Simulation Study of Applying Thermal Insulation in the Condominium Rooms to Reduce Cooling Energy

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Abstract

The purpose of this research is to evaluate the effect of insulation on the reduction of air conditioning energy used in the condominium room. The base case models were built in the eQuest 3.65 energy simulation program, which will calculate the baseline energy consumption using the Bangkok meteorological data. Residential room plan in this study was adopted from previous research, which had surveyed data on room types in condominiums in Bangkok. This research created a simulated model of a 33 m^2 room located at different positions in the condominium. The total of 6 positions included the room on the left, right and center of the building that located on the top floor and the middle floor. These rooms were different in the area of interior wall, exterior wall and roof. The 75- and 150-mm thick insulation were added to the existing wall and ceiling to evaluate the reduction of air conditioning energy. The results showed that insulation reduced cooling energy by 1.9-21.3% compared to the base case. Installation of a 75-mm thick insulation on the existing ceiling of the room on top floor showed the shortest payback period of 4.4-5.5 years. For rooms on the middle floor, installation of 75- mm thick insulation on the wall of the room on the right of the building facing to north and west was also showed the simple payback period within 5 years.

Keywords: Insulation, Energy efficiency, Space cooling, Energy savings, Bangkok

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Received 1/1/2018
Revised 30/3/2018
Accepted 12/7/2018

1. Introduction

Energy use in buildings account for 24 percents of total energy use in 2017, an increase of 22 percents from 2011 (Energy Policy and Planning office [EPPO], 2018). To reduce greenhouse gas emissions and energy imports, the government has set a policy to reduce the final energy consumption by 20 percent in 2030 (Energy Policy and Planning office [EPPO], 2015). The electricity consumption in air conditioning is 47-60% of the total electrical energy used in the building. Reducing the cooling load could contribute to increasing the efficiency of the building's energy consumption, as well as saving the nation's energy. The number of condominium in Bangkok has been increasing due to high land cost and the need of residential room in the large city. There are 300–1,000 air conditioned rooms in one building, therefore high cooling energy is expected. Cooling energy reduction using insulation appropriately on the walls and/or roof of the residential rooms in the condominium could be an effective way to reduce cooling energy and lead to global warming mitigation.

The previous research showed that building envelope characteristic was widely studied in building energy simulation (Jareemit & Inprom, 2015, pp. 1-14). The thermal properties of construction materials have been studied, categorized and stored in library of the building energy simulation programs such as DOE-2 library. The new insulation materials made of agricultural waste has been invented in Thailand such as bagasse (Puthipiroj, 2011) with thermal conductivity (k) of 0.055 W/mK corn cob (Woraput, Kamhangrittirong, Surit, Hancharoen & Saimo, 2016) with k =0.66 W/mK, pineapple peel and stems (Hancharoen & Chotikaprakhan, 2016) with k=0.0320-0.0713 W/mK.

The fiber-glass insulation retailed in the market had a thermal conductivity coefficient of 0.032 W/mK (Siam Cement Group, 2016). The use of insulation not only reduced the heat transfer to the building, but also directly enhanced energy efficiency. The use of insulation in the building also supported the building to meet the green building standards such as Leadership in Energy and Environmental Design (LEED) (The U.S. Green Building Council [USGBC], 2017) and Thai's Rating of Energy and Environmental Sustainability (TREES) (Thai Green Building Institute [TGBI], 2018). Moreover, utilization of insulation promotes the invention of new insulation products and enhanced trades and industry in the country. The manufacturer of a fiber-glass insulation claims the life of fiber-glass up to 10 years, but the material may deteriorate during use, such as reduced thickness due to heat and humidity in the air (Siam Cement Group, 2016). The 3-6-inch fiber insulation cost were 188-270 THB/m^2, which may encourage the buyer if the insulation can reduce energy costs with short time payback. There is a research gap in the study of the cooling load in the condominium rooms located at difference positions in the building, i.e. the rooms on top floor, the middle floor and the rim of the building. This research investigated the effect of insulation on the reduction of the cooling energy of a residential unit in the condominium building. The total heat gain, space cooling in the one-bedroom unit positioned on the top- and middle floors facing different orientations were studied.

2. Methodology

2.1. The base case model

This study adopted the design of a condominium room of 32.82 m^2 from the previous research for the base case (Koonprueksee, 2013), where the room designs and programs were collected from 15 construction projects. The room layout and air conditioned zone are shown in Figure 1. From the given layout, the 3D building model was constructed in the eQuest program as shown in Figure 2. The room on the top floor was covered with the top roof and the room in the middle floors was enclosed by the internal ceiling. The two large windows adjacent to the terrace were shaded by the terrace of the upper floor.

