Energy Savings and Optimum Insulation Thickness in External Walls in Palestinian Buildings

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***Abstract*—The determination of the optimum wall insulation thickness (OWIT) of the building's external wall has major drawbacks on building wall thickness, insulation material type, insulation cost, and energy consumption by air conditioning system. Therefore, this study focused on a systematic approach for optimization of insulation thickness for building's external wall in Palestine. Hence, the environmental conditions such as temperature and solar radiation fluctuations were collected for the cities covered in this study over one year while preparing this study. The Palestinian energy-efficient building code divided Palestine into seven climate zones. These zones are studied and investigated in this study. The OWIT in these zones has been calculated and compared based on the life cycle cost analysis and for two different types of insulation which are Expanded Polystyrene (EPS) and Polyurethane (PUR). Consequently, life cycle savings of the insulated buildings, simple payback periods, and optimum insulation thickness as a function of degree days and wall thermal resistance have been addressed. These types of comparisons and findings could promote the futuristic use of optimum insulation thickness in Palestinian buildings towards establishing a Palestinian standard code.**

Keywords— Energy savings, optimum insulation thickness, payback period, life-cycle cost, degree-day regions, climate zones.

I. Introduction

The vast population growth, globalization on welfare state, and technology advancement that societies face nowadays worldwide increase the energy demand which is mostly prevailed in the residential sector among others; industry, transport, and agriculture [1, 2]. To balance such a huge energy consumption in Palestine, the infrastructure depends on the building and construction sector. This sector, according to the Palestinian Energy and Natural Resources Authority (PENRA), is the main consumer of electricity with more than 60% of the total consumption [3]. Statistically speaking, according to the Palestinian Central Bureau of Statistics (PCBS) [4], around 2,600 building licenses were issued in the region under Palestinian control in the fourth quarter of 2018, which represents an increment of 0.7 % compared to the same period of 2017. Moreover, Palestine's population and energy statistics for a 5-year time interval between 2014 and 2019 are listed in Table I [5]. As seen, during this period, the estimated population and energy dependency rate have increased by 12.3 and 7.6%, respectively. This increase in the energy consumption levels has added extra pressure on Palestine's economic, social, and political sectors. Consequently, PENRA in partnership with the World Bank has developed a national energy efficiency action plan for 2020 – 2030 also referred to as national energy efficiency action plans (NEEAP)-II within the light of the previous plan for 2012 – 2020. This action plan aims at reducing the consumption of energy and not on the development of renewable energy such as wind, biomass, or solar PV [3]. Thus, the present study comes hand in hand with the new PENRA-II 2020 – 2030 action plan which will help in increasing society's awareness of the importance of consuming energy more economically through implementing an accurate insulation thickness in their residential buildings. This could be achieved by providing them with an accurate analysis that shows the feasibility of installing an adequate thickness of insulation material.

The open-access literature reveals several contributions related to the effect of OWIT on building energy savings. For instance, Table II summarizes some of the OWIT research during the period from 2017 to 2019 under different worldwide conditions, such as Greece [6], Jordan [7], Turkey [8], and Palestine [9]. It can be inferred that the OWIT depends on many parameters, such as type/cost of insulation material, energy type, heating/cooling loads, inflation and discount rates, building lifetime, and heating/cooling equipment coefficient of performance (*COP*). Moreover, researchers adopted many techniques in obtaining the OWIT, i.e., Finite Fourier Transform (FFT) [10-13], Heating/Cooling degree-days (*HDD*/*CDD*) [8, 9, 14-16], and P_1-P_2 optimization model [17, 18]. Interestingly, *HDD*/*CDD* prevailed over other techniques and continued to be the most accurate method to estimate the space annual cooling and heating loads in different climate zones.

Determining the optimum wall insulation thickness (OWIT) is very challenging in the building industry as many parameters including energy, environment, and economy should be taken into consideration [19]. Herein, the objective of the study is to optimize the OWIT by studying many parameters such as wall construction material, climate zone, building orientation, type of insulation, weather condition, energy prices, and heating and cooling load. As a result, this study will provide enough information about the importance of energy stability in Palestinian buildings. Moreover, this study put hands on the important element needed to establish a Palestinian standard code for optimum insulations thickness in buildings which are crucially needed nowadays due to the vast dependence, by the societies, on electricity for cooling and heating purposes. The remainder of the paper is organized as follows: Section II describes the research methodology, Section III outlines the method of solution using the mathematical equations, results and discussion are presented in Section IV, and Section V concludes the paper.

