Available online at www.sciencedirect.com

ScienceDirect

Energy Procedia 78 (2015) 67 – 72

Energy Procedia

6th International Building Physics Conference, IBPC 2015

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

Fitsum Tariku*, Emishaw Iffa

BCIT Building Science Centre of Excellence, Burnaby BC V5G 3H2, Canada

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

* Corresponding author. Tel.: +1-604-432-8402; fax: +1-604-430-0145.
E-mail address: Fitsum_tariku@bcit.ca

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.

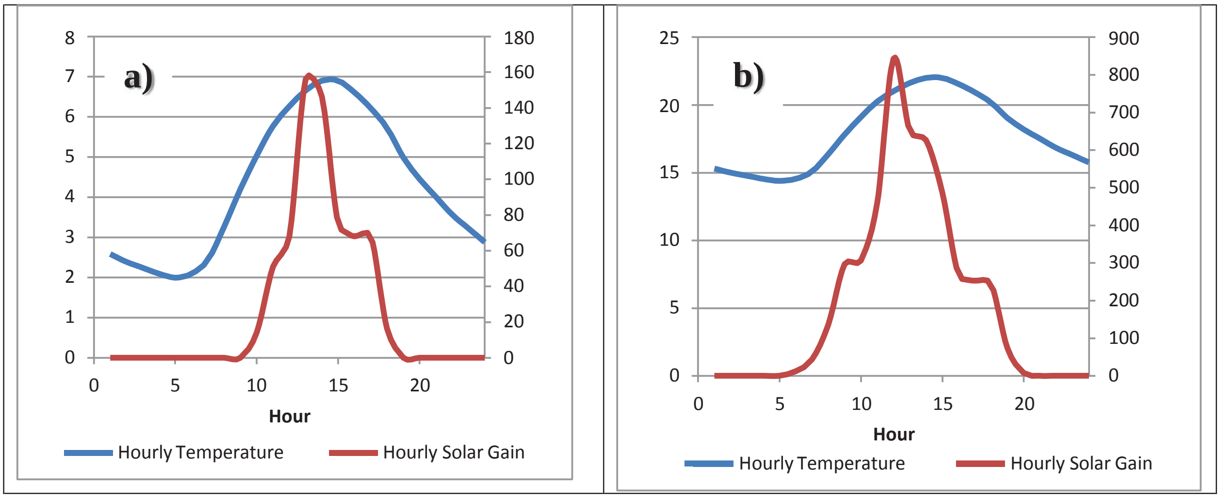

Figure 1 Hourly temperature and solar radiation during a) Winter and b) Summer typical days

3. Results

In Figure 2, two snap shots of air flow distributions in an attic space with R-30 insulation are presented. The airflow patterns correspond to a time of a day when there is no solar radiation and when there is. As can be seen in the figures, the flow is symmetrical when there is no solar radiation (Figure 2 a), and when the buoyancy flow is predominately induced by solar radiation, the outside air is pulled through the soffit vents and flows under the heated sheathing board before leaving through the ridge vent (Figure 2 b). The attic ventilation rates in ACH during the typical winter and summer days are shown in Figure 3 (a). As can be seen in the figure, during the night and morning times, attic ventilation rates in the winter are higher than that of the summer day (~3ACH vs ~2 ACH). This is due to the fact that the temperature difference between the indoor and outdoor temperature are higher during the winter period. The attic ventilation rates during the day time are higher in the summer when compared with a typical winter day, which is attributed to the high solar gain and the associated solar induced buoyancy flow. Figure 3 (b) shows attic ventilation rates (in ACH) at different solar radiation values. From the figure it can be seen that attic ventilation is directly correlated with the amount of solar radiation the roof received. Such correlation can be useful to properly account solar induced ventilation and estimate attic ventilation rates in energy and hygrothermal simulations.

