Energy Efficiency and Economical Analysis of Constructions Materials for Controlled Buildings in Thailand

S. Phetcharat

***Abstract*—Comparison of heat transfer reduction efficiency of construction materials and its economical worthiness was performed for materials popularly used in the construction industry in Thailand. Heat transfer through walls and roofs on the southern side of a model constructed according to the criteria and specifications for controlled buildings in the category for offices and educational institution as announced by the Ministry of Energy. Economical analysis results show that foam cellocrete is the best wall material for heat resistance properties with an OTTV value of 18 W/m^2 but lightweight concrete is more cost effective with a B/C ratio of 2.93 and a payback period of 1 year and 7 months. For the best concrete block arrangement, double walls with gap, has B/C ratio value of 2.56. Light screening film on glass or double glass walls help to lower the heat transfer rate but not to the required 50 W/m^2 by the Ministry of Energy. Thus, it should be integrated with other materials at the appropriate portions. For roofing materials, the best material for heat insulator is polyurethane foam but the most cost-effective material is polystyrene foam with highest B/C = 1.12 and a return period of 4 years and 5 months.**

***Index Terms*—Construction materials, energy conservation, controlled buildings.**

I. Introduction

Countries around the world are aware of the importance of energy conservation. Policies have been issued to support the use of energy efficiently and effectively in order to reduce the investment costs required in maintaining the national energy supply. Thailand issued her first Energy Conservation Promotion Act in 1995 (B.E. 2538) and amended in 2007 (B.E.2550). Within this Act, there is a clause on taking care of, promoting and assisting energy conservation in a concrete manner. There are 7 types of buildings under the controlled category including hospitals, academic institutes, office building, apartments, meeting halls, event buildings, hotels, entertainment/service buildings and shopping centers. Under this clause, all of the stated building types with an area of more than 2000 m^2 must incorporate an energy conservation plan when submitting for a construction permit or a building amendment permit [1]. The specification for the overall heat transfer rate, the luminosity and lighting inside the building and the ventilation system used in the design must be in accordance to the regulations announced by of the Ministry of Energy [1], [2]. If there is non-compliance to the set regulations then the overall energy usage of the building must considered prior to obtaining the construction permit. Set regulations according to the Energy Conservation Act requires specific material selection and design criteria that is appropriate to the condition so that Overall thermal transfer value (OTTV) and the Roof thermal transfer value (RTTV) is in accordance to Ministerial specifications [1]. Each type of wall and roofing material has different heat resistant properties. The price for materials is proportional to its heat resistance efficiency, the more the efficiency, the pricier the item [3]. However, the materials with higher heat resistant efficiency will help reduce the cost of electricity borne from use of air conditioning system. Therefore, it is important to perform an economical analysis and heat prevention properties of walls and roofing materials because it plays a significant role in the material selection process. The information from the analysis not only significantly contributes to the selection of materials that impacts electrical energy consumption by air conditioning system in controlled buildings but it also helps in the selection of the equipment and electrical appliances required for use in those buildings accordingly.

Manuscript received February 10, 2013; revised May 17, 2013.

The author is with Department of Civil Engineering Department, Srinakharinwirot University, 63 Moo 7 Ongkharak, Nakornnayok, Thailand (e-mail: sudniran@swu.ac.th).

II. Methodology

Calculations for heat transfer capacity through walls and roofs for each side $OTTV_i$ and $RTTV_i$ are according to (1) and (2) respectively using the specifications for controlled buildings type academic institution and office buildings as the controlled factor [4]. This specification states that the OTTV must not exceed 50 W/m^2 and RTTV must not exceed 15W/m^2 [1]. The wall model in Fig. 1 is used for calculating the heat transfer value through the wall. For Fig.1a) the wall model uses one type of material throughout the wall. 9 types of materials were used for the comparison including brick, concrete block, light-weighted concrete, cellocrete, cellocrete foam, hard wood, clear glass, tinted glass, and titanium-chapped mirror. In Fig.1b) another wall model was used, for this model, the walls are plastered in concrete and painted which is the general practice in construction, this is used to compare the properties of materials except for glass-type materials. For Fig.1c)-d) the wall arrangement used re double walls with and without gap in between. This is the technique for heat ventilation popularly used in Thailand.

