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Theoretical and experimental investigation of total equivalent temperature difference (TETD) values for building walls and flat roofs in Turkey

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A B S T R A C T

The aim of this study is to find time lag (TL), decrement factor (DF) and total equivalent temperature difference (TETD) values for multilayer walls and flat roofs of buildings using experimental and theoretical methods, and to compare the experimental results with theoretical ones. The TETD is a method for calculating cooling load due to heat gain from the walls or flat roofs, and it can be obtained using values of inside and outside air temperatures, solar radiation, TL and DF. The TL and DF depend on the highest and the lowest temperatures at the inner and outer surfaces of the walls or flat roofs, and the time periods involved in reaching these temperatures. Hence, two testing rooms each consisting of four multilayered walls and a flat roof, air conditioner, measuring elements are built to measure all required temperatures. The required temperatures, which are hourly inside and outside air temperatures, and surface temperatures of each structure layer, are measured in every minute during testing periods of the 2007 summer season of Gaziantep, Turkey. Hourly solar radiation values on the walls are computed using hourly measured solar radiation on a horizontal surface. The TL, DF and TETD values of eight different walls and two different flat roofs commonly used in Turkey are computed utilizing the measured temperature and solar radiation values. The computed values for the TL, DF and TETD are compared with theoretical results obtained numerically using periodic solution of one dimensional transient heat transfer problem for the same structures.

1. Introduction

Energy consumption is one of the most important indicators pointing out the growth of society. Energy required per capita continuously increases with development of indoor comfort conditions in living medium. It raises utilization of energy sources, which leads to serious implications on pollution, climate change, increasing cost of energy and depletion of the energy resources [1]. Great amounts of the utilized energy are consumed by the air conditioning systems of buildings. An accurate cooling load calculation method should be built up and applied to enhance the operating efficiency of air conditioning system components [2]. Hence, it is necessary to use more suitable materials in construction of buildings to decrease energy need for heating and cooling of the buildings [3]. Building energy requirement for the winter and summer seasons constitutes loss or gain through windows, walls, roofs, infiltration and equipments. In many buildings, walls and roofs have very significant fraction of heat gains for the heating or cooling loads [4]. Accurate determination of the heat gain through the walls and roofs of a building is very important in order to select a suitable air conditioning system for the efficient utilization of energy [5,6].

Different methods exist for evaluating heat gain through the walls and roofs of the building elements, which are exact, numerical and transfer function methods. The exact method involves the application of heat balance equation to the inner surfaces and finding a solution to the transient heat conduction equation for the walls and roof using suitable numerical methods. Transfer function method (TFM), cooling load temperature difference (CLTD) method and total equivalent temperature difference (TETD) method are based on the transfer functions [4]. The TFM is a widely used computer aided cooling load calculation method in air conditioning industry [7]. In this method, hourly heat gain due to walls, roofs, glass and other components is computed, and the conversion of heat gain to cooling load is done by multiplying with some transfer coefficients [8], which are tabulated for certain types of walls, partitions, roofs, floors, and ceilings in ASHRAE [9]. The CLTD is another cooling load calculation method which is used with the CLTD values generated by utilizing the TFM or heat balance method for particular walls and roofs [4]. The TETD method differs from the CLTD method in that heat gains are handled to obtain cooling load [8], and it includes both conduction heat gain through the

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Nomenclature

A	surface area of wall and roof (m^2)
C	specific heat (kJ/kg K)
h_i	combined heat transfer coefficient at the inner surface (W/m^2 K)
h_o	combined heat transfer coefficient at the outer surface (W/m^2 K)
i	complex argument
I	radiation heat flux on horizontal surface, (W/m^2)
I_b	beam radiation heat flux on horizontal surface (W/m^2)
I_{bT}	beam radiation heat flux on tilted surface (W/m^2)
I_d	diffuse radiation heat flux on horizontal surface (W/m^2)
I_{dT}	diffuse radiation heat flux on tilted surface (W/m^2)
I_r	reflected radiation heat flux on horizontal surface (W/m^2)
I_{rT}	reflected radiation heat flux on tilted surface (W/m^2)
I_T	radiation heat flux on tilted surface (W/m^2)
K	thermal conductivity (W/m K)
L	thickness (m)
q_c	heat gain through the wall (W/m^2)
q_k	Complex Fourier coefficient of dimensionless solar heat gain
t	time (s)
T	temperature (°C)
T_i	design inside air temperature (°C)
T_n	complex Fourier coefficient of temperature
T_o	outside air temperature (°C)
t_e	solar–air temperature (°C)
t_{ea}	daily average sol–air temperature (°C)

