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Thermal performance and cost effectiveness of wall insulation under Thai climate

Surapong Chirarattananon[a,b,*], Vu Duc Hien[c], Preecha Tummu[a]

[a] The Joint Graduate School of Energy and Environment, King Mongkut's University of Technology Thonburi, Thailand
[b] Science and Technology Postgraduate Education and Research Development Office, Ministry of Education, Thailand
[c] Energy Field of Study, Asian Institute of Technology, Pathum Thani, Thailand

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ABSTRACT

Traditional houses and public buildings in Thailand were constructed from materials of low thermal mass and the walls were not insulated. Brick and concrete began to replace wood as walling material before air-conditioning was introduced into the country. New large buildings have glazed and closed windows so interior spaces require air-conditioning and forced ventilation. Up to the present, no insulation is used on walls. This paper presents results from an experimental and simulation study on comparative energy and economic performance of walls used to enclose air-conditioned spaces. The walls are externally and internally insulated to different thicknesses. The spaces are assumed to serve three commercial functions. Results show that insulation can generally help improve thermal performance of walls, but the function that a space serves dictates where insulation should be placed and how cost effective it is.

1. Introduction

Most cities in tropical Thailand have very low wind speed and the climate is too warm and too humid. Air-conditioning to provide cooling for thermal comfort is now invariably used in commercial buildings.

Heat gain through building envelope or due to building envelope can contribute substantial load to the air-conditioning system of a building. During daytime, solar radiation is the main force that drives heat gain through building envelopes. Heat is transferred through an opaque wall by conduction. The rate of heat transfer is influenced mainly by thermal resistance, thermal mass and other thermal properties of a wall. There is some belief that insulation could improve thermal performance of a wall enclosing an air-conditioned space, but no clear evidence of the cost effectiveness of insulation has been presented and no insulation has been used up to now.

Zhai and Previtali [1], suggests that local climate and cultural heritage are the main influences on vernacular architecture of a location. Traditional houses in two locations in Indonesia were used to illustrate that in tropical region, houses were constructed from materials that offer good insulation and of low thermal mass. Comakli and Yuksel [2], utilize annual heating degree days and the *U*-value of a wall to determine annual heat loss from the wall and then relate this to annual heating energy. The cost of insulation is added to the cost of heating energy to form life cycle cost for a given thickness of insulation. The optimum insulation thickness corresponds to minimum cost. The authors apply the methodology to building walls in three cities in the coldest of four climate regions of Turkey. Khawaja [3], uses standard solar radiation model to generate solar radiation and calculate sol–air temperature for the city of Doha in Qatar. The sol–air temperature is then related to heat gain through a wall and to air-conditioning load and then to annual cooling energy. Adding the cost of insulation to the cost of cooling energy, the author is able to minimize the total cost at optimum insulation thickness. Even though cooling is needed for 7 months in a year, Bojic and Yik [4], note that cooling is a dominant energy end-use of buildings in Hong Kong. The authors also observe that in Hong Kong, like the practice in several countries in hot climate region, insulation is not used on walls. The authors utilized a computer program for building energy simulation called HTB2 to simulate electrical energy and peak electrical demand of housing units in a new high-rise public housing block called 'Harmony'. The authors used the existing design as base case and investigated another 11 alternative constructions. The alternatives include combinations of the use of massive (base case) and light walls, and insulation placed on interior, exterior, and on both wall surfaces. The authors focus their discussion on results from more realistic alternatives to conclude that the simpler case of exterior insulation on massive exterior wall with massive interior wall without insulation offers significant reduction of both annual cooling energy and peak demand. Dombayci et al.

* Corresponding author at: The Joint Graduate School of Energy and Environment, King Mongkut's University of Technology Thonburi, Thailand.
E-mail address: surapong@jgsee.kmutt.ac.th (S. Chirarattananon).

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Nomenclature

U-value	thermal transmittance or heat transfer coefficient of a wall or glazing section, W m^{-2} K^{-1}
WWR	the ratio of window area to overall wall area
PS foam	polystyrene foam
q_c	convective heat flux from a wall surface
q_r	thermal radiation heat flux from a wall surface
α	solar radiation absorptance of a wall surface
$E_{et\theta}$	effective solar radiation onto a wall surface
q_f	heat flux reaching wall surface from the wall interior
C	convective heat flux from a wall surface
LW	long wave radiation flux from a wall surface
HF	heat flux from the wall interior to the wall surface
COP	coefficient of performance of an air-conditioning system

