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Temperature and power consumption measurements as a means for evaluating building thermal performance

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ABSTRACT

A simple methodology is introduced to obtain an empirical relation between power consumption and indoor–outdoor temperature variations for a small residential building. The effects of house occupants, air/moisture leakage, material deterioration, etc. were not considered in the analysis. The Tuskegee Healthy House was used as a test building for the experiment. Empirical equations for power consumption as a function of temperature area differences were obtained from the measured data of winter 2009 with and without mechanically-induced ventilation fresh air, i.e. using fan "ON" and fan "OFF" condition, respectively. The equations were applied to the measured temperature data of winter 2002 to compare and evaluate the thermal performance of the test house. The equations agree favorably with the winter 2002 data revealing that there is no significant difference in power consumption values of winter 2002 and winter 2009 and, hence, no appreciable change in the thermal performance of the house. The methodology presented in the work can be utilized to compare and evaluate the thermal performance of a given building envelope from season to season and between the same seasons in different years.

1. Introduction

Minimizing power consumption is one of the many aspects of energy conservation and economic operation of a building envelope. At the same time, maintaining a hourly/daily time-history of the power consumption data as a function of the indoor and outdoor climate conditions can serve as a good measuring tool for evaluating the thermal performance of a building envelope as it begins to age. The energy consumption depends upon different factors, such as the building construction type and the materials used (in walls, roof, floor, windows, door, etc.), the orientation of the building, outdoor climate, heating and cooling systems used, airtightness, type of insulation, lighting, ventilation, number of occupants, and many other variables. Thus, the thermal responses of building components and the thermophysical properties of building envelopes together determine the energy consumption behavior and comfort conditions of a building.

Because of the varied nature of building types, location, and climate the power consumption of a given building envelope varies with time as the building starts aging. Several studies dealing with any one or two individual aspects of energy conservation, such as the energy transmission through different types of wall construction, insulation material, effect of climate conditions, inhabitants have been reported [1–4]. Moisture content also affects the thermal resistance (*R*-value) of the insulation and other materials [5]. In the energy analysis of home constructions, because the insulation cannot be replaced without a major dismantling, the *R*-value is assumed to remain constant for many decades (20 years or more) [6–7].

Energy consumption is also affected by air leakage and air infiltration in the building. Literature review indicates that there is no linear correlation between air leakage and building age. It is found that a new building sometimes may have more leakage than the older ones [8–10]. Regular inspection of the building for any structural damage or deterioration, therefore, must be a part of the thermal performance evaluation process.

Combinations of analytical/modeling and experimental techniques are also used in practice sometimes to assess the thermal performance of a building [2–4]. But, from a point of view of just the power consumption alone, there is no specific methodology available that suggests how the thermal performance of a building varies as it starts aging.

The present study attempts to address this issue by presenting a methodology that involves measurements of power consumption as a function of indoor–outdoor temperature variations. The methodology is simple and it can be easily applied to any type of building envelope. The methodology is applied to a test house, called the Tuskegee Healthy House (THH), situated in the south-eastern region of the United States. A description of the THH is given in the next section. The study presented here includes measured power

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and weather data in the winter season of 2009. The methodology can be applied to other seasons also. Given the same inside operating conditions, the methodology can be used to compare and evaluate the thermal performance of a building envelope from season to season and between the same seasons in different years.

2. Tuskegee Healthy House

In order to address the energy efficiency and the indoor air quality in residential buildings, researchers at Tuskegee University, Alabama, have designed and constructed a ''healthy house''. Three main criteria for the design and construction of the Tuskegee Healthy House were low cost, energy efficiency, and healthy indoor air quality (IAQ) [11]. Research studies to address the various issues related to thermal performance of this building have been reported elsewhere [12–14].

The one-story test house is built on a crawlspace. A schematic of the THH floor plan is shown in Fig. 1. A photograph of the house is given in Fig. 2. The area of the house is 24 ft × 32 ft (7.32 m × 9.75 m) or 768 ft^2 (71 m^2). The floor-to-ceiling height is 8 ft (2.44 m) and therefore the house volume is about 6144 ft^3 (174 m^3). The house has two bedrooms, one bath, a dine-in-kitchen, a living room, and small utility areas. The house has seven windows, six with dimensions of 3 ft × 5 ft (0.92 m × 1.52 m) and the other with 3 ft × 3 ft (0.92 m × 0.92 m).