The total heat resistance of materials of the exterior wall and roof (Hirsch & Associates, 2009) are shown in Table 1. The building walls are 100-mm thick precast concrete. In this study, the waterproof layer is omitted from the top floor construction. In addition to the material of the building envelope, the input data of window glass, glass area, operating schedule, efficiency of air conditioner and thermostat set point were entered into the eQuest 3.65 as shown in Table 2 to calculate the space heat gain and the space cooling energy.

The electric load such as lighting intensity and electric appliances were excluded in this study. The cooling energy consumption was calculated mainly from the building envelope heat gain. The weather file with Bangkok meteorological data was used in this study.

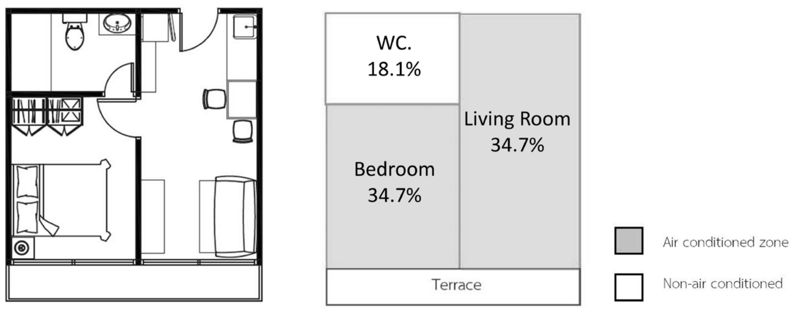

Figure 1. The layout of a unit of 32.82 m² in the condominium. (Koonprueksee, 2013)

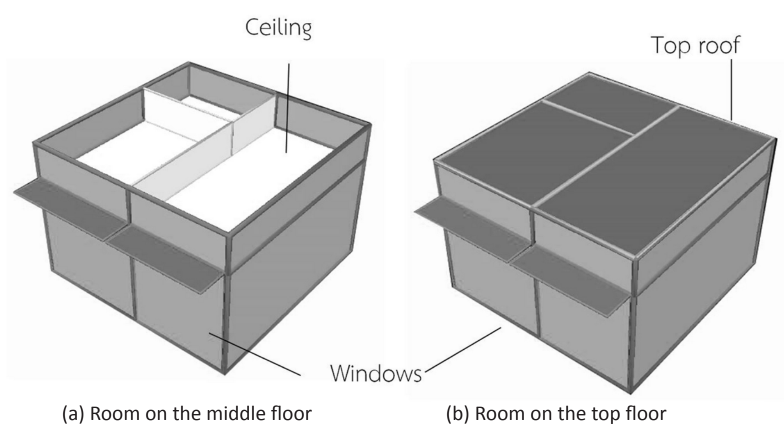

Figure 2. The 3D model of the rooms in the middle floor and the top floor of the condominium.

2.2. Positions and orientations of the room

The top roof of the rooms on the top floor were exposed to the solar radiation and ambient environment. The cornered rooms on the top floor, both on the left and on the right of the condominium, were expected to have high total heat gain due to the exposure to outdoor. Hence in this study, the condominium rooms were classified into 6 types according to its vertical and horizontal positions: (1) the top-left, (2) the top -center, (3) the top-right, (4) the middle-left, (5) the middle-center, and (6) the top-right rooms, as shown in Figure 3. In addition, the orientation of the rooms were varied in 4 orientations: (1) north, (2) south, (3) west, and (4) east. Totally, there were 24 simulated cases in the base case study.

Figure 4 shows the enclosure components of the rooms corresponding to the positions in the condominium viewing from the top. The room located at the center composed of three interior walls, one internal floor and one ceiling. The centered rooms on the top floor were covered with the top-roof materials. The exterior wall of the left room was the bedroom's wall. The exterior wall of the right room was the living room's wall. As the bed room and the living room operated in different schedules, the two rooms would show different cooling energy

Table 1. Total heat resistance (R) of the construction materials (Hirsch & Associates, 2009).

