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Abstract

Traditionally, attic space in buildings is perceived as a source of nuisance where the moisture condensation occurs in winter encourages mildew growth, and heat build up in the attic space in summer increases the cooling load. However, if the attic is integrated in a holistic design and control strategy, it can function as a solar collector, a heat exchanger, and a desiccant!.

This research investigates energy saving by optimizing direct and indirect ventilation through attic to pre-cool buildings and reduces humidity. This strategy was examined in a double story house with attic in a moderate- humid climate. The built up heat in the attic space and outside air ventilation were used to dry up roof construction materials during the day. When outside air cools down during the night but maintains high humidity, the indoor air circulates through the attic space. The attic construction materials absorb moisture from the indoor air. Thus indoor air loses both heat and moisture. EnergyPlus Simulation software was used to simulate this cooling and dehumidification strategy. The simulation results showed significant passive cooling and dehumidification in the building.

Key notes: Dehumidification, Nighttime ventilation, Indirect Ventilation, Cooling load

Introduction

Traditionally, utilizing nighttime ventilation and thermal mass is a major strategy for passive cooling in dry climates. However, in moderate and humid climates, passive cooling through ventilation is more difficult to achieve. In these climates, the outside air is relatively cold during the early evening, but its relative humidity is high. Therefore, it is not suitable for nighttime ventilation. Later at night, outside relative humidity reaches the upper limit of the comfort zone, but the outside air enthalpy remains equal or more than the inside air enthalpy. Thus, introducing outside air to the space may reduce the inside air temperature without reducing the air enthalpy. Instead it could lead to more moisture absorption by inside building materials and furniture [1]. In the daytime, more moisture is produced inside the building due to the required ventilation and other inside latent energy sources. In most cases, dehumidification is needed to extract the excess moisture. Thus, more active cooling is needed to extract the extra moisture, which is admitted to the space during nighttime ventilation [2].

Conventional building materials usually store heat efficiently for short period of time. However, moisture content of building materials and furniture varies widely in their capabilities to store moisture. In addition, to achieve comfort, the air temperature tolerance in a space usually should not exceed 8-11 Fº(5-6 Cº), but the comfort level can be achieved with wide relative humidity range of approximately 30-60%. Thus, the "enthalpy storage" capacity of the building materials can significantly contribute to cooling load. In addition, during the day where active cooling is required, if inside relative humidity is lower, thermal comfort can be achieved at higher air temperatures, and less dehumidification is required.

During sunny winter days, solar radiation heat gain in the attic space may exceed the conduction and convection heat loss. Thus attic space will act as a passive heating collector. In summer, the attic space can work as a desiccant, here, the desiccant materials are the attic wood construction, and the regeneration energy is the solar energy collected in the roof.

Summer Dehumidification

Unlike heat transfer in building materials, which is clearly defined, moisture transfer in buildings is rather complex and involved many mechanisms that are still not fully explained [3]. There are at least 9 different mechanisms of water transport in solids which are; molecular vapour diffusion, molecular liquid diffusion, capillary flow, Kundsen diffusion, surface diffusion, Stefan diffusion, evaporation condensation, Poiseuville flow, and movement due to gravity.

To get a general idea of moisture transfer in building materials and to explain the concept of using the attic space to dehumidify buildings let us consider the following example;

In a typical clear sky summer day in a moderate climate, if the outside air temperature reaches 90Fº(32Cº) and relative humidity of 50%, the attic air temperature in a typical wood building can reach 108Fº(42Cº) and relative humidity 29%. During the night, if the air inside the attic is mixed with the house living space, we can assume that relative humidity in the attic will equal the living space relative humidity and let us say that it is 50%. Under steady state condition, the moisture isotherm curve shows that moisture content in the particleboard insulation will drop from .08 to .05 lb/lb (kg/kg) [4]. Isetti showed that the particleboard could approach the steady state in 12 hours [1]. This suggests that in a house with a roof area of 861 F^2 (80 m^2), if the relative humidity fluctuated between 50% and 29%, roof particleboard insulation will have a daily moisture capacity of approximately 353 lb (160 kg) of water. From another hand, the wood attic construction has also high moisture absorption capacities, which can reaches .15 lb/lb (kg/kg) under relative humidity of 50%, and .1lb/lb (kg/kg) under relative humidity of 29% [4]. In addition, wood can reach the balance point in more than 3 months [5]. In this case attic wood construction can contribute to moisture control in the short and the long term. Thus, in a typical wood house with attic space, moisture capacity of the attic construction materials is more that moisture produced in the house due to ventilation and internal latent heat gain (Figure 1)(Figure 2).

