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Effect of indoor design temperature on the heating and cooling transmission loads

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ABSTRACT

In this study, the effect of indoor design temperature on cooling and heating transmission loads through walls is investigated numerically over the whole year. The investigation is carried out for different wall orientations in the climatic conditions of Elazığ, Turkey. For this purpose, as indoor design temperature is increasing from 18 to 26 °C, the transmission loads are calculated using an implicit finite difference method under steady periodic conditions. It is noted that south wall provides minimum heating load while north wall provides minimum cooling load. It is seen that as indoor design temperature increases, the heating transmission loads increase while the cooling transmission loads decrease. Results show that the cooling transmission load decreases16–27% with every 2 °C rise of indoor design temperature while the heating transmission load increases 18–30% for all wall orientations with every 2 °C rise of indoor design temperature.

1. Introduction

A large part of the energy used by air-conditioning is caused by heat transmission through building envelope especially in residential buildings, because of prevailing extreme outdoor conditions. Therefore, improving building envelope design is one of the most effective ways to conserve energy in buildings [1]. Building envelope is designed to protect the inner space from harsh outdoor climatic conditions, hot and cold alike, and hence provides necessary thermal comfort to occupants. In addition, building envelope should be designed and built in a way to reduce energy consumption by air-conditioning and heating equipment. Reducing energy consumption also reduces adverse impact of power plants on the environment [2].

One of the important and essential aims in building design is to achieve acceptable indoor comfort levels with minimum energy requirements. Low energy demands have also a lower impact on the outdoor environment. To accomplish this, firstly a serious consideration must be given to various construction and design parameters, such as the building's envelope structure and shape, its orientation, as well as the climatological data of the region. Secondly, as the envelope heat transmission contributes to the cooling and heating loads, the incorporation of an appropriate heating, ventilating and air-conditioning (HVAC unit) system must be considered [3]. Indoor design air parameters not only affect thermal comfort of people in buildings but also closely link with the energy consumption of HVAC system. The energy consumption will also rise with the increase of the relative humidity for heating design or rise with the decrease of the relative humidity for cooling design [4].

In northern regions, comfortable warm room condition in winter and electrical demand are the prime concerns. Electrical consumption varies greatly during the day and the night. Commonly, a thermal energy storage is used to shift energy loads to off-peak periods in order to reduce utility charges and minimise or avoid high, on-peak demand charges [5].

Insulated building walls are integrated parts of a building envelope. They protect the inner space from extreme weather conditions and damp down large fluctuations in temperature. As such, the building envelope should provide the necessary thermal comfort for the occupants as well as reduce energy consumption requirements for cooling and heating. This is usually done through increasing thermal resistance of this envelope and, hence, reducing transmission loads. Therefore, addition of thermal insulation is important, particularly in regions with extreme climates [6].

In literature, there are many studies on building thermal performance [7–22]. Some of them are reviewed below.

Al-Sanea and Zedan [16] studied the effect of insulation location on the heat transfer characteristics of building walls under steady periodic conditions. In their study, the thermal performance with an insulation layer placed on the inside of a wall structure was compared to that when the insulation layer was placed on the outside. The same authors [17] investigated the dynamic thermal characteristics of building walls having the same thermal mass with one, two and three layers of insulation. Their results showed that the optimum thickness of a single insulation layer was independent of its location in the wall; and that, when more than one insulation layer was used,

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Nomenclature

a	solar absorptivity of outdoor surface of wall
c	specific heat (J/kg K)
h_i	heat-transfer coefficient at the indoor surface of wall (W/m^2 K)
h_o	heat-transfer coefficient at the outdoor surface of wall (W/m^2 K)
I_T	incident total solar radiation for vertical surfaces (W/m^2)
I_b	beam solar radiations on the horizontal surface (W/m^2)
I_d	diffuse solar radiations on the horizontal surface (W/m^2)
I	total solar radiations on the horizontal surface (W/m^2)
k	thermal conductivity (W/m K)
L_i	insulation thickness (m)
q_i	heat flux at indoor surface of the wall (W/m^2)
t	time (s)
T_i	indoor air temperature (°C)
T_o	outdoor air temperature (°C)

Greek letters

δ	declination angle (deg.)
φ	latitude (deg.)
γ	surface azimuth angle (deg.)
ω	hour angle (deg.)
ρ	density (kg/m^3)
θ	incidence angle (deg.)
θ_z	zenith angle (deg.)

their total optimum thickness was the same as the optimum thickness of a single insulation layer.

