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Conversion of electric heating in buildings
An unconventional alternative

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ABSTRACT

To decrease the electric energy used for heating buildings it has become desirable to convert direct electrical heating to other heat sources. This paper reports on a study of the possibility of using an unconventional method for conversion to avoid installing an expensive hydronic system. The conversion method combines the ventilation and heating systems and uses air instead of water for distribution of heat within the building, taking advantage of thermal forces and the special properties of gravity currents. Full-scale tests have been carried out in a test apartment inside a laboratory hall where the conditions could be controlled. Temperatures and efficiency of ventilation have been measured to ensure that the demands with respect to thermal climate and air exchange were fulfilled. The results show that it is possible to use the method for heating and ventilation when converting the heating system, but further work has to be done to develop a detailed solution that works in practice.

1. Introduction

This work reports on an experimental study of the prerequisites of distributing heat using air as the heat carrier in order to avoid introducing an expensive hydronic heating system when converting direct electric heating to other heat sources.

1.1. Background

Residential buildings in Sweden constructed during the 1960s and 1970s are often equipped with electric radiators for heating. The main reasons to choose electric heating were the low installation cost and the low price of electricity. Today the situation on the energy market is quite different and the price of electricity has increased significantly, an increase we can expect to continue in the future. Therefore it has become desirable to convert the heating system to reduce electricity usage. Examples of alternative energy sources are district heating or heat pumps.

The most common ventilation principles in the actual buildings are stack ventilation or extract ventilation, where the air is transported from the building through openings in the kitchen and bathroom. Replacement air comes directly from outside, driven by the under-pressure caused by the ventilation system and entering the building through purpose-built openings usually located above or below the windows. During winter time, the temperature of the supply air often is very low; therefore, there are frequent complaints of cold draught in buildings equipped with stack or extract ventilation.

1.2. Conventional conversion

The conventional method to convert from electric to district heating is to install a hydronic system with a radiator below each window. This type of heating system is known to work satisfactorily. A disadvantage with a hydronic system is, however, the great installation cost.

1.3. Unconventional conversion of heating and ventilation

An alternative solution is to use air as the heat carrier, thus combining the distribution of heat and ventilation air. An unconventional way to achieve this is to make use of so-called gravity currents for distribution of warm air for heating and ventilation. As the supply air will be heated before it enters the occupied zone it is likely that this solution also will reduce the risk of complaints from the occupants about cold draught from supply air inlets.

To accomplish the unconventional conversion there are two phenomena of crucial importance:

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- Air movements caused by thermal forces
- The special properties of gravity currents with positive buoyancy (warm currents)

There are also a number of questions that must be answered about the performance of the conversion method:

1. Are the thermal forces sufficient for the distribution of heat?
2. Why should we use gravity currents?
3. Can we meet the thermal comfort demands?
4. Will the increased heat loss through the ceiling/roof be of importance?
5. Is air leakage from the building envelope of importance?

1.4. Air movements through large openings

Thermal forces can be used to distribute heat and ventilation air within a building. Even very small temperature differences can cause large airflow rates through the doorway between adjacent rooms. If there are only thermal forces present the airflow pattern will consist of two flows of equal size and opposite direction (see Fig. 1).

If the area of the opening is $A = h \cdot w$, the flow rate in each direction can be written as:

$$q_e = C \cdot A \cdot (g' \cdot h)^{1/2} \quad (1)$$

where g' is the reduced gravity ($g' = g \cdot \Delta T/T$) and C is a proportionality coefficient depending on several parameters which must be determined experimentally.

Etheridge and Sandberg have summarised a number of studies carried out to determine C, both at full scale with air as the operating fluid and on a model scale using other operating fluids [1]. The value of the coefficient was found to vary between 0.12 and 0.20. Some of the studies reported that the coefficient showed a weak temperature dependence.

Thermal-driven flows through horizontal openings can be described in a way similar to the flow through vertical openings [2,3]. However, the proportionality coefficient, C, is significantly less due to the more complex flow pattern (see Fig. 2). The conclusion is that the potential of distributing heat through horizontal openings using thermal forces is substantially less than for vertical openings and will therefore be excluded from this study.

1.5. Gravity currents

A gravity current consists of a fluid propagating along a horizontal surface driven by its density difference to the ambient fluid [4]. In ventilation applications the fluid is the ventilation air and the difference in density is caused by temperature difference.

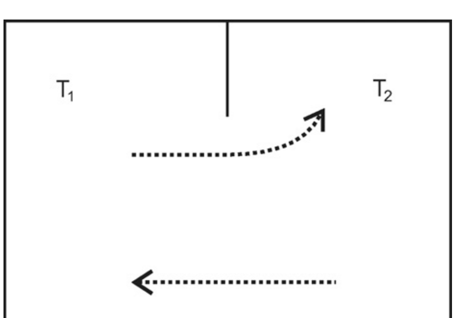

Fig. 1. Airflow pattern in vertical opening ($T_1 > T_2$).

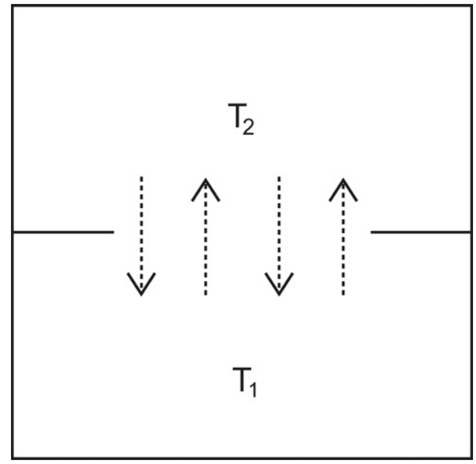

Fig. 2. Airflow pattern in horizontal opening ($T_1 > T_2$).

When cool air is introduced to a room at low momentum flux, a gravity current will develop along the floor and the distribution of air will be governed to a certain extent by the heat sources in the room. In a similar way a warm gravity current will spread along the ceiling and distribute heat to the parts of the room where the heat requirements are greatest.

An interesting property of gravity currents is their ability to pass obstacles easily. Fig. 3 shows a series of pictures from a model test where a cool two-dimensional gravity current passes obstacles of various heights. For the visualisation the shadowgraph technique was used [5], with salt water as the supply fluid to achieve the density difference to the ambient. The inlet conditions correspond to a temperature difference of 3 °C on a full scale with air as the operating fluid.

1.5.1. Differences between cold and warm gravity currents

1.5.1.1. Cool gravity currents (negative buoyancy—ventilation). Cool gravity currents are used in connection with displacement ventilation. When cool air enters the room at low momentum, a gravity current will develop, distributing the supply air evenly over the floor while the heat sources in the room transport the air upwards into the occupied zone. Then the air is carried further to the extract devices, usually located close to the ceiling level.

1.5.1.2. Warm gravity currents (positive buoyancy—heating). In this study the building is to be heated using gravity currents propagating along the ceiling. Within the occupied zone there are no heat sinks corresponding to the heat sources as there are in the cooling case. The cold external wall and the window will, however, serve as heat sinks and contribute to the distribution of heat within the room. Whether this is enough to avoid an unacceptable thermal climate due to high temperature gradients or excessively low local temperatures has to be explored.

1.6. Unconventional heating and ventilation

The aim of the present work is to explore the possibility of using thermal forces and gravity currents to distribute heat within a building. The warm air is supplied to the room at ceiling level by thermal forces from a neutral space, passes the occupied zone and leaves the room through ventilation openings at floor level (see Fig. 4). The airflow rate and consequently the amount of heat that is transferred are determined by the temperature difference between