The moisture balance in buildings can be defined by the following equation [6];

$$\frac{\partial ci}{dt}\times V = G-\frac{n\times V}{3600}\times(ci-cu)-\sum_{i=1}^{n}\beta\times(ci-csur)\times A$$

Where

ci = moisture content in indoor air lb/ m^3 (kg/m^3)

t = time(s)

V = Building volume ft^3 (m^3)

G = moisture production lb/s (kg/s)

N = air change per hour

cu = moisture content in outdoor air lb/ft^3 (kg/m^3)

β = moisture resistance from air to material ft/s (m/s)

csur = moisture content of air in material lb/ft^3 (kg/m^3)

A = area of material in room ft^2 (m^2)

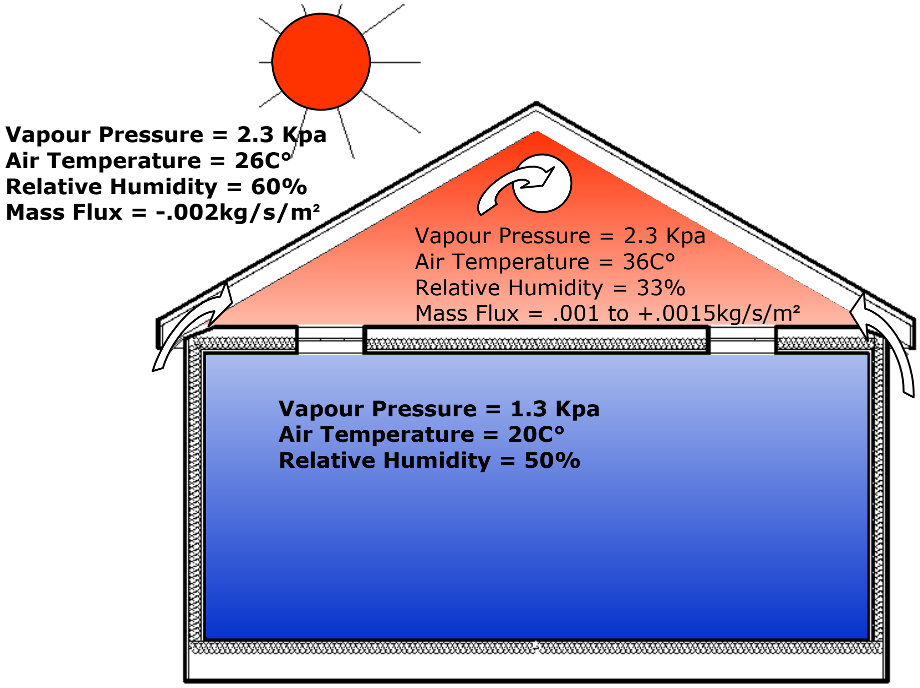

Figure1: Moisture transfer and Air circulation in a typical house during the day

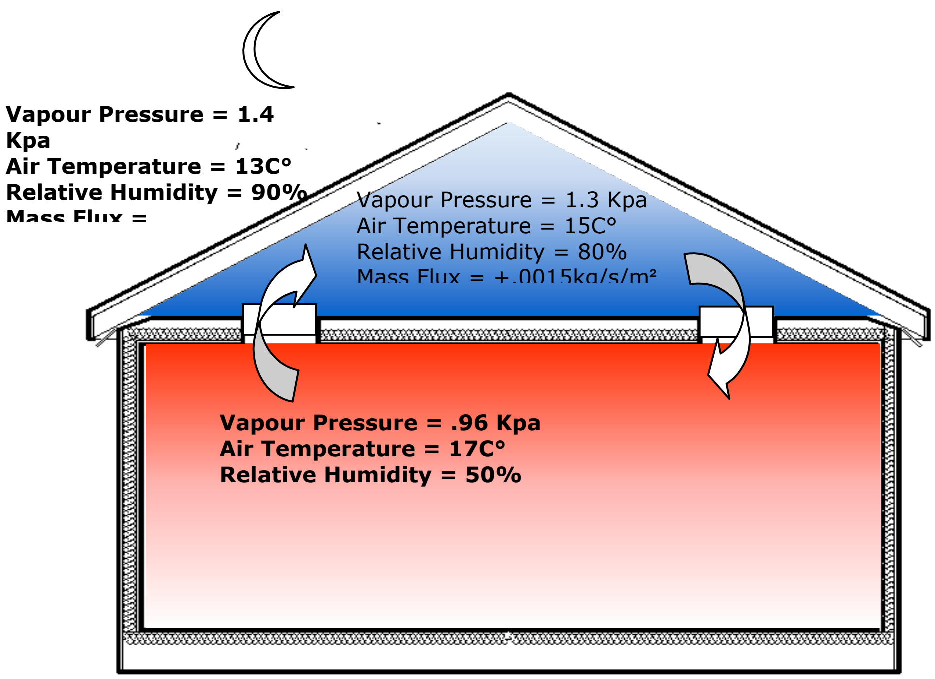

Figure2: Moisture transfer and Air circulation in a typical house during the night.

From the equation above, to make sure no moisture build up in the space, building moisture production due to ventilation and other building activities should be less than or equal to the moisture absorption of building interior materials. The moisture production in a house may range between 32- 53 lb (14-24 kg). In order to flush the extra moisture, which is produced during the day in the living space, the internal building material and furniture shall also accommodate the moisture production in the house during the day. Nielson showed that this is achievable if considering the internal building material and furniture [6].

Testing

To predict the yearly dehumidification cycle through attic space, Energy Plus simulation software was used to simulate a simple two-floor house with a floor area of 2691 ft² (250m²) and an attic space. An actual yearly weather data for Roanoke, Virginia was used. This climate is relatively cold in winter, and warm and humid in summer.