Exterior walls	R (h·ft²·°F/Btu)	R (m² K/W)	Top roof	R (h·ft²·°F /Btu)	R (m² K/W)
Concrete 140 lb. 100 mm	0.319	0.06	Concrete 140 lb. 150 mm	0.880	0.16
(Precast concrete)			Air gap	0.890	0.16
Internal air film	0.680	0.12	Gypsum panel	1.261	0.22
			Internal air film	0.620	0.11
Total	**0.999**	**0.18**	**Total**	**3.651**	**0.64**

Input	Data
Air conditioned area (m²)	Living room =10.0 m², Bed room =9.3 m²
Non air conditioned area (m²)	Water closet (WC) = 5.2 m²
Exterior wall area	Living room =19.6 m2, Bed room =12.8 m²
Interior wall material	Common brick 100 mm
Glazing material	Clear glass 6 mm U-value=1.01 SHGC=0.81 Overhang shading depth= 0.8 m
Ceiling material	Gypsum board
Interior floor material	Concrete 150 mm with ceramic tile finished
Interior insulation material	None
Area per person (m²/person)	24
Operating schedule: occupancy and air conditioning	8 am-8 pm living room 8 pm-8 am bed room
AC Energy Efficiency Ratio (EER)	11.0
Thermostat set point	25°C

Table 2. Input data of the base case model in the eQuest 3.65 program.

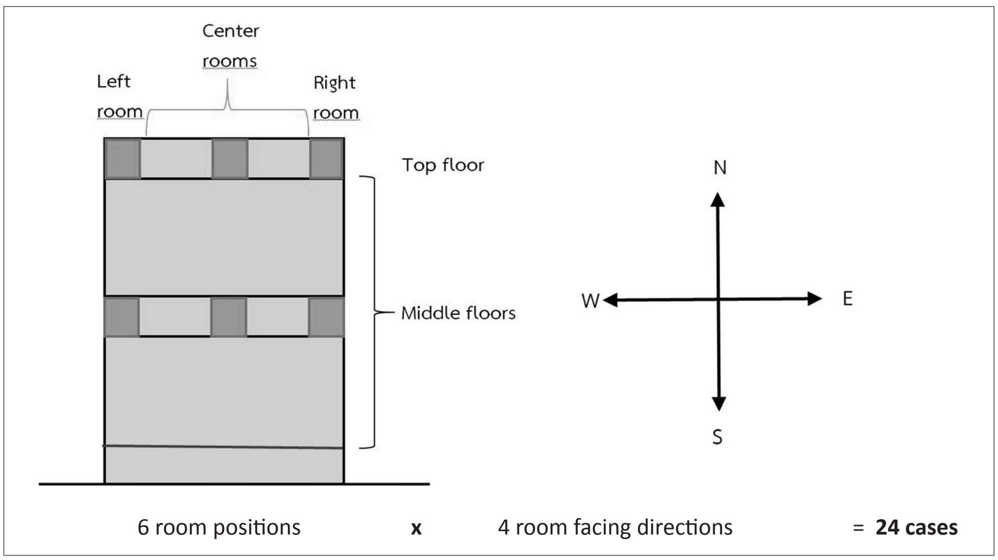

Figure 3. Room positions in the condominium and the building orientations.

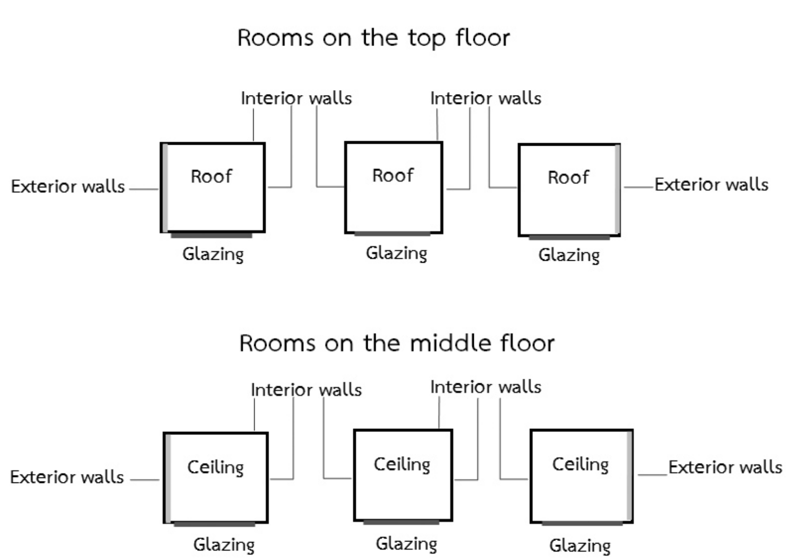

Figure 4. Materials assignment for different room positions.

Table 3. Total heat resistance (R) of the wall and roof with insulation. (Hirsch & Associates, 2009).