The roof model in Fig. 2 is used for calculating the overall heat transfer from the roof. Both models are walls and roofs on the south side of the building. This is the direction with the

DOI: 10.7763/IJET.2013.V5.602

most impact from the sun. The roofs in Fig. 2a) were modeled using consistent materials, 3 roof and 2 ceiling materials were used including concrete roof tiles, cement roof tiles and asphalt roof tiles and gypsum board and smooth ceramic tiles. Fig. 2b) is the roof model constructed using each of the selected materials to test 5 insulation materials including optic fiber insulation, Rockwool insulation, Polystyrene foam, Polyethylene foam and Polyurethane foam.

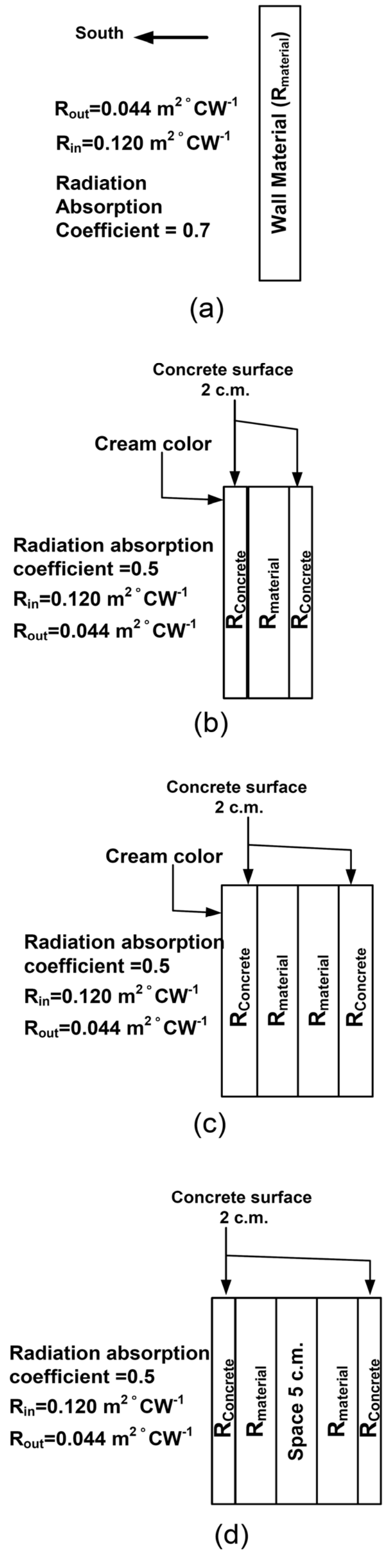

Fig. 1.Wall models; (a) Single material wall model, (b) Painted concrete plastered walls model; common construction method, (c) Double wall model and (d) Double wall with gap model

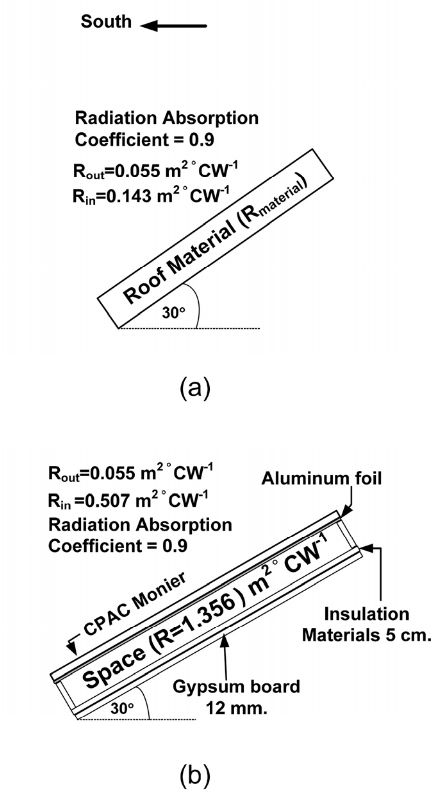

Fig. 2. Roof models; (a) Single material roof model and (b) Mixed roof material model

