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ScienceDirect

Energy Procedia

Energy Procedia 78 (2015) 67 – 72

6th International Building Physics Conference, IBPC 2015

Effect of attic insulation thickness and solar gain in a mild climate

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Abstract

Attic air ventilation can be influenced by various vent considerations. In addition to vent ratio and location of roof vents, attic insulation thickness can be considered as an influential factor in attic air flow and temperature distribution. Most existing building codes do have a minimum requirement for venting parameters and type and thickness of the insulation used. In this paper, the effect of insulation thickness in attic ventilation rate, attic air temperature and heating and cooling loads in a mild climatic zone is studied. A typical mild climate summer and winter temperatures and solar radiations data are used for 24 hours transient conjugate heat transfer simulations. Results show that solar radiation has significant impact on the amount and the pattern of airflow in attic. An increase in attic insulation yields a decrease in attic ventilation during winter period, but has no effect in summer period for the climate considered. In general, the higher the attic insulation thickness is the lower the building takes advantage of solar gain during winter period, but higher insulation levels tend to be advantageous during summer cooling period.

Peer-review under responsibility of the CENTRO CONGRESSI INTERNAZIONALE SRL

Keywords: Attic; Air change per hour; Heat flux; Insulation; Solar gain;Ventilation

1. Introduction

Attic ventilation helps to reduce moisture accumulations inside an attic space during both summer and winter weather conditions mitigating durability and mold growth problems that otherwise may occur due to moisture accumulation on roof structure. In cold climate, ventilating an attic protects ice damming that would create moisture related problems due to trapped water and ice dam in the soffit region by keeping the attic cold [1] and it also

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Peer-review under responsibility of the CENTRO CONGRESSI INTERNAZIONALE SRL
doi:10.1016/j.egypro.2015.11.116

removes moisture that escapes from living space [2] by air leakage or vapor diffusion. During summer venting contributes to help lower the cooling load [3].

In order to understand the energy and moisture performance of attic roof systems it is necessary to explore how the buoyancy and wind driven incoming air, through inlet vents, interacts with the air in attic space and the temperature distribution behaves in the space and structural components. Most attic simulation models assume a shape of isosceles triangle with the two inclining sides representing the roof while the horizontal side symbolizes the ceiling. Flack et al. [5] conducted experimental measurement of natural convection in attic like shape with temperature variation from below. The flow inside the triangular shape was visualized using Schlieren and laser velocimetry tools. Poulikakos et al. [6] assuming symmetry, have used right angle triangle with adiabatic vertical wall to study natural convection in a triangular enclosure. Salmun et al. [7, 8] studied the convection patterns in a triangular space filled with water and air of different aspect ratios and Rayleigh numbers. A transient heat and mass model of attics with radiant barrier is simulated and hourly ceiling heat loss and gain was predicted by Medina et al. [9, 10]. Holtzman et al. [11] used triangular model that is heated below and uniformly cooled from above, depicting winter conditions. Their study shows assuming mid plane symmetry only works for small Grashof number flow. Asan et al. [12] investigated air flow transition from single cell to multi cell under laminar natural convection in an attic space. Saha et al. [13] work on study of heat transfer in attics subjected to periodic thermal loading shows a flow inside attic space is more or less stratified in day times whereas the airflow is unstable during night times. Wang et al. [14] developed unsteady Computational Fluid Dynamics CFD model that assumes a mid-plane symmetry, to study the impacts of ventilation ratio and vent balance on attic cooling.

In this paper, a transient CFD model with time dependent outdoor boundary conditions, and a realistic attic geometry with soffits and ridge vents as per the Canadian Building Code [15] are considered. The study investigates the airflow, temperature and heat flow in the attic with different insulation thickness. In this work, hourly temperature and solar radiation data of typical summer and winter days of a representative mild climate region of North America, Vancouver, BC are used as outdoor boundary conditions.

The air change per hour and the temperature profile computations are used to estimate the amount of attic air change and the heating and cooling loads required to counter heat flux through attic floor.

2. Approach

The air flow and temperature distributions in attic are affected by the temperature difference between the ambient and attic space air conditions, the solar radiation absorbed by the roof, the temperature difference through ceiling and the mass air flow which inters through inlet vents. The attic space model takes into account the radiation heat exchange between the roof sheathing and the ceiling insulation surfaces. To study this dynamic phenomenon, a computational model is developed and solved using COMSOL 4.4.

This paper uses same model which is benchmarked and verified in [16]. A coupled Navier-Stokes and a heat transfer equations are used to solve the air flow distribution in the attic space and the temperature profile in both attic space and structural constituents

A 24 hour summer and winter temperature and solar radiation data of Vancouver, BC is used as a representative condition for mild marine climatic zone. The attic model with a sloped roof of 4:12 pitch and an attic floor area of 800 ft^2 is used for the study and the attic vent size ratio is 1:300 of free vent area to insulated ceiling area. The roof is comprised of wooden shingles on the top of plywood. For the study, three different insulation thicknesses with thermal resistance values of R-30 h·ft2·°F/Btu (RSI-5.28 K·m2/W), R-45 h·ft2·°F/Btu (RSI-7.92 K·m2/W) and R-60 h·ft2·°F/Btu (RSI-10.57 K·m2/W) are employed over plasterboard ceiling. The outdoor boundary conditions, hourly varying temperature and solar radiations, used for simulation of winter and summer conditions are presented in Figure 1 The indoor boundary condition, the temperature below the ceiling floor, is assumed to be constant at 21ºC. In order to allocate 60 % of the ventilation opening at the bottom (soffit) and 40 % at the top (ridge) of the roof space, according to NBCC 2010 [15], the soffit and ridge vent opening areas are made to be 116.25 in^2 per side, respectively, which are equivalent to having 10 mm and 15 mm continuous openings at the soffit and ridge level. To prevent the insulation from blocking airflow at the bottom of the roof, a baffle with 50 mm depth and 91 mm long is placed between the sheathing and the insulation.