Exterior walls	R (h·ft2·°F/Btu)	R (m2K/W)	Top roof	R (h·ft2·°F/Btu)	R (m2K/W)
Concrete 140 lb 120 mm	0.320	0.06	Concrete 140 lb 150 mm	0.880	0.16
Fiber-glass insulation 75 mm	10[1]	1.76	Air gap	0.890	0.16
Gypsum board 12 mm	0.68	0.12	Fiber-glass insulation 150 mm	202	3.52
Internal air film	0.68	0.12	Gypsum board 12 mm	1.261	0.22
			Internal air film	0.620	0.11
Total	11.68	2.06	Total	23.65	4.17

Source: 1, 2 from manufacturer (Siam Cement Group, 2016)

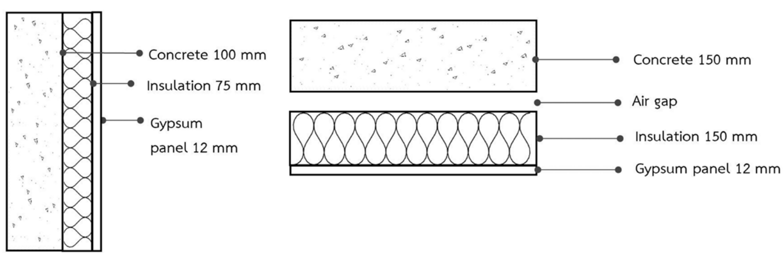

Figure 5. Insulation installation on the wall and roof of the residential room in condominium.

Table 4. Utilization of insulation in the condominium room in this study.

Insulation position	Thermal resistance $h^2 \cdot ft^2/Btu$	Insulation thickness (mm)	Middle floor Left	Middle floor Center	Middle floor Right	Top floor Left	Top floor Center	Top floor Right
Exterior wall	R=10	75	√	-	√	√	-	√
Top roof	R=10	75	-	-	-	√	√	√
Top roof	R=20	150	-	-	-	√	√	√
Roof and wall	R=10	75	-	-	-	√	-	√
Roof and wall	R=20 (Roof) R=10 (Wall)	150 75	-	-	-	√	-	√

consumptions.

2.3 Installation of insulation materials

The fiber-glass insulation with thickness of 75 mm and 150 mm with thermal conductivities (k) of 0.0377 W/mK were selected in this study. The thermal resistance (R) of the insulation with thickness of 75 mm. and 150 mm. provided by the manufacture were 10.0 h·ft2·°F /Btu (1.76 m^2K/W) and 20.0 h·ft2·°F /Btu (3.52 m^2K/W), respectively (Siam Cement Group, 2016). Therefore, installation of the insulation to the wall or roof increases the thermal resistance by 11.7-23.7 h·ft2·°F /Btu as shown in Table 3. Figure 5 illustrates the layers of roof and wall with insulation.

Table 4 shows the utilization of insulation on the roof and/or wall of the condominium units in this study. There was no insulation installation in the units locating in the center room on the middle floor because there were no exterior wall or roof in these units. The insulation with thickness of 75 mm. and 150 mm. were installed on the roofs of the center room on the top floor. The wall insulation with thickness of 75 mm were applied in the left and right rooms. The 75 mm. fiber-glass insulation was selected for the wall to avoid the loss of interior space. Normally, the insulation used in wall/roof are different densities. Therefore, they have different R-values at the same thickness. This study assumes the application of insulation with similar

R-values for wall and roof.

2.4 The eQuest 3.65 program

The eQUEST is the building energy simulation program with DOE 2 engine with the wizards and graphic built in. eQUEST is a free program widely used for engineers and energy modeler. Figure 6 shows the procedures of the simulation. The input data was divided into the weather file, the Building Load, the System and Plant. In this study, the input data into the Building Load computation included building form, building construction materials, building orientations, A/C zoning, operating schedules and air infiltration. All opaque building envelopes were delayed calculation, i.e. time dependent heat transfer. The input data into the System computation included air conditioning type, energy efficiency ratio (EER) of air conditioning system, thermostat setting, fan motor efficiency, and supply air schedule. The Plant calculations were omitted because the air conditioning was split-type and the energy consumption was derived from the system calculation. The computed results extracted from the Building Load to consider in this study were the building peak load components of each room. The computed results extracted from the system and considered in this study were the summary of monthly electricity consumption and the peak electricity demand.

