Fourth-a.

TABLE 8

Annual Heating and Cooling Loads and Money Saving for Zones Second-a and Fourth-a Before and After Using Thermal Insulation

A. Wall Insulation-A, and roof insulation			
	Loads for zone Second-a (kWh)		
	Heating	Cooling	Total
Before Insulation	1959	9711	11670
After Insulation	1507	9500	11006
Diff. (kWh)	452	211	664
Money Saved ($)	59	27	86
	Loads for zone Fourth-a (kWh)		
Before Insulation	3447	11710	15157
After Insulation	2139	9184	11323
Diff. (kWh)	1308	2526	3834
Money Saved ($)	170	328	498
B. Wall Insulation-B, and roof insulation			
	Loads for zone Second-a (kWh)		
	Heating	Cooling	Total
Before Insulation	1959	9711	11670
After Insulation	671	10224	10895
Diff. (kWh)	1288	-513	775
Money Saved ($)	167	-67	101
	Loads for zone Fourth-a (kWh)		
Before Insulation	3447	11710	15157
After Insulation	1781	9528	11309
Diff. (kWh)	1666	2182	3848
Money Saved ($)	217	284	500

Heating and cooling loads are estimated in kWh. According to the local price, each kWh costs about ILS 0.5. This is equivalent to USD 0.13 according to 2014 rates. Results obtained show that it is possible to save an annual amount of USD 86 and 498 for zones Second-a and Fourth-a, respectively, when comparing the total heating and cooling loads before and after using thermal insulation, given that Wall Insulation-A is used.

In the case of using Wall Insulation-B, it is possible to save an annual amount of USD 101 and 500 for zone Second-a and Fourth-a, respectively. There is no significant difference between Wall Insulation-A and Wall-Insulation-B as a total in terms of heating and cooling loads. However, it can be noticed that Wall Insulation-B saves more money in heating on the account of cooling, while Wall Insulation-A offers more balanced savings, especially in zone Second-a. Also, it can also be noticed that the effect of roof insulation is more significant as more money can be saved in zone Fourth-a.

In order to estimate the payback period, construction costs of the external walls and top roof have been estimated before and after using thermal insulation. The following sections summarize the findings:

A. Wall Insulation-A

Given that the additional cost of using Wall Insulation-A (35cm double wall with a middle air cavity) in zone "Second-a" is USD 390 per housing unit, and that the annual saving in heating and cooling as a result of using thermal insulation is 86 USD, it is possible to get back insulation cost in zone "Second-a" in 4.5 years. As for zone "Fourth-a", the additional cost of insulation includes walls (USD 390), and the roof (USD 5520). This equals USD 5910 per housing unit. Given that the annual saving in heating and cooling as a result of using thermal insulation is USD 498, it is possible to get back insulation cost in zone "Fourth-a" in 11.9 years.

B. Wall Insulation-B

Given that the additional cost of using Wall Insulation-B (35cm double wall with polystyrene in the middle) in zone "Second-a" is USD 813, and that the annual saving in heating and cooling as a result of using thermal insulation is USD 101, it is possible to get back insulation cost in zone "Second-a" in 8 years. As for zone "Fourth-a", the additional cost of insulation includes walls (USD 813) and the roof (USD 5520). This equals USD 6333. Given that the annual saving in heating and cooling as a result of using thermal insulation is USD 500, it is possible to get back insulation cost in zone "Fourth-a" in 12.7 years.

VI CONCLUSION

Thermal behaviour modelling of buildings is a complicated process in which several aspects interact, and several assumptions should be reasonably treated. However, the use of computer simulation significantly facilitates this process. This study showed the great potential of passive design techniques to save energy and improve thermal comfort in buildings, considering the climatic conditions of Gaza Strip, Palestine.

With the focus on thermal insulation, it has been found that it is possible to significantly reduce heat gains and losses through building fabric by using thermal insulation in walls and top roof. This can reduce thermal discomfort by about 17% over the year. However, the use of air cavity in a double wall has been found more effective when compared to the use of polystyrene in the same double wall. The positive effect of thermal insulation in summer can be invested when it is coupled with other passive design strategies to reduce the adverse effect of internal heat gains. This includes night-time ventilation, which has been examined in this study. Despite the fact that thermal insulation of walls and final roof has been solely explored in this study, the potential of other design techniques cannot be neglected in order to achieve a comprehensive perspective of energy efficient design strategies. This includes shading, the use of double glazed windows, the use of other insulating materials available in Gaza such as natural stone, and the use of landscaping.

As for the economic benefits, the use of air cavity in a double wall has been found more feasible when compared to the use of polystyrene in the same double wall. It is possible to get back insulation cost in 4.5 years in the middle floor (compared to 8 years in the case of using polystyrene insulation), and in 11.9 years in the top floor (compared to 12.7 years in the case of using polystyrene insulation). However, the observed payback period in both cases may be reduced by optimizing the thickness of the invested thermal insulation. Thus, the shortage of conventional energy sources in Gaza Strip necessitates effectively investing the available passive design strategies. In this regard, it is required from all parties involved in the construction sector to adopt effective strategies for energy-efficiency that integrate them into building design, taking into account their economic and environmental benefits. This requires that the concerned official bodies take an action to legalize the issue through appropriate building norms and policies that put energy efficiency of buildings in action.

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