CONSTRUCTION AND SET-UP OF A FULL-SCALE EXPERIMENTAL HOUSE FOR VENTILATION STUDIES

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ABSTRACT

This paper reports on the construction, experimental set up and infiltration characteristics of a purpose built full-scale experimental house. The building has been designed as an experimental platform for measuring the moisture removal effectiveness of active and passive ventilation systems with indoor and outdoor climate conditions seen in New Zealand.

The two bedroom building was purchased as a pre-fabricated shell and moved onto the testing site. The inner wall lining was then airtightened following the Canadian “airtight drywall” approach to achieve less than 1 N_{50} (air changes per hour under a pressure difference of 50Pa). We then installed ventilation ports in walls, floor and ceiling so that the airtightness can be adjusted between 1 and 10 N_{50} to cover the current range of new housing in New Zealand. The building is equipped with temperature, relative humidity probes and multi-tracer gas equipment to track inter zonal air and moisture flows.

Early work has measured infiltration rates at four levels of airtightness, some of which are compared to infiltration rates calculated using a zonal model of the building.

KEYWORDS

Ventilation, infiltration, full-scale, moisture removal

INTRODUCTION

The New Zealand Building Code offers an acceptable solution to home ventilation [1, 5, 6] that allows homes to be naturally ventilated through openable window and door openings greater than or equal to 5% of the floor area. Such a simple passive approach has been satisfactory given the temperate climate in New Zealand but this is potentially now not the case for the following reasons:

- The airtightness of new houses in New Zealand has increased over time, even though there is no airtightness requirement in the building code. The average airtightness of houses built pre-war is around N_{50} = 19 ACH and this reduced to N_{50} = 9 ACH for houses built 1960-1990 when large area sheet materials replaced strip lining and flooring. For houses built between 1990 and 2010 the average N_{50} = 4.5 ACH [4, 5, 6]. These changes are a natural consequence of building design and material selection but they have closed down natural ventilation paths that may have added useful ventilation.

- A recent survey of ventilation rates in homes built since 1994 [4] showed that the infiltration minimum is often supplemented by opening windows but that a proportion are exhibiting moisture problems because windows are kept closed for security and privacy. Clearly window opening cannot always be relied on for ventilation.
- Mechanical supply-only ventilation systems have become a popular retrofit solution to indoor moisture in New Zealand homes but with relatively simple controllers, they are not optimised for energy efficiency.

This paper reports on early steps towards trialling a range of ventilation options in a new full scale ventilation research building at BRANZ. Its purpose is to study the effectiveness of ventilation solutions in removing contaminants (particularly moisture), along with their ability to adapt to an occupant that opens windows. The work forms part of a wider WAVE (Weathertightness, Air Quality and Ventilation Engineering) programme at BRANZ. One of the aims of WAVE is to provide guidance on suitable ventilation options that are optimised for moisture control, energy efficiency and the airtightness of the house.

Our intention is to trial ventilation systems similar to those investigated by Yoshino et al. [7] as well as Liu and Yoshino [8] who have studied the performance of different ventilation systems in a full-scale two storey house at a fixed airtightness level without monitoring moisture removal or other contaminants. The effect of moisture buffering and ventilation as studied by Lengsfield et al. [9] and Hasegawa et al. [10] will be of particular interest to our research. Moisture production levels of various domestic activities we intend to simulate are going to be used according to Aizawa et al. [11] or Pallin et al. [12].

THE EXPERIMENTAL BUILDING

The building shown in Figure 1 was constructed as a pre-built shell in 2007 and recently transported on to the research site. The single storey house has a floor area of 91 m^2 and a volume of 206 m^3. The volume of the roof cavity is approximately 45 m^3. The house is a traditional timber frame construction that is clad with painted fibre-cement weatherboard directly fixed over a flexible wall underlay. The gable roof has corrugated iron cladding on timber trusses. The floor is made of particle board which is sealed with polyurethane. The walls and the ceiling are insulated to the requirements of the New Zealand building code [13] with fibre glass. All inner wall surfaces and the ceiling are lined with gypsum based plasterboard which received 3 coats of an acrylic paint.