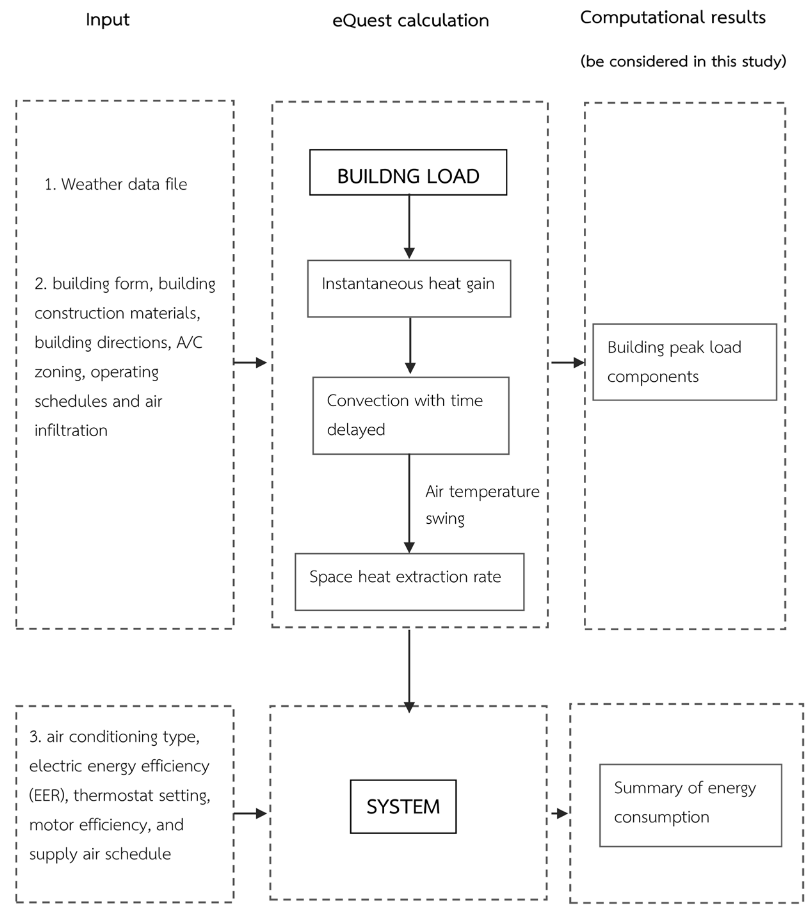

Figure 6. Calculation procedures in eQuest program

3. Simulation results of the base-case rooms

3.1. The room peak load components

Study of the building peak load components gave an insight of the instantaneous heat gain hence the high heat gain building components were identified and proper energy efficiency measures were applied. Table 5 shows the summary of cooling peak load of the room in different positions and orientations. The room with maximum peak cooling load were the rooms with west orientation located at the right of the building on the top floor. The maximum peak cooling load was 6.1 kW, happened on April, 30 at 6 PM when the outside air temperature was 36.7 ˚C. As shown in Table 5, rooms on the right of the building showed the highest cooling load compared to rooms in other positions because the room on the right had the living room with air conditioning during 8 AM - 8 PM. The peak cooling load of the rooms facing north located at the center of the middle floor was 16.7-59 % less than rooms in other positions and orientations. In winter, the peak cooling load happened around 3-4 PM for the room facing south and in summer at 6 PM for the room facing west.

Table 5. The results of room cooling peak load (kW).

Orientation	Position		Peak cooling			Temperature	
	Vertical	Horizontal	Load (kW)	Day	Time	Dry bulb	Wet bulb
South	Mid floor	Center	3.5	DEC-14	3:00 PM	34.4	23.9
		Left	4.3	DEC-14	4:00 PM	34.4	24.0
		Right	5.1	DEC-14	4:00 PM	34.4	24.0
South	Top floor	Center	3.7	DEC-14	3:00 PM	34.4	23.9
		Left	4.5	DEC-14	4:00 PM	34.4	24.0
		Right	5.2	DEC-14	4:00 PM	34.4	24.0
West	Mid floor	Center	3.8	APR-30	6:00 PM	36.7	24.4
		Left	5.0	APR-30	6:00 PM	36.7	24.4
		Right	5.8	APR-30	6:00 PM	36.7	24.4
West	Top floor	Center	4.3	APR-30	6:00 PM	36.7	24.4
		Left	5.3	APR-30	6:00 PM	36.7	24.4
		Right	6.1	APR-30	6:00 PM	36.7	24.4
East	Mid floor	Center	3.0	JUN-1	11:00 AM	33.0	25.6
North	Mid floor	Center	2.5	JUN-1	5:00 PM	35.6	26.1

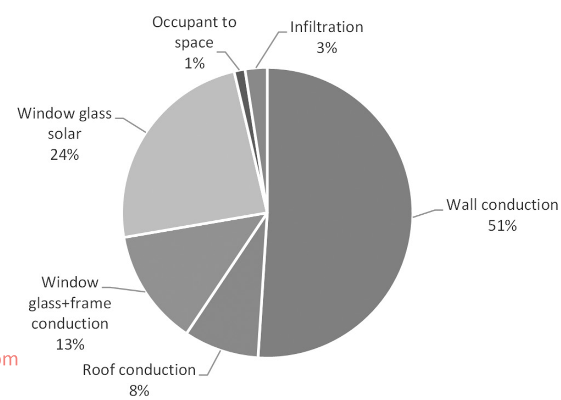

Figure 7. The average room peak load components.