Energy Plus, the official Department of Energy building simulation software is used to simulate heat transfer, moisture transfer, and air movement in the house. Energy Plus combines the best of DOE-2 and PLAST, and it has the capability of simulating moisture transfer in buildings and cross mixing airflow between building spaces [7].

The proposed house construction is mainly wood. The walls are composed of 13mm wood cladding from outside, R13 glass fibers insulation faced with building paper, and 13mm gypsum board from inside. The floor of the main level is constructed of a composite concrete and wood structure. It consists of 10mm plywood over to 100x250mm wood joists. The windows are composed of double-glazing with 30mm cavity and adjustable bronze blind inside this cavity. This window design allows for controlling the solar radiation admitted through it. The attic roof is composed of black asphalt shingles placed over 13mm wood. The attic floor consists of 150mm re-circulated paper particleboard insulation and 20mm wood board.

An outside air controller is scheduled to control the air flow rate in the attic, which was scheduled to operate introduce outside air flow rate of 5.29 ft³/s (.15m³/s) between 12pm and 7pm. A cross mixing airflow of 1.6m³/s was also scheduled to operate between the living space and the attic between 1 am and 6 am.

To account for long-term moisture sorption and desorption, the house was simulated for a full year in a passive mode.

Results

Under the new ventilation and dehumidification strategy, the house maintained a comfort Predictive Mean Vote between -.5, +. 5 for more than 95% of the entire cooling period (Figure 4). The simulation results also showed that during summer when the average outside relative humidity was 85%, the average relative humidity in the house living space was 61%(Figure 4). Further more, when outside air humidity ratio reached .018 kg/kg, the house living space maintained a humidity ratio of less than .011 lb/lb (kg/kg) (Figure 3).

