Experimental Protocol Development for a Passive Thermal Management System

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Abstract: Techniques to reduce the increasing energy costs have become a necessity for homeowners. For a typical residence, heating and cooling are two of the major energy consuming sources. A new technology was designed and developed in the Center for Industrial Research Applications at West Virginia University which utilizes passive convective cooling to help reduce this energy usage. The experimental testing protocol was developed for this novel passive thermal management system based upon typical materials and techniques used in the construction of residential homes. The base construction for the two units was identical. Each unit was equipped with 13 temperature sensors in identical positions on the shingled roof and inside the attic space. Each sensor was connected to a data logger installed in each unit. Baseline data was established in both controlled and environmentally exposed environments. The testing protocol and baseline data for both units are presented in this paper.

Keywords: Convective Cooling, Energy Conservation, Buoyancy

1 Introduction

The impact of rising energy prices on household budgets and the overall economy has increasingly become a focal point of public concern. A significant portion of the total energy costs can be attributed to heating and cooling. In 2005, approximately 111 million homes contained at least one heating unit with 65% of them for a single family detached dwelling [1]. For this type of home, the major heating sources are electricity and natural gas.

A typical residence has numerous energy consuming appliances and devices. Major contributors include air conditioning, refrigeration, and heating. Approximately 85% of the homes in the United States have cooling equipment, 76% of which use central air, while the remaining 24% have at least a window/wall unit [1].

With both heating and cooling being the major contributors to energy expenditures in most building structures, energy savings on these sources was the focus of this research. Currently, energy savings in a home can be accomplished in a variety of ways. One way is to replace normal window glass throughout the home with low emissivity (low-e) glass. Low-E glass has a special thin coating that will let visible light in, but helps to reduce the heat transfer between surfaces. Another alternative would include the planting of trees and/or shrubs to shade a building structure in summer and to provide a wind break in winter. The R-value of the insulation can be increased and it is also recommended that thermostats be adjusted to decrease energy usage. In addition, shading room air conditioners from direct sun will reduce their workload. Such energy savings measures will translate into reduced heating and cooling costs. [2]

The natural ventilation method that occurs in most structures takes advantage of two principles. First, as air is heated it becomes less dense and rises. Second, wind movement over and around a home creates areas of high and low pressure. If a space has high air outlets in conjunction with low inlets, ventilation occurs as the air within the space is heated, rises and escapes through the high outlets to be replaced by cooler air entering at the lower inlets. The greater the temperature differences between the outlet and inlet, the greater the ventilation rate. This is a natural result of buoyancy effects. Additionally, the structure serves as a differential pressure mechanism driven by creating a slightly higher pressure around the windward side of the structure. As the air passes over the ridge or top of the structure it creates a slightly lower than ambient pressure, the Bernoulli effect, and thus encouraging mass flow through the structure [3] - [5].

Enhancing and exploiting this buoyancy effect and taking advantage of the wind/structure interaction for convective ventilation is the goal of the current research. Traditional natural ventilation occurs in the interior of the attic. On the other hand, this research aims to enhance natural buoyancy driven convection in an exterior space immediately along the top most surface of a building to reduce attic temperatures. This could be accomplished with a variety of structures and control schemes retrofitted on top of an existing roof, or the design of a new roof structure with an air gap between the additional structure and the existing roof.

2 Experimental Setup

Two units were constructed for experimental verification testing, one for the control and the other as the experimental. Each unit was equipped with sensors to monitor the thermal attributes inside and outside of each unit, as well as the air velocity inside the stack vent. The base construction of each unit was identical with the only difference being that the second unit has the add-on roof feature. The construction of each building, as well as the experimental testing setup, is described next.

The attic test module is a gabled attic built with roof pitch of 45 degrees. The frame of the unit was constructed out of two-by-six pieces of lumber, placed 16 inches on center, and covered on the outside with plywood sheets for rigidity and strength. Tar paper was placed directly over the plywood...
sheets and 1/8 inch thick asphalt shingles were layered on both sides of the roof.

Figure 1 Experimental Test Units during Construction

The exterior of the building has standard tan vinyl siding, thin (~2 mm thick), installed over the house wrap which was attached directly against the plywood. Typical R-13 fiberglass home insulation was installed in between each of the two-by-four studs with drywall installed in the interior of the unit. A layer of thin plastic was placed over the insulation to create a vapor barrier. The interior ceiling consisted of R-30 insulation between the two-by-six ceiling joists and drywall. Both the ceiling and each wall was painted white to help to seal and maintain a steady temperature inside of each building. The interior floor was constructed in a similar fashion as the exterior walls without vinyl siding on the exterior.

In addition, the roof has an overhang located on both sides to create a 12 inch soffit vent and a gable on the front side of each building. The soffit vent was constructed of one porous vent located in the middle with a solid piece on either side with the same pattern to the ends of the overhang. A 7 ft steel exterior door was installed on the front side of each building to mimic the effect of typical building openings. In addition, a hexagon-shaped gable was installed directly over the exterior door to allow access to the attic area, as shown in Figure 2. During testing, the exterior door was closed and the gable was sealed shut. In order to analyze the impact of the convective heat roof and to keep the influence of the roof between experimental and control the same, the ridge vent was excluded for this phase of this research.

Environmental monitoring was used to determine which method provided the best protection against temperature elevation caused by exposure to solar radiation. This was accomplished by using two data loggers, 44 resistance temperature detectors, and downloading the weather for the test site.