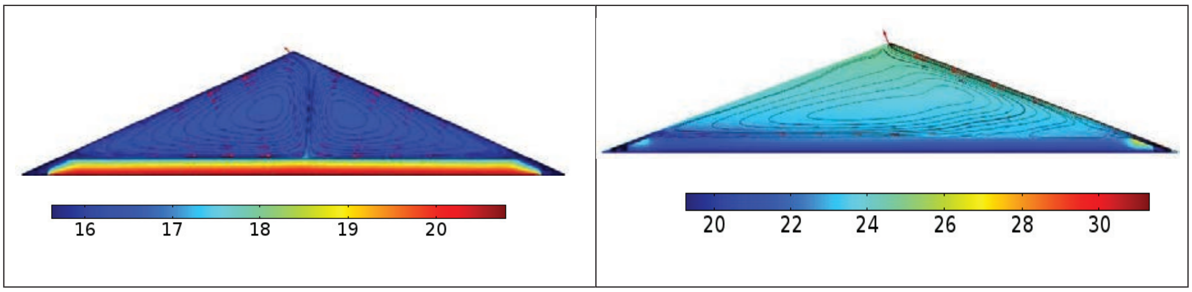

Figure 2 (a) and (b) Airflow distribution in attic space for cases without solar gain and with solar gain

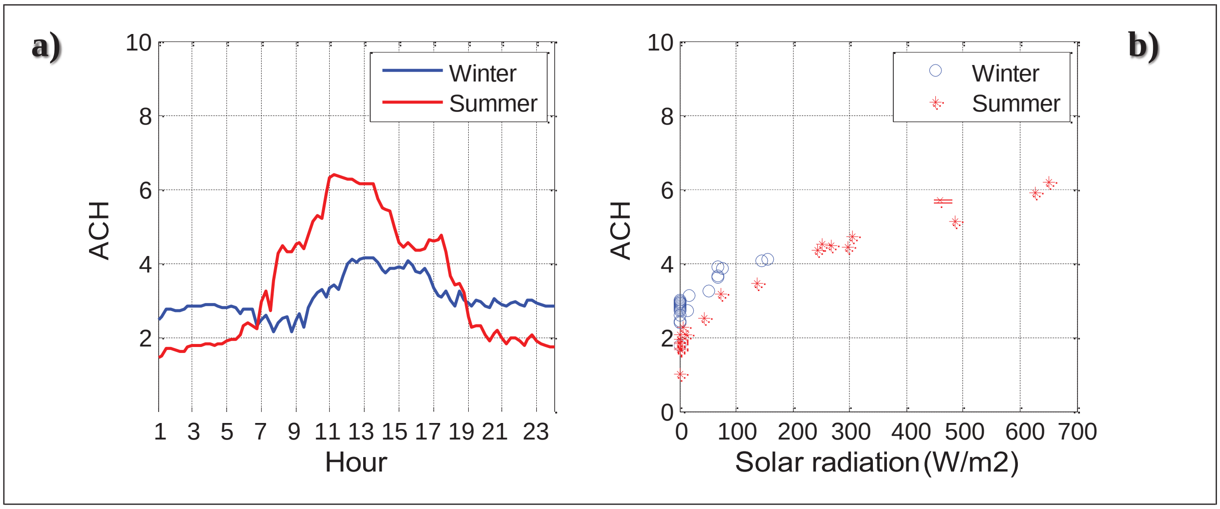

Figure 3 Attic ventilation rates during a typical winter and summer days (a); and ACH vs solar radiation (b)

The effects of insulation are studied by varying the insulation R-value. The mass flow rate per unit length for R-30, R-45 and R-60 are computed for typical summer and winter days and presented Figure 4 (a) and (b). The 24 hour transient simulation results suggest that as the insulation thickness increases the mass flow rate decreases during the winter day, Figure 4 (a). The differences are attributed to the fact that the insulation top surface temperature decreases with insulation thickness, and thereby decreases buoyancy driven flow because of the lower temperature difference between the outdoor air temperature and insulation top surface temperature. The negative correlation between mass flow rate and insulation thickness can be higher in cold climates. In the mild climate considered in this paper, insulation thickness doesn't have significant effect on attic ventilation rate during the summer period as shown in Figure 4 (b), which must be attributed to the lower temperature difference between the indoor and the outdoor temperatures. In summer the mass flow rates in all insulation conditions are about the same. In attic roof retrofit case, increase in insulation thickness decreases the attic air space volume. Thus for a similar mass flow rate a higher ACH is achieved.