$$OTTV_i = (U_W)(1 - WWR)(TD_{eq}) + (U_f)(WWR)(\Delta T) + (WWR)(SHGC)(SC)(ESR) \quad (1)$$

$$RTTV_i = (U_r)(1 - SRR)(TD_{eq}) + (U_s)(SRR)(\Delta T) + (SRR)(SHGC)(SC)(ESR) \quad (2)$$

From (1) and (2), heat transfer will be a function of the coefficient of total heat transfer for opaque walls and roofs (U_w and U_r), the ratio of transparent walls and roofs (WWR and SRR), Temperature different equivalent (TD_{eq}), the coefficient of heat transfer for transparent walls and roofs (U_f and U_s), the difference between indoor and outdoor temperature (ΔT), the solar heat gain coefficient through transparent walls or roofs (SHGC), the shading coefficient (SC) and the effective solar radiation (ESR) of transparent walls or roofs.

The appropriate amount of required electrical energy for air conditioning system to reduce heat can be calculated using (3) [4]. Assumptions for usage include the use of air conditioning machine for 12 hours a day for 22 days a month [5]. The efficiency of the air conditioning machine is 80% [3] and the cost of electricity is 3.85 THB/unit. Lastly, the Benefit Cost Ratio (B/C) is then calculated using (4) to obtain economical comparison data for the materials. Other than that, the payback period is calculated for the Benefit Cost Ratio =1.

$$W = \frac{Q \times 3.142}{EER \times 1000} \text{ kW} \quad (3)$$

$$B/C = \frac{\sum_{t=1}^{n} B_t (P/F, i\%, n)}{I + \sum_{t=1}^{n} C_t (P/F, i\%, n)} \quad (4)$$

The electrical energy consumed by the air conditioning machine (W) is dependent on the heat ventilation ratio (Q) and the Energy Efficiency Ratio (EER). For air conditioning machines with the No.5 energy efficiency label (Thai energy efficiency rating), the EER = 10.6 Btu $h^{-1}W^{-1}$. The Benefit Cost Ratio calculated from B_t. C_t is the benefit and expenditure of the project at year t. I Is the initial expense at the beginning of the project, n is the duration (n = 5 yrs) and is the interest per year (i = 5%). The benefits and investment is the cost of electrical energy used for the air conditioning system and cost of materials when compared with the cheapest material in the list for selection.

III. Analysis and Results Discussion

A. Wall Materials

The price of construction materials, the result of heat transfer calculation for each wall materials according to the model in Fig. 1(a) and the economical analysis in terms of Benefit Cost Ratio. The B/C ratio is comparing the cost of electrical energy used for air conditioners against the cost of concrete block materials as shown in Table I.

TABLE I: Heat Transfer Values for Wall Materials

Materials	Price (THB/m^2)	OTTV (W/m^2)	B/C (t=5 yrs)	Payback period (yrs)
1. Brick; thickness= 7.5 cm.	185	63	0.00	-
2. Concrete block; thickness 7.5 cm.	100	63	0.00	-
3. Light-weighted concrete; thickness 7.5 cm.				
-density 620 kg/m^3	216	38	2.93	1.6
-density 960 kg/m^3	416	52	0.47	12.5
-density 1280 kg/m^3	625	64	-0.03	-
4. Cellocrete; thickness7.5 cm.	708	25	0.85	6
5. Cellocrete foam; thickness 7.5 cm.	1256	18	0.53	10.8
6. Hard wood; thickness 1 cm.	630	109	-1.18	-
7. Clear glass; thickness 0.6 cm.	221	225	-18.21	-
8. Tinted glass; thickness 0.6 cm.	286	168	-7.68	-
9. 20%Titaniam-chapped mirror; thickness 0.6 cm.	1050	102	-0.56	-