The mass flux rate of the roof plywood was approximately between –0.024 to 0.033 lb/hour (-0.001 to +0.015 kg/hour), and the mass flux rate of the insulation was between approximately –0.001 to .007 lb/hour (-0.0003 to +0.0003 kg/hour) (Figure 6). This result suggests that the attic structure has higher moisture content fluctuation than the roof particleboard thermal insulation, which is placed, on the attic floor. That is because plywood in the attic roof is in direct contact with the roof asphalt shingles; hence its temperature is higher than the insulation temperature.

The simulation results showed that the humidity ratio fluctuation of the roof building materials was low (Figure 6). This suggests that there will be no negative effect of the new dehumidification mechanism on the roof construction. It also suggests that roof-building materials has the capabilities of balancing the building relative humidity for long periods.

Unlike building sensible thermal mass which can store heat for short periods of time (12-24 hours), building latent thermal mass continue to balance the house moisture content for long time periods. Figure 4 and figure 5 show how the house interior maintained low air moisture content and low relative humidity even when the outside air maintained high air moisture content for more than 8days.

When comparing the house performance before implementing the new dehumidification strategy, the overall annual latent cooling load reduction of the new dehumidification strategy is approximately 83%.

Recommendations

This research introduces a new approach of utilizing natural ventilation through attic space to reduce latent cooling load. The new approach makes attic space a source of energy saving rather than a source of nuisance. Other advantages of this strategy is utilizing indirect nighttime ventilation when the outside air is cold but humid, thus outside air is used for cooling without admitting more moisture to the space. Since air pollution diffusion has similar mechanism to moisture diffusion, better air quality will presumably be achieved through this ventilation strategy. However further research is needed to measure the air pollution desorption and absorption.

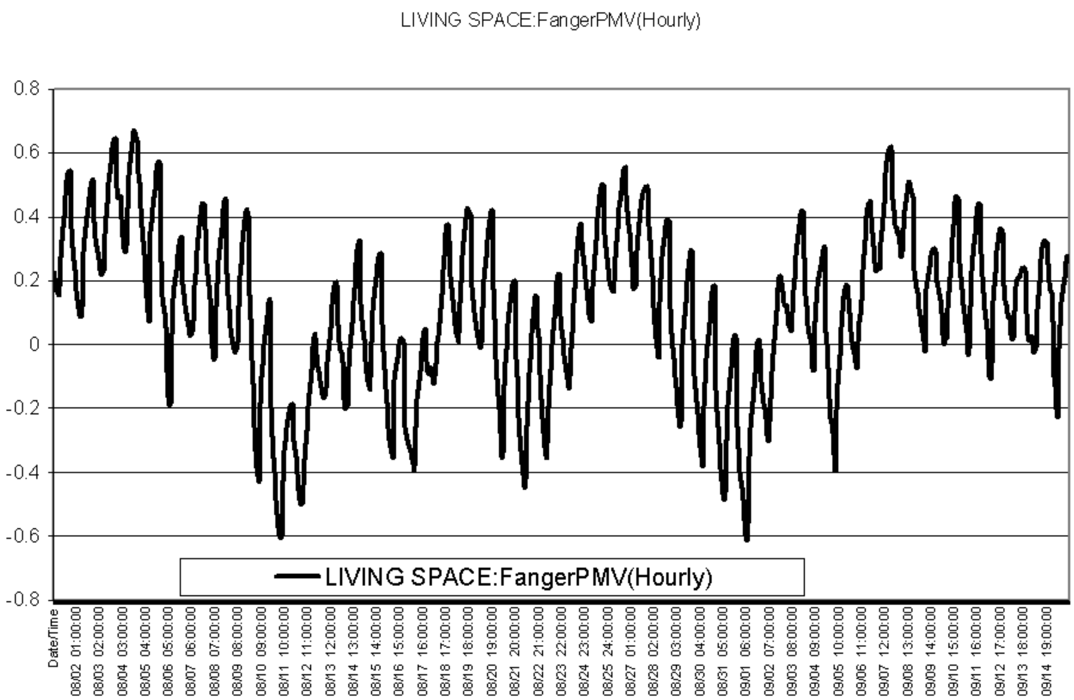

Figure3: Comfort Predicted Mean Vote (PMV) in the house living space.