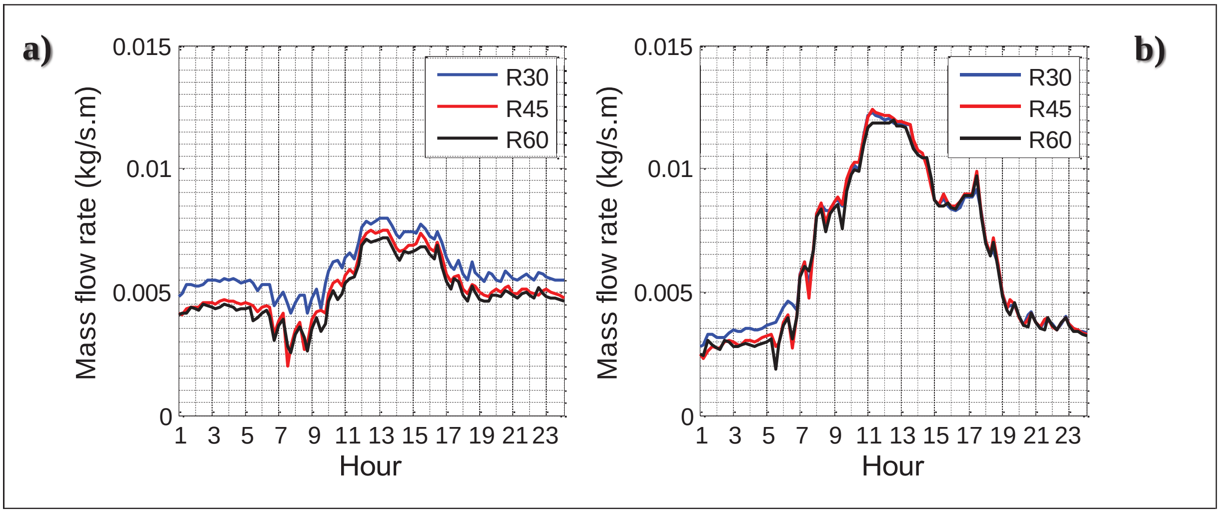

Figure 4 Attic ventilation rates during a typical winter (a) and summer (b) days

The average attic air temperature in both summer and winter cases are presented in Figure 5 (a) and (b). As can be seen in the figure, the attic air temperature in R-30 case is slightly warmer than that of the cases with R-45 and R-60 during winter, and in the summer, the temperature differences between the three cases are insignificant. I general, the attic air temperatures in the three insulation thickness varies by less than 1^{o}C, and no significant difference is seen between R-45 and R-60 attic roofs.