The breakdown of the source of heat gain is shown in Figure 7. The two highest shares of heat gain of 51% and 24% were conduction through wall and solar gain through window. It was implied that a large concrete wall and large window pane of the living rooms were the key factors of high heat gain and application of insulation to the wall could be an effective solution.

3.2 Electricity consumption from space cooling

Figure 8 shows the simulated results of electric consumption due to room cooling in this study. The high energy for cooling was found in the room on the right, where air conditioned living room was operated and the room face to south and west. Energy consumption was moderate in the rooms located at the center and those on the left side of the building because centered room's walls was internal walls and rooms on the left used A/C during the night time. The room facing north consumed minimum electrical energy due to less heat gain in the north orientation.

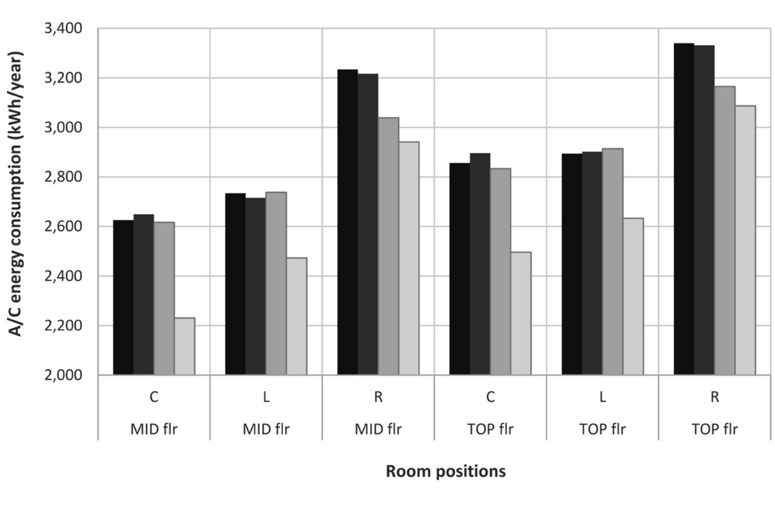

Figure 8. Electrical energy consumption from space cooling in the rooms with different positions and orientations.

4. Simulation results of the insulated rooms

Table 6 shows annual electric consumption and electrical energy savings for rooms at the top floor. The insulated walls of room located at the center can reduce electricity consumption by 6.4-10.2% compared to the base case. The insulated ceiling of rooms on the left and right of the building slightly reduce electricity consumption by 2.3-6.5% because the heat gain through roof was moderated. As shown in Figure 7, the ceiling of the room on the top floor was covered with the built-up roof and the air gap that prevent the heat gain through roof. The insulated walls in the rooms on the right reduced electricity consumption by 11.5-15.0%. The insulated wall together with the insulated roof in the room on the right reduced electricity consumption by 15.7-21.3%. The insulated wall and insulated roof of the room on the left also reduced energy consumption approximately 10.0-13.0 % compared to the base case. Hence, adding insulation in the wall and/or ceiling reduced cooling energy in all rooms. The exterior wall of the rooms with A/C operating on the daytime consumed highest cooling energy. Adding an insulation in these rooms enhanced the energy saving. Table 7 shows the results of electrical energy savings of the room in the middle floor after adding insulation on the exterior wall. The energy saving of the room on the right of the building was 9.1-13.0% higher than those of the room on the left.

Table 6. Simulation results of electrical energy consumption and savings in the room with insulation (top floor).