II. Methodology

A. Study area

Five representative cities, Jericho, Bethlehem, Hebron, and Jenin are selected as the sample cities (Table III). The outdoor conditions are taken from typical meteorological year data [20], which is generated based on the measured weather data of years 1972 – 1997. The cooling season is from June to

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TABLE I. PALESTINE'S POPULATION AND ENERGY STATISTICS [5].

Year	Population (million)	Energy Dependency Rate (%)	Electricity generated (GWh)	Electricity consumption (GWh)
2014	4.429	80.3	11827	1048.0
2015	4.530	84.8	11807	1151.4
2016	4.632	84.7	12098	1141.9
2017	4.733	87.3	9660	1138.3
2018	4.854	86.9	9725	1148.7
2019	4.976	86.4	11187	1280.0

TABLE II. A REPRESENTATIVE LIST OF OPTIMUM WALL INSULATION THICKNESS FOR CERTAIN SELECTED COUNTRIES.

Year/ Country	Description	Remarks	Refs.
2017/ Greece	Thermal insulation, orientation of external surfaces, indoor and outdoor environmental conditions, energy performance of buildings wall, and variation of insulation thickness have been studied. The thermal insulation layer used rigid extruded polystyrene sheets (XPS) with variations in the thickness of 2.5 up to 20 cm.	The variation in insulation thickness and wall orientation has a direct effect on the initial cost and on the energy consumption cost which is a very intricate process and involving many uncertainties.	(6)
2017/ Jordan	OWIT for external walls, energy-saving, and pay-back period was investigated using the degree-days method combined with life cycle cost analysis for three climatic zones for heating purposes. Three commercially insulation materials Expanded Polystyrene (EPS), Extruded Polystyrene (XPS) and polyurethane Boards (PURB) were utilized.	Applying 0.13-m thickness of EPS gives the highest energy savings (89-90) % for heating using diesel or kerosene fuels while applying 0.12-m of XPS reduces energy by (88–89) % for heating using liquified Petroleum Gas (LPG).	(7)
2017/ Turkey	OWIT for external walls, energy-saving, and pay-back period was presented using life-cycle cost analysis over a lifetime of 15 years integrated with the degree-days method. Six different fuels and insulation materials for four cities with different climatic regions were selected for analysis. Six insulation materials were chosen as Extruded Polystyrene (XPS), Expanded Polystyrene (EPS), glass wool (GW), rock wool (RW), polyisocyanurate (PIR), and polyurethane (PUR).	They found that the greatest energy savings for the four cities were achieved using LPG with energy savings between 16.4 ₺/m^2 and 479 ₺/m^2. Furthermore, the insulation optimum thickness on the exterior walls of the building varies between 2.8 cm and 45.1 cm according to the number of heating degree-days and the insulation material used.	(8)
2019/ Palestine	Optimal thickness was proposed in eight representative governorates of Palestine for cooling (electricity as an energy source) and heating (LPG as an energy source). Several typical exterior wall constructions and two insulation types, namely Polystyrene (PS) and Polyurethane (PUR).	By using the degree-days method combined with life cycle cost analysis, the OWIT was figured between 0.4 and 9 cm for all cases.	(9)

August, and the heating season is from November to January [21]. The indoor conditions are set as 24°C for cooling and 18.3°C for heating according to the Palestinian Energy Efficient Building Code (PEEB) [22].

B. Wall Configurations and Insulation materials

Following the guidelines of PEEB for a typical exterior wall design, the common wall construction materials in Palestinian residential buildings are mainly comprised of four types [22]. Table IV lists the wall structural material layers from exterior to interior, walls thermal resistance value, and their overall heat transfer coefficient. Hence, the present work took into consideration heat gain in hot summer and heat loss in cold winter zones of Palestine via the external walls (i.e., EWI, EWII, EWIII, and EWIV) in order to evaluate the optimum insulation thickness. In this study, two commercially available insulation materials have been analyzed, namely Expanded Polystyrene (EPS) and Polyurethane (PUR). Their thermal conductivities and costs are pointed at in Table V.