Bojic et al. [18] demonstrated that providing thermal insulation in the envelope of residential buildings would lead to a reduction of the yearly maximum cooling demand, and largest reduction of around 10.5% was found when this thermal insulation was put either at the indoor side or at the outer side.

Al-Sanea [19] compared the thermal performance of different roofs and showed that a slightly better thermal performance was achieved by locating the insulation layer closer to the inside surface of the roof structure.

Konteleon and Bikas [20] investigated the effect of outdoor absorption coefficient of an opaque wall on time lag, decrement factor and temperature variations by employing a dynamic thermal-network model. Kossecka and Kosny [21] analysed insulation location on heating and cooling for six characteristic exterior wall configurations. They showed that the best thermal performance was obtained when massive material layers were located at the inner side and directly exposed to the interior space. The effect of wall orientation and exterior surface solar absorptivity on time lag and decrement factor for several insulated wall configurations was investigated by Kontoleon and Eumorfopoulou [22]. The influence of indoor-temperature settings on the cooling/heating loads for fixed and controlled ventilation in a single zone in both cooling and heating seasons by employing a thermal-network model was also investigated by Konteleon and Bikas [3]. In their study, the energy demands and the resulting indoor-temperature variations were determined for fixed ventilation as well as temperature-controlled ventilation. Computer results showed that energy savings in summer and winter depend mainly on the wall structures and the settings of the indoor temperature.

Cui et al. [23] evaluated the effects of air temperature on thermal comfort, motivation, performance and their relationship. Steady-state environments at five different temperatures (22 °C, 24 °C, 26 °C, 29 °C, 32 °C) were created in climate chamber. Thirty six subjects (eighteen males and eighteen females) were recruited and they were divided into Group A and Group B. Group A was exposed to all five temperature conditions while Group B was only exposed to 26 °C. A significance test showed that the optimum temperature range for performance in this study was between 22 °C (slightly cold) and 26 °C (a little higher than neutral).

Djamila et al. [24] predicted and evaluated the indoor comfort temperature for naturally ventilated residential buildings in a hot-humid tropical environment in the region of Kota Kinabula city, in Malaysia. Multiple and stepwise regressions were applied for the selection of the independent variable for neutral temperature prediction. Air temperature was chosen as an index for the indoor thermal comfort. The comfort temperature was determined using various approaches. The predicted temperature was found to be nearly 30 °C regardless of the adopted approach. Indoor comfort temperature was close to the recorded mean indoor air temperature of all responses having a difference of about 0.7 °C.

Karjalainen [25] examined thermal comfort and the use of thermostats at home and in office rooms by a quantitative interview survey with a nationally representative sample in Finland. The results showed that thermal comfort levels were lower in offices than in homes. People felt cold and hot more often in offices than in homes during both the winter and summer seasons. The perceived control over room temperature was remarkably low in offices. Higher thermal comfort levels and perceived control in homes were supported by greater adaptive opportunities.

Xu et al. [26] presented the results of two pre-cooling and zone temperature reset strategies that were tested in the building under a limited range of summer weather conditions. A simple demand limiting strategy performed well in this building. This strategy involved maintaining zone temperatures at the lower end of the comfort region during the occupied period up until 2 p.m. Starting at 2 p.m., the zone temperatures were allowed to float to the high end of the comfort region. With this strategy, the chiller power was reduced by 80–100% (1–2.3 W/ft^2) during normal peak hours from 2 to 5 p.m., without causing any thermal comfort complaints.

Braun and Lee [27] developed and evaluated a simple algorithm for limiting peak electrical demand in buildings using building thermal mass. The algorithm was developed based upon a simple model and heuristics derived from simulation results. The peak demand savings potential and the effect on utility costs were evaluated using simulations for representative small commercial buildings for climates in California. The basic strategy is to set the thermostat at 70 °F (21.1 °C) in the morning, and gradually increase that temperature in pre-determined manner to a maximum around 78 °F (25.6 °C) during the afternoon in the summer. In general, it is possible to achieve between 1 and 2 W/ft^2 (10.76 and 21.53 W/m^2) of demand reduction for a four-hour demand-limiting period.

Various methods with different levels of simplification exist for building energy calculations such as the transfer function, the degree day and bin methods. Computer codes are also available to perform complicated building load analysis. Indeed, computer codes for building energy simulation can benefit from improvement in the modelling of their components. The problem can thus be reduced, in general, to solving the Fourier heat conduction equation through a composite structure subject to time-dependent boundary conditions [19]. Analytical methods for modelling heat transfer in buildings have attracted many researchers. One of