Wood is one of wall materials that has higher than standard OTTV. In the present, it is not popularly used as wall materials for buildings designed for use of air conditioning system. On the other hand, glass is another material that has high ventilation properties but is a popular material for office buildings due to its transparency quality that lets light through which helps indoor luminosity level and allows occupants to have a good view for recreation. Furthermore, it is believed that glass panes give the building a modern touch. The material that best prevents heat from outside coming in to the inside of the building is cellocrete foam. At the same time, cellocrete foam is the most expensive material in the market and thus its use is limited. For a 5-year utilization period of cellocrete foam as wall material, it is found that the B/C = 0.53 and has a payback period of 10 years and 10 months. In comparison, light-weighted concrete blocks with a density of 620 g/m^3 is the best in its category with the B/C = 2.93 and the payback period of 1 year and 7 months.

TABLE II: The Total Heat Transfer Values of Wall Materials that Reduce Heat Inside the Buildings and its Economical Analysis results. Arrangement of Channels

Materials	OTTV (W/m^2)	Price (THB/m^2)	B/C (t=5 yrs)	Payback period (yrs)
Case 1 Concrete plastered on both sides and painted in cream				
1.1 Bricks	38.38	315	-0.07	-
1.2 Concrete blocks	37.96	230	0.00	-
1.3 Light-weighted concrete blocks (density 620 kg/m^3)	22.94	346	1.76	2.7
1.4 Cellocrete	16.51	838	0.48	12.3
1.5 Cellocrete foam	11.83	1386	0.31	25
Case 2 Double walls, concrete plastered on both sides and painted in cream				
2.1 Bricks	24.56	500	0.68	7.9
2.2 Concrete blocks	25.01	330	1.76	2.7
Case 3 Double walls with gap in between, concrete plastered on both sides and painted in cream				
3.1 Bricks	19.14	500	0.95	5.3
3.2 Concrete blocks	19.13	330	2.56	1.8

TABLE III: Cost and Heat Transfer Values of Glass Materials

Type of Glass	OTTV (W/m^2) (Price (THB/m^2))			
	Normal	Film-coated	Double layer glass	Double layer glass with film coat
Clear	225 (221)	109 (1641)	212 (442)	97 (1842)
Tea-colored tint	168 (286)	86 (1686)	166 (572)	83 (1972)
Mirror	102 (1050)	59 (2450)	100 (2100)	58 (3500)

Light screening film with S.C=0.41 costs 1400 THB/m^2

Most wall material has higher OTTV than specified by the Ministry of Energy. Therefore, it is important to use construction techniques that support ventilation keeping indoor heat lower than the specified limit and creating economical benefits. The walls in the models are plastered with concrete and painted as other general buildings as shown in Fig. 1(b) which helps to reduce heat transfer into the building. Other than that the double wall technique in Fig. 1(c) or double walls with a gap in between in Fig. 1(d) are popular methods to help reduce heat transfer. Table II shows the calculation results for heat transfer of walls constructed according to models in Fig. 1 (b) –(d) and the B/C comparing the cost for electricity from air conditioning and materials against material costs and concrete blocks plastered with concrete on both sides and painted in cream.

It was found that the most cost effective method with a B/C = 2.56 and a payback period of 1 year and 10 months is the model of double wall concrete blocks with a gap in between while outside is plastered with concrete and painted crème. This method has one limitation, due to the space it consumes the utilization area of the building is decreased. Light-weighted concrete blocks used with the same technique of being plastered in concrete on both sides and painted in crème color has a reduced B/C ratio of 1.76 and has a payback period of 2 years 9 months but does not have the same limitations with spacing. For the material that is widely used in the construction industry is brick. Bricks are more expensive than concrete blocks and have higher heat transfer value, still, after being plastered on both sides with concrete and painted with crème colored paint, its OTTV= 38.38 W/m^2 which is lower than specified standard. However, in terms of investment purposes for energy conservation it is not advised as its B/C= -0.7. Bricks are materials that are necessary in construction and are not easily substitutable as its porosity properties are desirable for walls used in wet areas such as bathrooms. This will help reduce the load on the air conditioner in maintaining indoor moisture [6].