Cases	Top	center	Top	right	Top	left
	Electric consumption (kWh/y)	Energy saving (%)	Electric consumption (kWh/y)	Energy saving (%)	Electric consumption (kWh/y)	Energy saving (%)
South						
Base case	2,856.50		3,340.10		2,893.80	
75 mm. Insulation (wall)			2,839.40	15.0	2,726.00	5.8
75 mm. Insulation (ceiling)	2,667.40	6.6	3,262.90	2.3	2,775.90	4.1
150 mm. Insulation (ceiling)	2,636.40	7.7	3,250.80	2.7	2,757.60	4.7
75 mm. insulation (wall & ceiling)			2,704.90	19.0	2,583.50	10.7
150 mm. insulation (wall & ceiling)			2,684.30	19.6	2,561.10	11.5
North						
Base case	2,496.00		3,086.50		2,633.10	
75 mm. Insulation (wall)			2,726.00	11.7	2,584.20	1.9
75 mm. Insulation (ceiling)	2,277.30	8.8	2,979.90	3.5	2,483.60	5.7
150 mm. Insulation (ceiling)	2,241.70	10.2	2,963.70	4.0	2,462.00	6.5
75 mm. insulation (wall & ceiling)			2,453.40	20.5	2,348.00	10.8
150 mm. insulation (wall & ceiling)			2,428.40	21.3	2,321.40	11.8
West						
Base case	2,895.70		3,331.90		2,902.40	
75 mm. Insulation (wall)			2,905.40	12.8	2,800.80	3.5
75 mm. Insulation (ceiling)	2,694.60	6.9	3,251.50	2.4	2,782.90	4.1
150 mm. Insulation (ceiling)	2,661.90	8.1	3,237.00	2.8	2,744.30	5.4
75 mm. insulation (wall & ceiling)			2,757.40	17.2	2,642.10	9.0
150 mm. insulation (wall & ceiling)			2,734.20	17.9	2,617.20	9.8
East						
Base case	2,833.50		3,165.30		2,913.70	
75 mm. Insulation (wall)			2,801.90	11.5	2,715.50	6.8
75 mm. Insulation (ceiling)	2,652.80	6.4	3,070.90	3.0	2,782.90	4.5
150 mm. Insulation (ceiling)	2,622.60	7.4	3,057.00	3.4	2,762.80	5.2
75 mm. insulation (wall & ceiling)			2,667.20	15.7	2,559.60	12.2
150 mm. insulation (wall & ceiling)			2,646.30	16.4	2,535.90	13.0

Table 7. Simulation results of electrical energy consumption and energy savings in rooms with insulated wall (middle floor).

Cases	Building orientation	Middle right Energy (kWh/y)	Middle right Energy saving (%)	Middle left Energy (kWh/y)	Middle left Energy saving (%)
Base case	South	3234.3		2,733.70	
75 mm. Insulation (wall)		2655.3	9.1	2,531.10	9.5
Base case	North	2941.3		2,472.80	
75 mm. Insulation (wall)		2394.1	16.9	2,285.90	6.8
Base case	West	3217.1		2,716.20	
75 mm. Insulation (wall)		2702.3	15.9	2,583.40	4.9
Base case	East	3038.3		2,737.40	
75 mm. Insulation (wall)		2617.0	13.0	2,505.50	8.5

Table 8. Material costs of insulation installation

Material	Area (m^2)	Frame and finishing materials (THB/m^2)	Insulation material (THB/m^2)	Total material cost (THB/m^2)
75 mm. Insulation (living room wall)	19.63	1300	2187.5	487.5
75 mm. Insulation (bed room wall)	12.82	300	187.5	487.5
75 mm. Insulation (ceiling)	19.31	0	187.5	187.5
150 mm. Insulation (ceiling)	19.31	0	2270.8	270.8

Source: 1. (Siam Cement Group, 2016)
2. (King Mongkut's Institute of Technology Ladkrabang, 2013)

5. The simple payback period

The cost of insulation was high and a criteria to help decision making was required. The insulation lasted about 10 years but it deteriorated due to heat and humidity. This research considered a criteria of payback period of 5 years. The payback period (PP, year) was calculated from material cost (MC, THB) divided by the electrical energy saving (ES, THB/year) shown in Eq.1,

$$PP = \frac{MC}{ES} \quad \text{(Eq.1)}$$

The material cost for wall insulation included the insulation cost, frame and finishing cost as shown in Table 8. Insulation laid on the existing ceiling required no frame or finishing, therefore adding insulation to the ceiling was less expensive. The cost of frame and finishing was higher than the insulation cost, 300 Thai Baht per m^2 (King Mongkut's Institute of Technology Ladkrabang, 2013) and it possibly will effect the payback period.

Electrical energy savings (ES, THB/year) was calculated from Eq.2 as follows:

$$ES = EC \times (E_{base} - E_{insu}) \quad \text{(Eq. 2)}$$

where EC is the electrical energy cost per kWh (THB/kWh), E_{base} is the electrical energy consumption in the base case room, and E_{insu} is the electrical energy consumption in the insulated room (kWh/year)]

The electrical energy cost was 4.5 THB/kWh for a residential house with consumption between 250-400 kWh/month. The calculated results of payback periods of rooms in the top and middle floors are shown in Table 9 and Table 10, respectively. As shown in Table 9, the centered rooms on the top floor with insulation of 75 mm thickness achieved a pay back within 5 years. The rooms on the left and right of the building showed longest time of 22.9 years to get pay back from installing an insulation because too low energy savings and too high installation cost in these room types. For rooms in the middle floor shown in Table 10, the shortest payback period were 4.7 and 5.0 years in the insulated room on the right that face to north and west, respectively. Referring to energy saving of 16-17% in these rooms in the middle floor (Table 7) and the moderate the investment cost, the payback time within 5 years was possible.