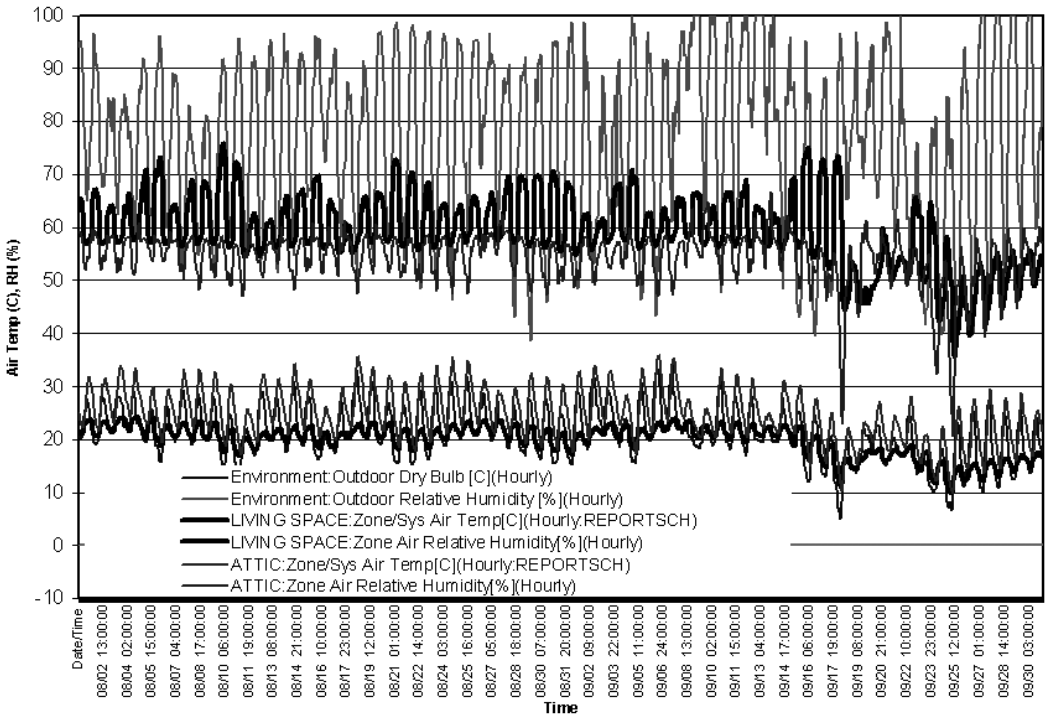

Figure4: The air Temperature and relative humidity, which are predicted by simulation.