TABLE III. CLIMATE REGIONS AND CERTAIN DATA AT REFERENCE COOLING TEMPERATURE ($T_{C,REF}$)=24°C AND AT REFERENCE HEATING TEMPERATURE ($T_{H,REF}$) =18.3°C FOR SELECTED CITIES.

Region	City	HDD (°C − day)	CDD (°C − day)
1st, 2nd	Jericho	362.2	925.4
3rd, 7th	Tubas	853.2	129.9
4th	Jerusalem	1139.8	0.0
5th	Jenin	471.7	401.7
6th	Gaza	315.3	184.8

TABLE IV. PROPERTIES OF THE EXTERIOR WALL COMPONENTS [22].

External Wall material	Thickness, x (m)	Thermal conductivity, k (W/mK)	Thermal resistance, R (m^2°C/W)	Wall thermal resistance, R_w (m^2°C/W)	Overall H.T. coefficient, U (W/m^2°C)
External Wall-I					
(EWI)	0.02	1.2	0.016	0.198	5.050
Ext. Plaster	0.20	0.9	0.166		
Hollow Brick	0.02	1.2	0.016		
Int. Plaster					
External Wall					
(EWII)	0.07	1.7	0.041	0.171	5.848
Stone	0.2	1.75	0.114		
Reinforced Concrete	0.02	1.2	0.016		
Int. Plaster					
External Wall					
(EWIII)	0.02	1.2	0.016	0.146	6.850
Ext. Plaster	0.2	1.75	0.114		
Reinforced Concrete	0.02	1.2	0.016		
Int. Plaster					
External Wall					
(EWIV)	0.07	1.7	0.041	0.257	3.880
Stone	0.20	1.75	0.114		
Reinforced Concrete	0.07	0.9	0.077		
Hollow Brick	0.03	1.2	0.025		
Int. Plaster					

TABLE V. PARAMETERS OF THE INSULATION WALL

Insulation Material	Insulation conductivity, k_{ins} (W/mK)	Insulation Cost, C_y (\$/m^3)
Expanded Polystyrene (EPS)	0.038	68.6
Polyurethane (PUR)	0.025	214.3

III. MATHEMATICAL FORMULATION

By using long-term measured ambient temperature data for the selected five regions, the number of *HDD* and *CDD* can be calculated according to (1) and (2). For HDD, it can be calculated as the difference between the building inside reference temperature ($T_{h,ref}$) and the outdoor atmospheric temperature (T_a) as shown in (1).

$$HDD = \left(T_{h,ref} - T_a\right)^{+} \times N_h \quad (1)$$

where N_h is the number of heating days over heating season and the plus sign above the parentheses indicates that only positive values are to be counted.

For *CDD* are obtained by summations of the outdoor atmospheric temperature (T_a) and the effect of solar heat gain (*SHG*) which is controlled primarily by the location and orientation of the conventional building as per (2).

$$CDD = \left(T_a + 0.026 \times SHG\right) \quad (2)$$

To consider the heating and cooling load in one system, degree-days (*DD*) can be calculated by:

$$DD = \text{CDD}/COP + HDD/\eta \quad (3)$$

where *COP* is the cooling equipment coefficient of performance and η is the efficiency of the space heating system.

To estimate the insulation economy, life cycle costing (LCC) method and simple payback period (*SPBP*) are essential to be identified because they are depending on lifetime (*N*), interest rate (*I*), inflation rate (*g*), and present worth factor (*PWF*), which in turns affecting fuel and insulation materials costs.

For heating purposes, the annual heating cost per unit area (C_h) is given by:

$$C_h = 86400 \times HDD \times C_f \Big/ \left[\left(R_t + \left(\frac{X_{ins}}{k_{ins}}\right)\right) \times H \times \eta\right] \quad (4)$$

where C_f is the fuel cost (*\$/l*), R_t is the total wall thermal resistance in the absence of insulation material (*W/mK*), X_{ins} is the insulation layer thickness (m), k_{ins} is a thermal conductivity of insulation (*W/mK*), and *H* is heating value of fuel (*J/l*),.