Glasses are material with high heat transfer values therefore light screening films are popularly used with this material. Another method for construction using glass is to use double wall with gap method. This method helps to reduce heat transfer as shown in Table III. It is found that light screening film with S.C.=0.41 can reduce the heat transferred into the building at from 41-52 percent while the cost of material is higher by 7.78 times for clear glass, 5.89 times for tea-colored tinted glass and 2.33 times for mirrors. Double layer glass walls with gaps for 13 mm and more will reduce heat transfer by 1.5-5.7 percent where the cost of construction materials is doubled. However, it must be noted that using glass as wall materials is not aimed at energy conservation or economical benefits because its heat transfer properties is higher than the specified standard. Glass walls are purely for design and lighting purposes. It will in part contribute to reduction of lighting costs.

The use of light screening film or double glass walls still have OTTV higher than specified standard therefore it should be used as integrated material with other materials to create the appropriate condition and maintain the heat transfer value below the standard. For example, it should be designed to integrate with light-weighted concrete block walls that is plastered on both sides with cement and painted in crème color. For this case, if film coated clear glass is designed at 30 percent of the wall area, the OTTV= 48.89 W/m^2. Similarly, with 40 percent tea-colored tinted glass, OTTV = 48.29 W/m^2 and 70 percent wall area of mirrors, OTTV = 48.14 W/m^2. If the design requires more glass in the walls, then other light screening film with S.C. value of lower than 0.41 can be used, else, it should be used along with other materials with lower heat transfer values than light-weighted concrete such as cellocrete or cellocrete foam.

B. *Roof Materials*

The heat transfer values for roofing materials are calculated according to the model in Fig. 2 (a). The results as shown in Table IV indicate that there are 3 types of roofing materials with similar values, 235-239 W/m^2. These materials are concrete roofing tiles, cement roof tiles and asphalt roofing tiles. For ceiling materials, it was found that gypsum boards are the best for heat prevention. However, a roof without insulator will still have the RTTV higher than the specified standard. Therefore, all controlled buildings must have insulator linings on the ceiling to reduce the heat transfer to the required limit. Each type of insulation material has different capacity and can prevent heat transfer into the buildings at different rates. The heat transfer of each type of material is compared using RTTV for roofs on the southern side according to the model in Fig. 2 (b). The results shown in Table V will be the comparison of the heat transfer values of each material and it's the B/C ratio. The B/C ratio is comparing the electricity costs and the material costs for using and not using insulation material.

TABLE VI: THE PRICE OF MATERIALS AND THE OTTV OF ROOFING MATERIALS

Materials	Price (THB/m^2)	OTTV (W/m^2)
1. 11 mm concrete roof tiles	144	234.91
2. 4 mm cement roof tiles	112	237.76
3. 4mm asphalt roof tiles	210	238.62
4. 12 mm gypsum board	97	200.43
5. 4 mm smooth ceramic tile	57	237.83

TABLE V: HEAT TRANSFER VALUE OF DIFFERENT INSULATION MATERIALS AND ITS ECONOMICAL ANALYSIS

Materials	Price (THB/m^2)	RTTV (W/m^2)	B/C (t=5 yrs)	Payback period (yrs)
No insulation material	-	20.49	0.00	-
Optic fiber insulation	110	13.20	0.90	5.6
Rockwool insulation	140	12.41	0.79	6.6
Polystyrene foam	87	13.30	1.12	4.4
Polyethylene foam	295	10.91	0.44	13.8
Polyurethane foam	620	9.74	0.24	51

Table V shows that the use of all 5 materials, optic fiber, Rockwool insulation, polystyrene foam, polyethylene foam and polyurethane foam at 5 mm thickness all contributes to reducing heat transfer from the roof to below standard specifications. The economical analysis found that polystyrene foam has the best B/C for investment purpose, B/C= 1.12 and payback period of 4 years and 6 months. Therefore, for best cost efficiency, polystyrene should be used as insulator in the construction industry. However, if the aim is to conserve energy and reduce the load on air conditioning system, polyurethane foam should be used because it has the best heat prevention property.