[5], use a method similar to that of Comakli and Yuksel in Ref. [2] in finding optimum insulation thickness for a city called Denizli in Turkey. However, Dombayci et al. considers two types of insulation materials and different types of heating fuels and energy sources as well as variation in heating degree day and the value of present worth factor. Dombayci [6], considers the same method for calculating heat loss and fuel required as that in Ref. [5], but assumes the use of coal as the heating fuel. The author considers composition of combustion products of coal to relate generation of carbon and sulfur dioxides to insulation thickness. Bolatturk [7], presents results of an economic analysis of using insulation in warm cities of Turkey. The author uses local climate data to obtain cooling degree and heating degree hours (CDH and HDH) using identical base temperature and derives sol–air temperatures. The author relates electricity required during cooling season and natural gas required during heating season to CDH and HDH and utilizes the analysis method of Duffie and Beckman [8], to calculate optimum insulation thickness for cooling and for heating under a number of situations. Mahlia and Iqbal [9], in reference to the condition in Maldives use U-value of an insulated wall, the difference between annual average ambient temperature and interior set-point temperature, and given number of hours annual cooling demand to relate annual cooling requirement to electricity required for cooling when two types of insulation materials are used on a wall. Considering electricity to be generated from diesel fuel, the authors related thicknesses of insulation to fuel cost and to emission of carbon and sulfur dioxides. Yu et al. [10], utilize a method similar to that of Bolatturk in Ref. [7] to obtain cooling degree day and heating degree day data for four representative cities in China based on the use of sol–air temperature of each location. Yu et al. use 18 °C and 26 °C as base temperatures for calculation of cooling and heating degree days respectively. Energy requirements and life cycle costs and savings are obtained for different types and thicknesses of insulation using the P1–P2 method of [8], but Yu et al. add annual life cycle cost of cooling to that of heating to form a combined cost function. Eventually, the authors present sensitivity of the optimum results with respect to changes in values of various parameters including degree day, discount rate, and thermal resistance of un-insulated wall. Uker and Balo [11], apply the same cost effectiveness analysis method to that of Yu et al. to determine optimum insulation thickness on walls for four cities of Turkey. Here, Uker and Balo use standard heating and cooling degree day data, but consider use of four types of heating fuels for heating and electricity for cooling. Costs of heating and cooling are treated separately. Bojic et al. [12,13], simulate electricity consumption and peak demand in two units of residential flat using HTB2 program mentioned in Ref. [4]. The smaller two-bedroom unit was assumed occupied only during evening and night time while the living room of three-bedroom unit was assumed occupied during day and evening hours of every day. Both units have windows with total area of 10% of total wall area that are glazed with clear glass. Cases used in the simulation include base case where no insulation is used on walls that face exterior environment, cases where insulation is placed on the interior surfaces, within wall material and on the exterior surfaces of walls. For the three-bedroom unit, insulation reduces cooling load and peak demand to different extents for all cases. Further decreases are incremental when insulation thickness exceeds 50 mm. For the two-bedroom unit, insulation placed on exterior surfaces or within the wall material *increases cooling load* but decreases peak demand. Interior insulation leads to decreasing cooling load and peak demand. The authors do not attribute the difference in the results from the two units to the difference in orientations. The authors simply note that the two units *differ on occupancy pattern*. Kossecka and Kosny [14], examined theoretical performance of six configurations of insulation placement in heavy walls. Program DOE 2.1E was used for simulating energy consumption of a ranch house in six climatic regions of USA, where heating or cooling was assumed employed for 24 h of every day of a whole year They concluded that the wall with exterior insulation performs best, with lowest heating and lowest cooling energy, while the one with interior insulation performs worst. Even though Balocco et al. [15], investigate transient performance of walls with different insulation placement, the authors conclude that the wall with exterior insulation performs best under both cooling and heating climates. The phenomenon of the increase in cooling load when insulation is used on walls is called ‘anti-insulation behaviour’ that is noted by Masoso and Grobler [16], who write that ‘it is world wide established knowledge that adding wall insulation in buildings reduces annual energy consumption’. The authors cite six instances from literatures that this phenomenon is reported but not taken note of because ‘it only happens in summer cooling and most researchers are in Europe and North America’. The authors then conducted a simulation of cooling application in a building model to demonstrate that annual cooling load decreases with increasing interior temperature and becomes negative when interior set-point temperature increases beyond a value. Reference [17] utilizes the same meteorological data, same computer program, and same building model used in this paper to examine effects of wall mass where in one situation the wall thickness increases resulting in increasing its thermal mass as well as its thermal resistance. No insulation is applied, but the increase in thermal resistance together with the increase in thermal mass results in the decrease in heat gain through wall and the consequential reduction of cooling load of the space that the wall encloses particularly for spaces that are used to serve daytime functions.

This paper first presents salient features on the climate of Thailand, Thai vernacular architecture and the recent trend in building design. It then refers to experiments described in Ref. [17], and briefly describes a computer simulation program used to obtain part of the work reported here. The paper then presents and discusses results of computer simulation on a generic building model when the spaces in the zones consequentially serve three commercial functions. The paper first examines the case where there is no window on walls and the walls are externally and internally insulated to different levels. It then examines more complicated situations when a space is enclosed by walls that comprise windows. In the literatures reviewed, the insulated walls do not comprise windows or the effect of windows is not accounted. This paper shows that solar radiation transmitted through window into a space enclosed by insulated wall can have significant effect on heat transfer mechanisms that reduces the effectiveness of insulation.