Test data collection was performed using two data loggers setup to monitor 15 and 29 temperature sensors for the 500 and 800 data units, respectively. Temperature sensors were placed in identical positions on each test unit to minimize the effects that varying the probe position could have on the test data. The test points for each unit are located twelve inches from the ridge (top), twelve inches from the attic floor (bottom), and in the middle of the top and bottom sensors (~30 inches from ridge) on both the exterior and interior of each roof surface. Each sensor was encased with a flame retardant, thermal urethane, as depicted in Figure 3 and Figure 4. Every exposed lead was also covered with this thermal urethane to negate radiation effects.
The temperature sensors were monitored using two data loggers. The dataTaker® DT505 and DT800 were installed in the control and experimental units, as shown in Figure 5 and Figure 6, respectively. The 6-outlet power supply is on the far left with the data logger located in the middle. The dataTaker® DT505 setup also included an Omega® iServer™ Microserver to convert the serial DB-9 to an Ethernet RJ45 connection. The heat load from each datalogger setup was relatively small (5 W) and hence considered negligible for this research.

A 3-wire RTD configuration was used in the DT800 with six sensors sharing a common return to increase the amount of sensors to be measured. One lead resistance sensing loop was used for each set of six sensors necessitating each wire in the set to be the same length.

On the other hand, the dataTaker® DT505 was setup with a 4-wire configuration which used two wires to supply a constant current to the sensor while the other two wires carried no current and therefore could sense the exact voltage across the resistor without any voltage drop in the wire.

The dataTaker® software was utilized to configure, set schedules and download data from each data logger unit. The configuration included channel selection, sensor type, data logger, and label for each sensor. The labels started with the number one and were preceded with a letter for the type of location (e.g. A1 indicated attic sensor in position location one). In addition, each data logger was programmed to have Schedule A take data once a minute for each sensor. The data from each unit was downloaded at least twice per week in a comma separated values (.csv) file format over the internet or Ethernet configurations.

3 Results

Two sets of baseline data were collected for the control and experimental test units. The first set of tests was performed in a controlled environment. The units were exposed to environmental conditions for the second set of tests.

3.1 Controlled Baseline

After each unit was fully constructed, each unit remained inside of a large hangar bay, for a period of 2 months to establish baseline data in a controlled environment. During this time period, the gable was open and hence natural convective air currents would flow in through the soffit and exit through the gable. A representative set of data for the attic temperatures is shown in Figure 7 and Figure 8 for the 500 (control) and 800 (experimental) units, respectively. In addition, the same time period is shown as a representative set of data for the roof temperatures shown in Figure 9 and Figure 10 for the 500 and 800 units, respectively.
Each unit was located 20 feet from the hangar bay doors and raised 6 in from the floor by 6 inch square wood blocks for the controlled environment baseline testing. A series of representative tests were executed and the results were analyzed. The first test analyzed the effects of the automatic heaters located on the left and right above each of the units. The multitude of peaks in Figure 7, Figure 8, Figure 9, and Figure 10 clearly indicate when the heaters were operated intermittently.

A second test was also performed to show the opposite effect. This included fully opening the hangar bay door to allow the significantly cooler winter air to naturally flow into the hangar bay. There are six valleys shown in Figure 7, Figure 8, Figure 9, and Figure 10 on January 11th, 12th, 14th, 15th, 19th, and 20th, which clearly indicate when these events occurred. In both tests, all of the temperature sensors responded in a similar fashion in the controlled environment. The maximum difference from each of the sensors was one degree Celsius. In addition, there were minimal differences between each unit on both the roof and inside of the attic.

### 3.2 Environmentally Exposed Baseline

The gable on each unit was sealed with an octagon shaped particle board to minimize the convective currents in the attic. After the successful baseline testing inside of the hangar bay, each unit was moved to the tarmac area, outside of the Hangar. Testing commenced for a period of 2 months under various environmental conditions. A representative set of data for the attic temperatures are shown in Figure 11 and Figure 12 for the 500 and 800 units, respectively. In addition, the same time period is shown as a representative set of data for the roof temperatures shown in Figure 13 and Figure 14 for the 500 and 800 units, respectively.
Each unit was located 150 feet from the front of the hangar and placed such that they were not in the shadows of any structure for the environmentally exposed testing. The temperatures on the left hand side (LHS) and right hand side (RHS) of the roof and attic were within one degree Celsius, so an average of each side was calculated and shown in Figure 15 and Figure 16 for the 500 and 800 units, respectively. In addition, the ambient temperature for that time period is shown in each figure [6].

As expected, both sides of each unit increased as the ambient temperature increased. The LHS reached its peak temperature first, after which the RHS followed, but did not reach the same peak temperature. In this data set, there were two days (April 9th and 13th) in which the ambient temperature was significantly lower where most of the day was cloudy and hence the peak for both the RHS and LHS were similar and lower than the other testing days. In addition, the data for the LHS and RHS both follow the ambient temperature trend. For example, when there were noticeable ambient temperature fluctuations, the LHS and RHS exhibited the same pattern, as shown in Figure 17 and Figure 18, for the time period of April 13th through the April 15th when both cloudy and sunny days were observed.
4 Conclusions

An experimental testing protocol was designed and developed for a novel thermal management system utilizing passive convective cooling. Baseline data was established in both controlled and environmentally exposed environments which confirmed each unit was built identically and can be used for further experimental testing.

References


**Author Biographies**

**Emily D. Pertl** received her B.S., M.S. and Ph.D. degrees in Mechanical Engineering from West Virginia University (WVU), Morgantown, WV, USA, in 1999, 2001, and 2010, respectively. She is currently a Program Coordinator in the Center for Industrial Research Applications (CIRA) at West Virginia University (WVU) before which she was a Mechanical Engineer at Aquatech International Corporation. She has been the co-principal investigator for several projects funded by several agencies and has published 15 conference papers and journal articles. Dr. Pertl is a member of SAE, ASME, ASHRAE, and an Engineering Intern.

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