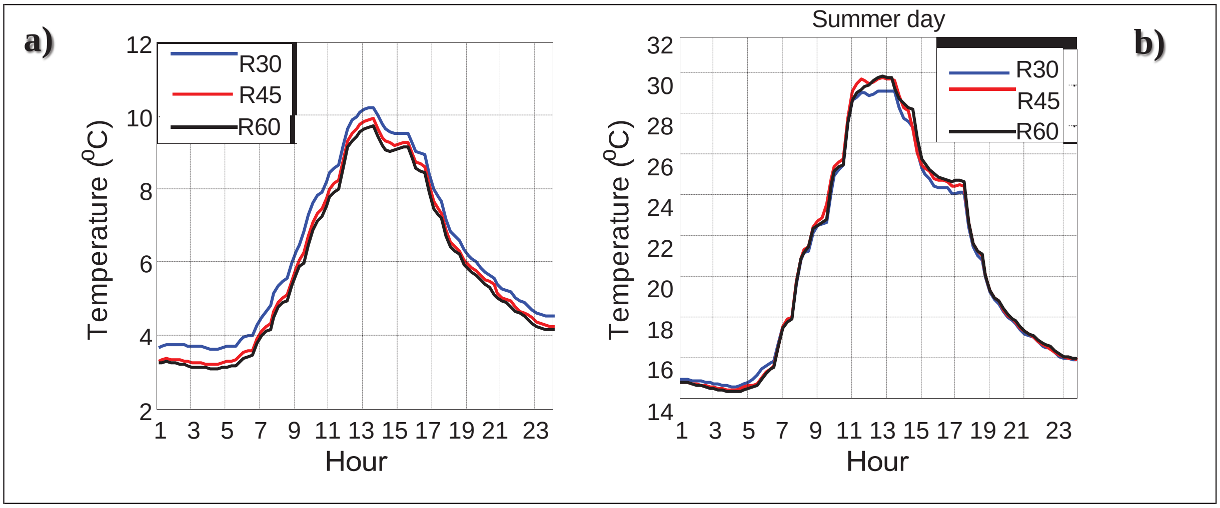

Figure 5 Attic air temperature for different insulation during winter (a) and summer (b) days

The total heat loss/gain during winter and summer days for the three insulation thickness cases are presented in Figure 6 (a) and (b), respectively. As shown in Figure 6 (a), the difference in heat loss through the different insulation thickness is higher during night time or when there is no solar radiation. The positive and negative signs represent the direction of heat flow. The result also suggest that R-30 attic roof is able to pass more solar gain to the indoor space than the highly insulated attic roof (R-60) as can be seen in the mid-afternoon hours where the heat flux differences get narrower. The daily heat loss in R-45 and R-60 insulation attics is reduced by 18% and 22% from R-30 heat loss, respectively. This result also shows an increase in insulation doesn't necessarily linearly decrease the heat loss through insulation ceiling in winter. In summer, as can be seen in the Figure 6 (b), the heat flux amplitude in R-60 attic is lower when compared with that of R-30 attic. Moreover, the daily total cooling loads in the R-45 and R-60 attic roof cases are reduced by 22% and 44% of the R-30 attic roof cooling load, respectively. 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. Therefore the choice for insulation thickness shall be determined based on analysis that takes into account both the solar gain and the outdoor temperature conditions of the specific climate.