Table 9. Calculated results of investment cost and payback period of insulated rooms (top floor).

Cases	Top center		Top right		Top left	
	Investment (THB)	Payback (year)	Investment (THB)	Payback (year)	Investment (THB)	Payback (year)
South						
75 mm. Insulation (wall)			6,250.05	10.0	9,567.56	5.1
75 mm. Insulation (ceiling)	3,621.46	5.0	3,621.46	8.2	3,621.46	12.6
150 mm. Insulation (ceiling)	5,230.93	6.4	5,230.93	10.3	5,230.93	15.7
75 mm. insulation (wall & ceiling)			21,691.17	18.7	26,284.64	11.1
150 mm. insulation (wall & ceiling)			24,368.99	19.6	29,529.53	12.1
North						
75 mm. Insulation (wall)			6,250.05	34.3	9,567.56	7.1
75 mm. Insulation (ceiling)	3,621.46	4.4	3,621.46	6.5	3,621.46	9.1
150 mm. Insulation (ceiling)	5,230.93	5.5	5,230.93	8.2	5,230.93	11.4
75 mm. insulation (wall & ceiling)			21,691.17	20.4	26,284.64	11.1
150 mm. insulation (wall & ceiling)			24,368.99	21.0	29,529.53	12.0
West						
75 mm. Insulation (wall)			6,250.05	16.5	9,567.56	6.0
75 mm. Insulation (ceiling)	3,621.46	4.8	3,621.46	8.1	3,621.46	12.1
150 mm. Insulation (ceiling)	5,230.93	6.0	5,230.93	8.9	5,230.93	14.8
75 mm. insulation (wall & ceiling)			21,691.17	22.3	26,284.64	12.3
150 mm. insulation (wall & ceiling)			24,368.99	22.9	29,529.53	13.2
East						
75 mm. Insulation (wall)			6,250.05	8.5	9,567.56	7.1
75 mm. Insulation (ceiling)	3,621.46	5.4	3,621.46	7.4	3,621.46	10.3
150 mm. Insulation (ceiling)	5,230.93	6.6	5,230.93	9.3	5,230.93	12.9
75 mm. insulation (wall & ceiling)			21,691.17	16.4	26,284.64	14.1
150 mm. insulation (wall & ceiling)			24,368.99	17.3	29,529.53	15.3

Table 10. Calculated results of investment cost and payback period of insulated rooms (middle floor).

Cases	Mid Investment (THB)	right Payback (year)	Mid Investment (THB)	left Payback (year)
South				
75 mm. Insulation (wall)	9,567.56	8.8	9,567.56	9.8
North				
75 mm. Insulation (wall)	9,567.56	4.7	9,567.56	13.7
West				
75 mm. Insulation (wall)	9,567.56	5.0	9,567.56	19.3
East				
75 mm. Insulation (wall)	9,567.56	6.1	9,567.56	11.1

6. Conclusions

This study investigated the energy reduction due to applying insulation to the residential rooms located at different positions in the condominium. The different positions associated with the different exterior walls and roofs where different heat gain penetrated into the room. The energy consumption in the base case room and the room with insulation were simulated in eQuest 3.65 computer program The energy savings in the rooms with an insulation at different positions were dissimilar. For example installation of a 75-mm. thick insulation resulted into 2.3-6.6 % of energy saving, varied from in the room on the left, centered, and on the right of the building. The highest energy savings was found in the installation of 75-mm. and 150-mm. thick insulation at the wall and ceiling but the cost of installation was also high. The application of insulation with 75 mm. thickness on the existing ceiling of the rooms on the top floor showed the shortest payback time of 4.4-5.5 years. The 75-mm. thick insulation also recommended to be used for walls of the room in the middle floors with exterior wall exposed to outdoor.

Acknowledgement

Authors would like to thank Ms. Pattarakon Limchutrakul, Ms. Pantaree Wilaianchali, Ms. Jinwara Arunchanayuth, Ms. Sarida Phromtan, and Ms. Praphatson Saemmongkhon for data collecting and preliminary assessment of the room models.

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