The HVAC system is located in the center of the living space to minimize ductwork. The heat pump capacity is 1.5 ton. The house incorporates a separate fresh-air ventilation system, in addition to the heat pump system, to provide extra air for additional occupants of the house. The fresh-air ventilation fan is a 'LifeBreath' turbulent flow precipitation (TFP) air cleaner provided to filter particles larger than 0.3 μm from the fresh air intake and is rated at 60 cfm (28.3 L/s).

The outer walls of THH consist of four layers: 1/16 in (0.159 cm) vinyl siding, ¾ in (1.905 cm) foam board sheathing, 3½ in (8.89 cm) *R*-19 fiberglass batt insulation, and ½ in (1.27 cm) gypsum board as shown in Fig. 3. Foam board is used for sheathing with thermal resistance of 5 (*R*-5) to provide a continuous layer of insulation as well as air and moisture barrier. There are two layers of *R*-19 fiberglass insulation placed in the attic. Several airtightness features are considered in the house construction to minimize leakage. The sheathing and framing are used to reduce the thermal loss and improve energy efficiency.

The crawlspace is based on a concrete masonry unit (CMU) foundation having the exterior wall footings filled with cement concrete mixture. The crawlspace floor is covered with 2 in. (0.05 m) of fine sand on top of a full-ground polyethylene vapor-retarding membrane. The crawlspace is enclosed and has a vent system that can be closed and opened as needed to minimize migration of air and moisture from the ground to the living area of the house and also to reduce energy loss through the house floor. The crawlspace is checked periodically for any formation of mold or mildew. The THH is inspected and maintained regularly to prevent any structural damage or degradation.

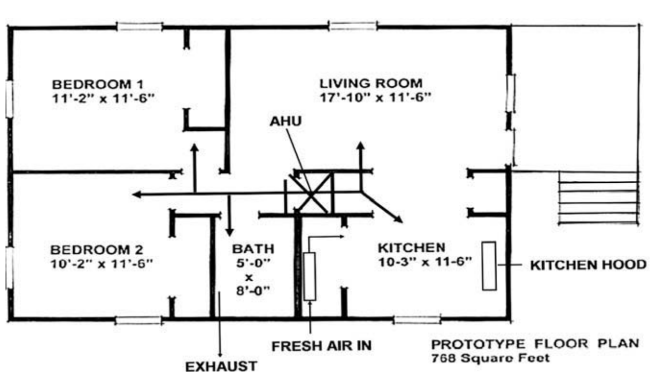

Fig. 1. Floor plan of Tuskegee Healthy House (THH).

Fig. 2. Photograph of THH.

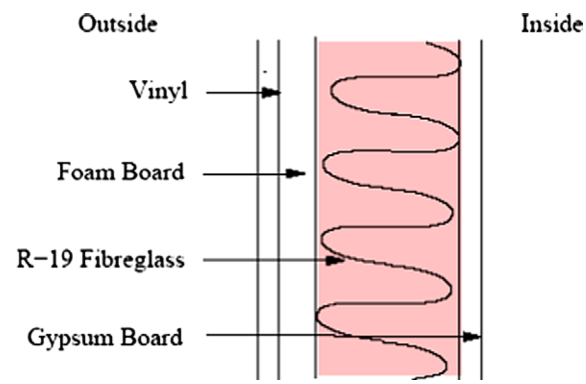

Fig. 3. Cross section of THH outer wall.

Off-the-shelf wall-mounted light fixtures are used to reduce penetration through the ceiling. The house has only one plumbing wall with one floor penetration. All ductwork and penetrations through the building envelope are sealed.

The THH is equipped with instrumentation and data acquisition systems to measure and record the indoor and outdoor climate conditions in addition to other indoor air quality parameters. The house energy consumption is measured using a conventional power meter situated outside the building. The instrumentation system is described in the next section.

3. Instrumentation

Dual temperature/relative humidity sensors (Vaisala Model HMW60U/Y-U190en-1.2) were used to measure and record the relative humidity (RH) and temperature inside the THH. The living room sensors were placed at a central location on a table about 3 ft (0.92 m) above the floor. The temperature measurement accuracy of the sensor is ±0.9 °F (±0.5 °C) for a range of −23 °F to +131 °F (−5 °C to +55 °C) with linearity better than 0.18 °F (0.1 °C) and the relative humidity measurement accuracy for the sensor is ±3% over the range of 0–95% [13,14]. A desktop computer system with an Agilent Technologies model 34,970 data acquisition unit was used to monitor, check, calculate, integrate, and save