Greek symbols

α	thermal diffusivity (m^2/s)
α_s	absorptance of surface
ρ_g	ground reflectance
θ	incidence angle
θ_z	zenith angle
Υ	dimensionless time

Subscripts

i	inside
j	number of terms
g	ground
n	number of layer
n	number of last layer
o	outside
Theo	theoretical
Exp	experimental

walls and roofs and effects of solar energy impinge on the external surfaces of the structures.

There have been many theoretical and experimental investigations for determining the cooling load of the buildings and for finding suitable building wall and roof materials to reduce cooling load. The walls and roofs involve large amounts of heat gain since they have large area relative to the other building components. In order to determine the cooling load due to heat gain through the structures, TETD method is a widely used calculation method which depends on the TL and DF of the structures. Several studies are focused on finding the TL, DF and TETD values of these structures. In this context, Asan and Sancaktar [10] have investigated the effects of wall's thermophysical properties on TL and DF. Their study shows that wall inner surface temperature reaches a constant value as a result of increasing heat capacity where thickness and thermal conductivity are held constant. Ulgen [11] investigated behavior of opaque wall materials constituting building surfaces under solar energy to find TL and DF for different wall compositions by utilizing experimental and theoretical methods. Vijayalakshmi et al. [1] investigated thermal behavior of opaque wall materials under influence of solar energy, and analyzed influence of thermophysical properties of different wall types on the interior environment. They concluded that large heat storage capacity increases TL, and decreases DF, and that higher thermal diffusivity leads to opposite results. Kontoleon et al. [12,13] investigated how wall orientation and solar absorptivity of exterior surface of an opaque wall effect the TL, DF and temperature variations for specific climatic conditions by employing a dynamic thermal-network model. They pointed out that the solar absorptivity has a very profound effect on the TL, DF and temperature variations. Yumrutaş et al. [5,6] developed an analytical methodology based on periodic solution of transient heat transfer problem for multilayer walls and flat roofs to find heat gain through the structures and TETD values of the structures. They obtained that higher solar radiation and ambient air temperatures give higher TETD values which lead to higher heat gains, and they stated that the thermophysical properties of the structures have a very important effect on TL and DF. Asan [14–16] solved one dimensional transient heat conduction equation with periodic boundary conditions for composite wall by applying numerical method of Crank-Nicolson, and investigated effect of wall's insulation thickness, type of material and position on the TL and DF. He found that thickness of material and the type of the material have a very profound effect on the TL and DF.

There have been several theoretical studies for finding TL, DF and TETD values of building walls and roofs in literature. But there are a few experimental studies and comparisons of the experimental and theoretical results for TL, DF and TETD values of the building structures. Ulgen [11] only performed both theoretical and experimental studies for laboratory conditions, in which results of TL and DF obtained from both studies are compared. The experimental setup was not installed in realistic conditions. The TL, DF and TETD values can be obtained practical and reliable if experimental study is performed in realistic conditions. In the present investigation, two experimental systems in practical conditions were installed to obtain TL, DF and TETD values of multilayer walls and flat roofs experimentally and theoretically, and to compare the experimental results with the theoretical ones for selected structures. The experimental systems consisting essentially of two rooms having eight different walls and two flat roofs, air conditioners and measuring elements are constructed for realistic conditions in order to measure inside and outside air temperatures, and surface temperature of each wall and roof layers. The TL, DF and TETD values are computed utilizing the measured temperatures and solar radiation flux. In theoretical model, a computer program based on the theoretical study given in Yumrutaş et al. [6] is prepared for determining the TL, DF and TETD values of the selected walls and roofs used in the experimental systems. The program is executed utilizing thermophysical properties of the wall and roof materials, measured ambient air temperatures and solar radiation on a horizontal surface. The TL, DF and TETD values obtained from the experimental and theoretical studies are compared. A comparison is also made with the values in literature.