In order to account for the fuel cost over the lifetime (*N*) of the insulation material, the interest rate (*I, %*) and the inflation rate (*g, %*) are compiled in one parameter which is the *PWF*. For inflation, *PWF* is evaluated as:

$$PWF = \begin{cases} \frac{(1-(1+I_1)^{-N})}{I_1} & ; I \neq g \\ (1+I)^{-1} & ; I = g \end{cases} \quad (5)$$

where *N* is taken as 10 years in this study. Parameters such as interest, inflation rate and insulation lifetime values are summarized in Table VI. Worth noting that I_1 is the interest rate adjusted for inflation rate as follows:

$$I_1 = \begin{cases} \frac{I-g}{1+g} ; & I > g \\ \frac{g-I}{1+I} ; & I < g \end{cases} \quad (6)$$

The cost of insulation (C_{ins}*,\$/m²*) for the building is given by:

$$C_{ins} = C_y \times X_{ins} \quad (7)$$

where C_y is the cost of insulation in *\$/m³* and X_{ins} is the insulation thickness in *m*.

The total heating cost for the insulated building is given by:

$$C_{t,H} = PWF \times C_h + C_{ins} \quad (8)$$

From (7) and (8), the total cost for heating system by diesel is evaluated by:

$$C_{t,H} = \frac{86400 \times PWF \times C_f \times HDD}{\left[R_t + \left(\frac{X_{ins}}{k_{ins}}\right)\right] \times H \times \eta} + C_y \times X_{ins} \quad (9)$$

OWIT can be evaluated by taking the derivative of (9) with respect to X_{ins}, from which the OWIT is obtained as follows:

$$X_{opt} = \left[\frac{86400 \times C_f \times HDD \times k_{ins} \times PWF}{C_y \times H \times \eta}\right]^{\frac{1}{2}} - k_{ins} \times R_t \quad (10)$$

where X_{opt} is the optimum insulation thickness in *m*, and it can be implied from (10) that X_{opt} depends on the properties of the wall, cost of insulation material, fuel type/price, *PWF*, inflation and interest rate values, and the total number of heating degrees-days. Consequently, the annual total net saving (AS_H*, \$/m²*) and the simple payback period (*SPBPH, year*) for the heating system using diesel can be calculated as:

$$C_{t,H,pre-ins} = \frac{86400 \times PWF \times C_f \times HDD}{R_t \times H \times \eta} \quad (11)$$

$$C_{t,H,opt-ins} = \frac{86400 \times PWF \times C_f \times HDD}{\left[R_t + \left(\frac{X_{opt}}{k_{ins}}\right)\right] \times H \times \eta} + C_y \times X_{opt} \quad (12)$$

$$AS_H = C_{t,H,pre-ins} - C_{t,H,opt-ins} \quad (13)$$

$$SPBP_H = \frac{C_{ins}}{AS_H} \quad (14)$$

where $C_{t,H,pre-ins}$ is the pre-insulation heating energy cost, $C_{t,H,opt-ins}$ is the optimum insulation heating energy cost.

Same LCC analysis conducted for heating system has been reused for cooling via electricity system. Certain parameters, such as C_f, *HDD*, and η, have been replaced with C_e, *CDD*, and *COP*, respectively.

$$C_{t,C} = \frac{0.024 \times PWF \times C_e \times CDD}{\left[R_t + \left(\frac{X_{ins}}{k_{ins}}\right)\right] \times COP} + C_y \times X_{ins} \quad (15)$$

$$X_{opt} = \left[\frac{0.024 \times C_e \times CDD \times k_{ins} \times PWF}{C_y \times COP}\right]^{\frac{1}{2}} - k_{ins} \times R_t \quad (16)$$

$$C_{t,C,pre-ins} = \frac{0.024 \times PWF \times C_e \times CDD}{R_t \times COP} \quad (17)$$

$$C_{t,C,opt-ins} = \frac{0.024 \times PWF \times C_e \times CDD}{\left[R_t + \left(\frac{X_{opt}}{k_{ins}}\right)\right] \times COP} + C_y \times X_{opt} \quad (18)$$

$$AS_C = C_{t,C,pre-ins} - C_{t,C,opt-ins} \quad (19)$$

$$SPBP_C = \frac{C_{ins}}{AS_C} \quad (20)$$

TABLE VI. PARAMETERS USED IN THE OPTIMIZATION OF THE INSULATION THICKNESS.