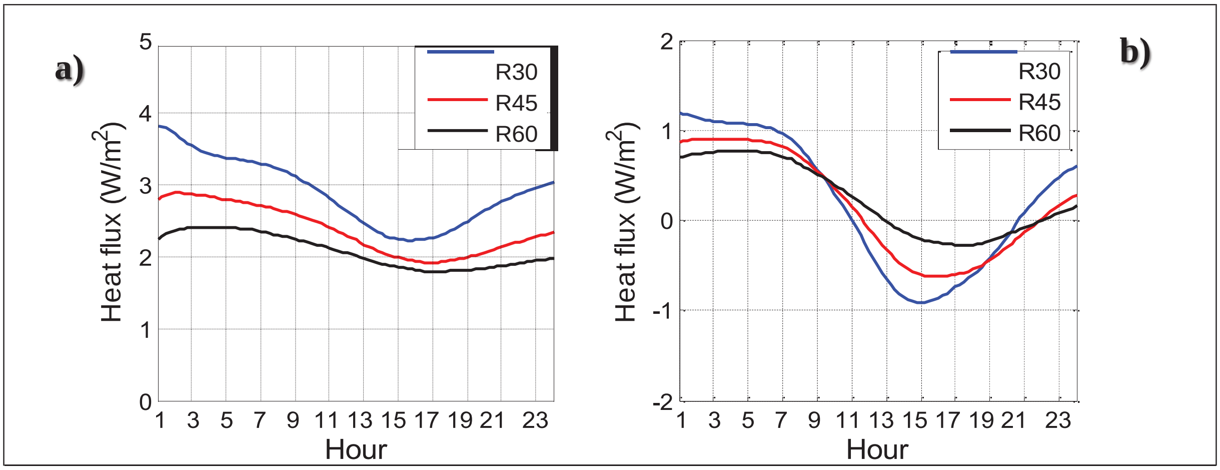

Figure 6. Total heat flow during winter (a) and summer (b) for different attic insulation cases

4. Conclusion

In this paper, effects of attic insulation and solar gain on the attic air change per hour (ACH) and thermal performances are investigated. Results show that solar gain increases the hourly attic air circulation during buoyancy driven ventilation. The ACH value gets higher during day time in both summer and winter due to solar gain. Higher attic insulation thickness decreases attic ventilation rate during the winter period. In the mild climate considered in this study, attic insulation thickness has insignificant effect on attic ventilation rate during the summer period. The average attic air temperature difference between R-45 (RSI-7.92) and R-60 (RSI-10.57) is minimum. Results show, 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.

References

[1] Tobiasson W, Buska J, Greatorex A. Ventilating attics to minimize icings at eaves. Energy and Buildings, 1994; 21 (3): 360-368.
[2] Gutt GS. Condensation in Attics: Are vapor barriers really the answer. Energy and Buildings, 1979; 2 (4):251-258.
[3] Susantia A, Hommab H, Matsumoto H. A Naturally Ventilated Cavity. Roof as Potential Benefits for Improving Thermal Environment and Cooling. Load of a Factory Building. Energy and Buildings, 2011;43: 211-218.
[5] Flack RD, Witt CL. Velocity measurements in two natural convection air flows using a laser velocimeter. ASME J. Heat Transf. 1979.
[6] Poulikakos D, Bejan, A. Natural convection experiments in a triangular enclosure. ASME J. Heat Transf. 1983; 105:652–655.
[7] Salmun H. Convection patterns in a triangular domain. Int. J. Mass and heat transf. 1995; 38(2): 351-362.
[8] Salmun, H. The stability of a single-cell steady-state solution in a triangular enclosure. Int. J. Mass and heat transf. 1995; 38(2): 363-369.
[9] Medina M.A, O'Neal DL, Turner WD. A transient heat and mass transfer model of residential attics used to simulate radiant barrier retrofits, Part I: Development. ASME J. Sol. Energy Eng. 1998; 120:32–38.
[10] Medina M.A, O'Neal DL, Turner WD. A transient heat and mass transfer model of residential attics used to simulate radiant barrier retrofits, Part II: Validation and simulations, ASME J. Sol. Energy Eng.1998; 120:39–44.
[11] Holtzman GA, Hill RW, Ball KS. Laminar natural convection in isosceles triangular enclosures heated from below and symmetrically cooled from above. ASME J. Heat Transf. 2000; 122:485–491.
[12] Asan H, Namli, L. Laminar natural convection in a pitched roof of triangular cross-section: Summer day boundary conditions. Energy Build. 2000; 33:69–73.
[13] Saha S, Patterson JC, Lei C. Natural convection and heat transfer in attics subject to periodic thermal forcing, Int. J. thermal Sci. 2010; 49:1889-1910.
[14] Wang S, Shen Z. Impacts of Ventilation Ratio and Vent Balance on Cooling Load and Air Flow of Naturally Ventilated Attics. Energies 2012; 5:3218-3232.
[15] BC Building and Plumbing Code – 2012, www.bccodes.ca/ retrieved September, 2, 2014.
[16] Iffa E, Tariku F. Attic Baffle Size and Vent Configuration Impacts on Attic Ventilation. Building and Environment. 2015; 89: 28-37.