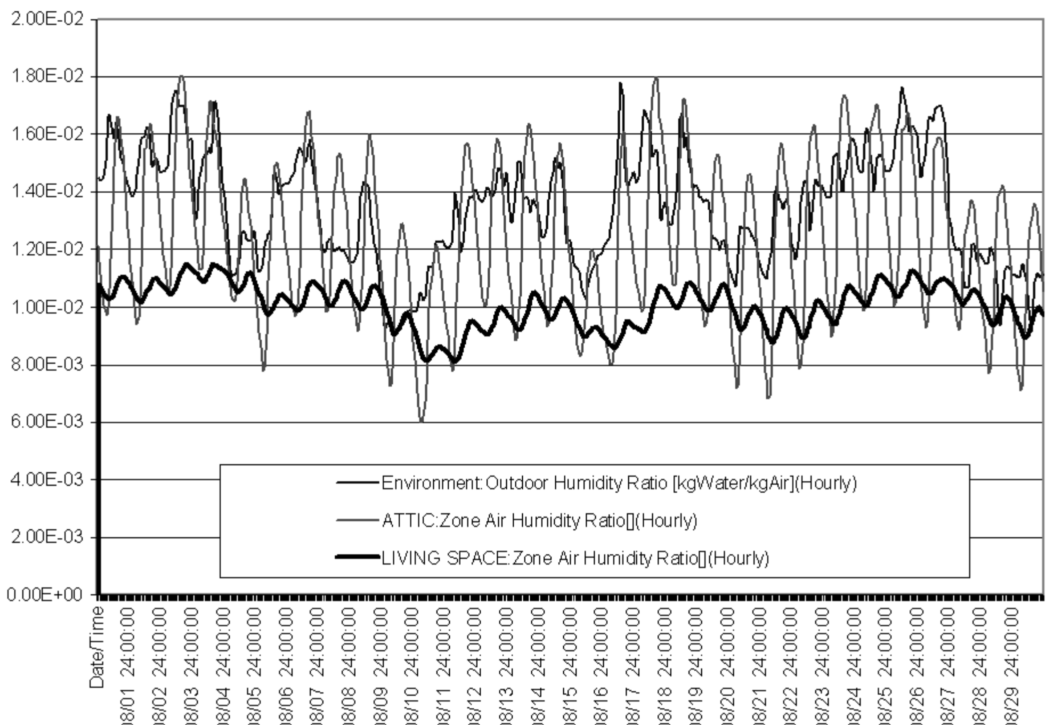

Figure5: Humidity ratio in the living space ant the attic.

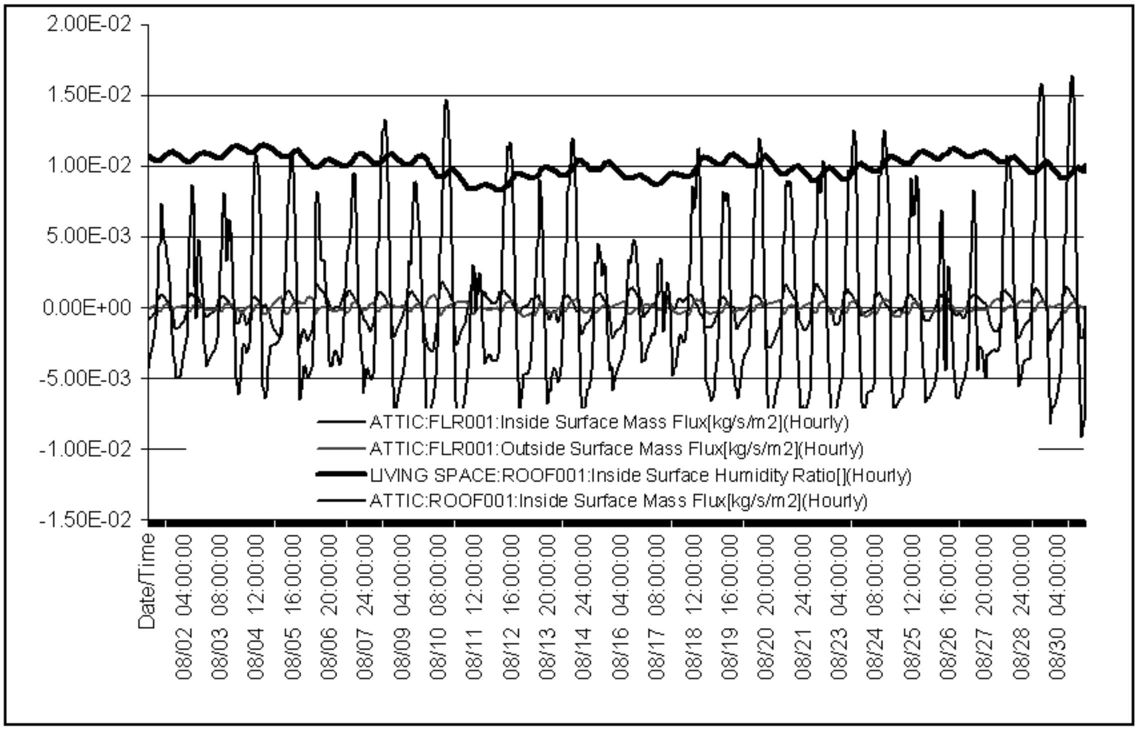

Figure 6: Moisture flux and surface humidity ratio in the attic and living space.

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