Parameter	Value	
Energy Type	Diesel	
	Fuel cost, C_f	1.47 \$/l
	Lower heating value, *H*	40.5× 10^6 J/l
	Heating system efficiency, η	0.7
	Electricity	0.2 \$/kWh
Interest rate, *I*	7 %/year	
Inflation rate, *g*	0 %/year	
Total project lifetime, *N*	10 years	

IV. RESULTS AND DISCUSSION

A. *OWIT for heating and cooling systems*

Table VII represents the OWIT of cooling the residential buildings by electricity in the different seven regions, using EPS and PUR as materials of insulations. Two wall composites are selected in this comparison, i.e., EWI and EWIV, due to their vast abundance in Palestine, along with their exposures. It is noticed that the north walls have a lower insulation thickness, which may be attributed to the lower time of sun exposure for this wall and the northern wind during the summer time. The South-East/West walls have the highest insulation thickness due to the effect of their exposure time to the sun. Table VII also clearly shows that using PUR insulation material reduces the OWIT drastically due to its effectiveness in insulation. The insulation thickness for EWIV walls is 40% – 50% smaller than the insulation thickness for EWI walls which is assigned to the high thermal resistance of buildings' stones. In addition, region 4 needs no insulation for all walls in the summer due to its high altitude (around 800 *m* above sea level). Whereas, the insulation thickness for walls in region 1, 2 (Jericho area) is the highest due to the altitude of Jericho (around 260 *m* below sea level).

Moreover, OWIT of heating the residential buildings via diesel and electricity over a lifetime of 10 years in the selected regions, using EPS and PUR as materials of insulations are listed in Table VIII. The insulation thickness for the EWIV walls is about (80% – 90%) less than the insulation thickness for EWI. Hence, the building stone is less significant in the heating condition. Similarly to Table VII (OWIT for cooling conditions), the insulation thickness for PUR material is smaller than it in EPS materials. As seen in Table VIII, OWIT depends on the type of heating system and source of energy; X_{ins} for the electrical heating source is about 55% less than its value in the Diesel heating source. This result is expected due to the effectiveness of the electrical heating system. In contradistinction to Table VII, region 1,2 has the smallest insulation thickness and region 4 has the largest insulation thickness and this is also expected due to the altitude of each region.

The findings of this research are quite convincing. For instance, summing up the estimated results from Tables VII and VIII, the OWIT can be ranged from 0.4 to 9 cm. In addition, the insulation type and the energy source have significant effect on OWIT. Indeed, these results line up with a recent study conducted by Alsayed and Tayeh, 2019 [9] for OWIT on Palestinian buildings.

B. *Economical analysis: Energy saving and payback period*

Table IX shows the annual total net saving (AS_C, $\$/m^2$) and the simple payback period ($SPBP_C$, *year*) in the selected regions for cooling by electricity at different insulation materials (i.e. EPS and PUR). It is clearly noticed that the $SPBP_C$ for PUR insulation material is longer than it for the EPS insulation materials due to the high cost of the PUR insulation materials. Although the $SPBP_C$ for the seven regions is very close (except region 4, which needs no insulation), region 3,7 is the longest period. The north walls for all regions have slightly longer $SPBP_C$ which may be attributed to the low cooling load need for these walls. However, the S-E/W and N-E/W walls need shorter $SPBP_C$ due to the effectiveness of the insulation for these walls, meanwhile, AS_C is the highest for these walls. The annual total net saving is the highest for region 1, 2 due to the elevated temperature during the summer time for these regions.

Nevertheless, Table X shows the annual total net saving (AS_H, $\$/m^2$) and the simple payback period ($SPBP_H$, *year*) in the selected regions for heating by electricity or diesel at different insulation materials (i.e. EPS and PUR) and for two types of wall composites (i.e. EWI and EWIV). Generally, the simple payback periods for the heating condition are shorter compared to the cooling condition, which caused by the high heating load needed during winter. The $SPBP_H$ for the seven regions is very close. The EWIV walls for all regions have slightly longer $SPBP_H$ which can be assigned to the high cost of the building stones. However, using the electrical heating system for the EWIV walls yields lower net saving AS_H and needs a longer payback period due to the high cost for both electrical energy and building stones. In addition, the AS_H for region 4 is the highest compared to the other regions, which may be assigned to the high heating loads in this region (800 m above the sea level). Hence, region 4 has the shortest $SPBP_H$ (i.e. effective heating).