IV. Conclusion

A. The Comparison of the Efficiency of Heat Prevention Property Found that

1) Cellocrete foam is the wall material with the best heat prevention efficiency where its OTTV= 18 W/m^2

2) Reducing the amount of heat transfer from glass with light screening film at S.C 0.41 or using double glass walls reduces the heat transfer through walls to lower than 50 W/m^2

3) Walls that are plastered with 2 mm thick cement and painted with crème color paint using different wall materials including bricks, concrete blocks, light-weighted concrete blocks, cellocrete and cellocrete foam reduces the OTTV to lower than specified standard of 50 W/m^2. Cellocrete foam has the lowest OTTV at 11.83 W/m^2.

4) For the insulator category, the best insulator is polyurethane foam. This material prevents the most heat and has an OTTV = 9.74 W/m^2.

B. Economical Analysis Shows that

1) Using light-weighted concrete blocks with the density of 620 kg/m^3 has the best payback period of 1 year and 7 months and for the 5 year period has the B/C = 2.93.

2) The construction technique used in reducing heat transferring into the building using double layer concrete block walls plastered on both sides with cement and painted using crème color painting is the most economically efficient with B/C=2.56 and a payback period of 1 year and 10 months.

3) The most economical efficient insulting material is polystyrene foam with the B/C for 5 years at B/C =1.12 and a payback period of 4 years and 5 months.

References

[1] Ministry of Energy, *Ministerial Regulation on Building Specification or Size and Standard, Criteria and Design Methodology for Buildings for Energy Conservation B.E. 2552*, 2009

[2] Ministry of Energy, *Ministerial Announcement on Lowest Capacity Coefficient, Efficiency of Cooling System and Cost of Electricity per Ton of Cooling Capacity by the Air Conditioning Systems Installed in Buildings, B.E. 2552*, 2009

[3] S. Intata, S. Attajariyakul, and R. Teeraroj, “The study on material selection for energy conservation homes,” in *Proc. Thailand 2nd Energy Network Symposium*, Suranaree University of Technology, Nakhon Ratchasima, 2006.

[4] Ministry of Energy, *Ministerial Announcement on Criteria and Calculation Method for Calculation of Overall Energy Consumption in Buildings and Usage of Rotational Energy in the Various Building Systems B.E. 2552*, 2009

[5] W. Jindarat, A. Suksaengphanomrung, and P. Atsmongkol, “Calculations that Assist in Selection of Air Conditioning System that is Appropriate and Conserves Energy in Building,” in *Proc. Thailand’s Energy Network 1st Academic Meeting*, Jomtien, Cholburi. 2005, pp. ECB11-1-ECB11-6.

[6] W Mungwititkul, *The Environment of Homes and Energy Conservation*, 5th ed, Energy Policy and Planning Office, Ministry of Energy, 2003.

S. Phetcharat was born in Phichit Province, Thailand, in 1973. He received the B.Eng. degree in transportation engineering from Suranaree University of Technology, Nakonrachasima, in 1997 and M.Eng.degree in civil engineering from the Kasetsart University, Bangkok, in 2001. From 1997 to 1998, he was a Teaching and Research Assistant with the transportation engineering department. Since 2007, he has been an Assistant Professor with the Civil Engineering Department, Srinakharinwirot University, College Station. His research interests include crumb rubber modified asphalt, highway materials, GIS application in transportation and house saving energy.