TABLE VII. OPTIMAL INSULATION THICKNESS IN (CM) FOR COOLING BY ELECTRICITY.

Wall Type	Expo-sure	Region 1, 2		Region 3, 7		Region 4		Region 5		Region 6	
		X_{ins}-EPS	X_{ins}-PUR	X_{ins}-EPS	X_{ins}-PUR	X_{ins}-EPS	X_{ins}-PUR	X_{ins}-EPS	X_{ins}-PUR	X_{ins}-EPS	X_{ins}-PUR
EWI	N	1.5	0.5	1.1	0.3	0.0	0.0	1.3	0.4	1.2	0.3
	S	1.9	0.7	1.5	0.4	0.0	0.0	1.7	0.6	1.6	0.5
	E/W	2.0	0.8	1.5	0.5	0.0	0.0	1.7	0.7	1.6	0.6
	S-E/W	2.0	0.8	1.5	0.5	0.0	0.0	1.7	0.7	1.6	0.6
	N-E/W	1.7	0.7	1.3	0.4	0.0	0.0	1.5	0.6	1.4	0.5
EWIV	N	0.8	0.1	0.5	0	0.0	0.0	0.7	0.1	0.6	0
	S	1.2	0.2	0.8	0.1	0.0	0.0	1.0	0.2	0.9	0.1
	E/W	1.3	0.3	0.9	0.1	0.0	0.0	1.1	0.2	1.0	0.1
	S-E/W	1.3	0.3	0.9	0.1	0.0	0.0	1.1	0.2	1.0	0.1
	N-E/W	1.0	0.2	0.6	0	0.0	0.0	0.8	0.1	0.7	0

TABLE VIII. OPTIMAL INSULATION THICKNESS IN (CM) FOR HEATING.

Wall Type	Energy	Region 1, 2		Region 3, 7		Region 4		Region 5		Region 6	
		X_{ins}-EPS	X_{ins}-PUR	X_{ins}-EPS	X_{ins}-PUR	X_{ins}-EPS	X_{ins}-PUR	X_{ins}-EPS	X_{ins}-PUR	X_{ins}-EPS	X_{ins}-PUR
EWI	Diesel	6.3	3.0	8.7	3.8	9.1	4.0	6.6	3.1	6.1	2.9
	Electricity	3.0	1.2	3.9	1.5	4.1	1.7	3.4	1.3	2.9	1.1
EWIV	Diesel	5.7	2.4	7.8	3.4	8.1	3.7	6.0	2.6	5.6	2.3
	Electricity	2.3	0.7	3.0	1.2	3.2	1.3	2.7	0.9	2.2	0.7

TABLE IX. ANNUAL TOTAL NET SAVING (AS_C, $\$/M^2$) AND SIMPLE PAYBACK PERIOD ($SPBP_C$, YEAR) FOR COOLING BY ELECTRICITY.

Wall Type	Exposure	Region 1, 2				Region 3, 7			
		$SPBP_C$ (year)		AS_C ($\$/m^2$)		$SPBP_C$ (year)		AS_C ($\$/m^2$)	
		EPS	PUR	EPS	PUR	EPS	PUR	EPS	PUR
EWI	N	1.3	1.9	2.0	1.2	1.8	2.3	1.5	0.8
	S	1.2	1.7	3.0	1.9	1.6	2.1	2.4	1.5
	E/W	1.1	1.6	3.4	2.2	1.5	2.0	2.6	1.8
	S-E/W	1.1	1.6	3.4	2.2	1.5	2.0	2.6	1.8
	N-E/W	1.2	1.8	2.5	1.6	1.7	2.1	2.0	1.1

Wall Type	Exposure	Region 4				Region 5			
		$SPBP_C$ (year)		AS_C ($\$/m^2$)		$SPBP_C$ (year)		AS_C ($\$/m^2$)	
		EPS	PUR	EPS	PUR	EPS	PUR	EPS	PUR
EWI	N	0.0	0.0	0.0	0.0	1.5	2.0	1.6	1.0
	S	0.0	0.0	0.0	0.0	1.3	1.8	2.6	1.7
	E/W	0.0	0.0	0.0	0.0	1.2	1.7	3.0	2.0
	S-E/W	0.0	0.0	0.0	0.0	1.2	1.7	3.3	2.0
	N-E/W	0.0	0.0	0.0	0.0	1.4	1.9	2.2	1.4

Wall Type	Exposure	Region 6			
		$SPBP_C$ (year)		AS_C ($\$/m^2$)	
		EPS	PUR	EPS	PUR
EWI	N	1.7	2.2	1.5	0.8
	S	1.5	2.0	2.5	1.6
	E/W	1.4	1.9	2.7	1.9
	S-E/W	1.4	1.9	2.7	1.9
	N-E/W	1.6	2.0	2.1	1.2

TABLE X. LIFE CYCLE SAVINGS (AS_H, \$/M^2) AND SIMPLE PAYBACK PERIOD ($SPBP_H$, YEAR) FOR HEATING.

Wall Type	Exposure	Region 1, 2				Region 3, 7			
		$SPBP_H$ (year)		AS_H (\$/m^2)		$SPBP_H$ (year)		AS_H (\$/m^2)	
		EPS	PUR	EPS	PUR	EPS	PUR	EPS	PUR
EWI	Diesel	0.6	0.8	42.3	35.5	0.4	0.5	66.0	61.0
	Electricity	0.7	1.1	10.8	8.8	0.5	0.8	17.1	14.6
EWIV	Diesel	0.9	1.3	17.5	14.3	0.6	1.0	29.0	25.0
	Electricity	1.3	1.9	3.5	1.8	1.0	1.6	6.2	4.2

Wall Type	Exposure	Region 4				Region 5			
		$SPBP_H$ (year)		AS_H (\$/m^2)		$SPBP_H$ (year)		AS_H (\$/m^2)	
		EPS	PUR	EPS	PUR	EPS	PUR	EPS	PUR
EWI	Diesel	0.3	0.4	70.2	65.0	0.5	0.7	48.2	39.9
	Electricity	0.4	0.7	18.5	15.8	0.6	1.0	13.3	10.7
EWIV	Diesel	0.6	0.9	31.0	26.5	0.8	1.2	21.2	19.1
	Electricity	0.9	1.5	6.8	4.5	1.2	1.8	4.6	2.0

Wall Type	Exposure	Region 6			
		$SPBP_H$ (year)		AS_H (\$/m^2)	
		EPS	PUR	EPS	PUR
EWI	Diesel	0.6	0.9	40.7	35.1
	Electricity	0.7	1.2	10.3	8.4
EWIV	Diesel	1.0	1.4	17.1	13.9
	Electricity	1.4	2.0	3.3	1.7

CONCLUSION

In this study, the optimum wall insulation thickness along with the economic analysis have been evaluated for cooling and heating in all climatic zones in Palestine. Many parameters have been evaluated such as wall construction material, climate zone, building orientation, type of insulation, weather condition, energy prices, and heating and cooling load. HDD/CDD along with LCC method, over a building lifetime of 10 years, were adopted to estimate the OWIT, AS, and SPBP. The conclusions of this study can be summarized as follows:

1- The majority of the Palestinians' zone is approximately shared the same OWIT except for regions 1, 2, and 4 showed the opposite extremes.

2- In summer season, the north walls have a lower insulation thickness, while the South-East/West walls have the highest insulation thickness which may be attributed to the sun exposure period and the northern wind. Nevertheless, using PUR insulation material reduces the OWIT drastically due to its effectiveness in insulation.

3- OWIT is inversely proportional to the wall thermal resistance, i.e., the insulation thickness for EWIV walls is 40% – 50% smaller than the insulation thickness for EWI walls which is assigned to the high thermal resistance of buildings' stones. Similar findings observed in winter season, the insulation thickness for the EWIV walls is about (80% – 90%) less than the insulation thickness for EWI.

4- OWIT for the electrical heating source is about 55% less than its value in the Diesel heating source.

5- A contradictory behavior of insulation material was observed in terms of AS and SPBP. The comparisons between Tables VII with IX showed clearly that the $SPBP_C$ for PUR insulation material is longer than it for the EPS insulation materials due to the high cost of the PUR insulation materials which directly affected the AS.

6- While, the comparisons between Tables VIII with X showed that the $SPBP_H$ for the seven regions is very close. However, the EWIV walls for all regions have slightly longer $SPBP_H$ and it yields lower net saving AS_H for the electrical heating system, which can be attributed to the high cost for both electrical energy and building stones.

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