In order to study ventilation effectiveness at airtightness levels that are present in a large part of the New Zealand housing stock we fitted the house with sealable ports that penetrate the envelope. The ports are located in the floor, the walls and the ceiling connecting the living area to the subfloor, the cavity of the outer walls and the attic, respectively. Our intention was to reach an airtightness level as low as 1 N_{50} (all ports sealed) and an upper level of about 9 N_{50} (all ports open). The pre-fabrication and the fact that it was going to be transported to its location on the research site made it necessary to achieve the airtightness through detailing of the indoor wall linings which were installed after the building reached its destination. We decided to implement the Canadian “airtight drywall” approach. To avoid air leakage from the outer walls through the inner walls into the room we isolated the inner wall by means of applying a 3 mm thick closed foam tape to the corners where the inner walls join onto the outer walls of the building. For the electrical outlets we used flush boxes that have seals at the

Figure 1: The experimental building on site.

cable inlet and where the plasterboard butts on the box rim. To avoid air leakage through gaps between the floor and the ceiling boards the plasterboards were sealed using silicone caulking. Every penetration of the plasterboards for cables, lighting, access hatch to the attic and the like was sealed as best as possible.

Characteristics of the Ports

In order to derive an model of the infiltration, we measured the pressure/flow characteristics of the ports by pressurizing the building. The ports were constructed from PVC tubing with an inner diameter of 38mm and 64mm. The ports were installed in the walls, the floor and the ceiling which has given rise to four different pressure/flow characteristics. These characteristics were determined by fitting a exponential function $Q = C(dP)^n$ to the measured data points. Figure 2 shows the measured data and the graph of the fitted model while the fit parameters are provided in Table 1.

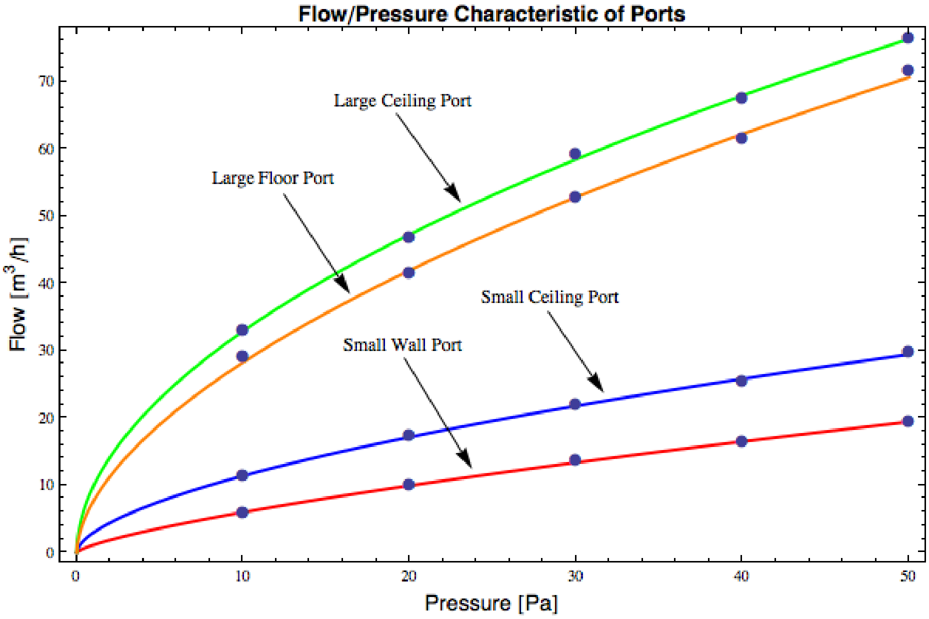

Figure 2: Measured data and fitted function for the flow characteristic of the various ports

The diameter of the port is the dominant factor determining the flow/pressure characteristics. The flow characteristic of the small ceiling ports and the wall ports show comparatively little differences taking into account that those ports lead on one hand into the large attic, while the wall ports lead into the confined space of the wall cavity. This indicates that the outer shell of the walls is not very airtight and that the airtightness level of 1 N_{50} achieved in the house is largely determined by the inner wall lining.

Port location/Size	Coefficient C	Exponent n
Wall Ports	1.1 ± 0.1	0.73 ± 0.02
Floor Ports	7.6 ± 0.5	0.56 ± 0.02
Small Ceiling Ports	2.9 ± 0.1	0.58 ± 0.01
Large Ceiling Ports	9.8 ± 0.4	0.52 ± 0.01

Table 1 Fit parameters of the power law pressure/flow model $Q = C(dP)^n$.

INSTRUMENTATION

The building is equipped with instruments that allow it to run infiltration and contaminant removal measurements in a semi automatic way. All operations are controlled by a computer which controls the indoor climate, the sampling of the tracer gas, the temperature and humidity sensors and writes the retrieved data into a database (see Figure 3). A database table is used to describe indoor climate parameters such as temperature and humidity. The house can be heated and the humidity can be increased but no cooling or dehumidifying is available at this point in time apart from what the installed ventilation system is providing. The airflow through the ventilation system into each zone is measured by means of pressure averaging tubes installed in the ducting.

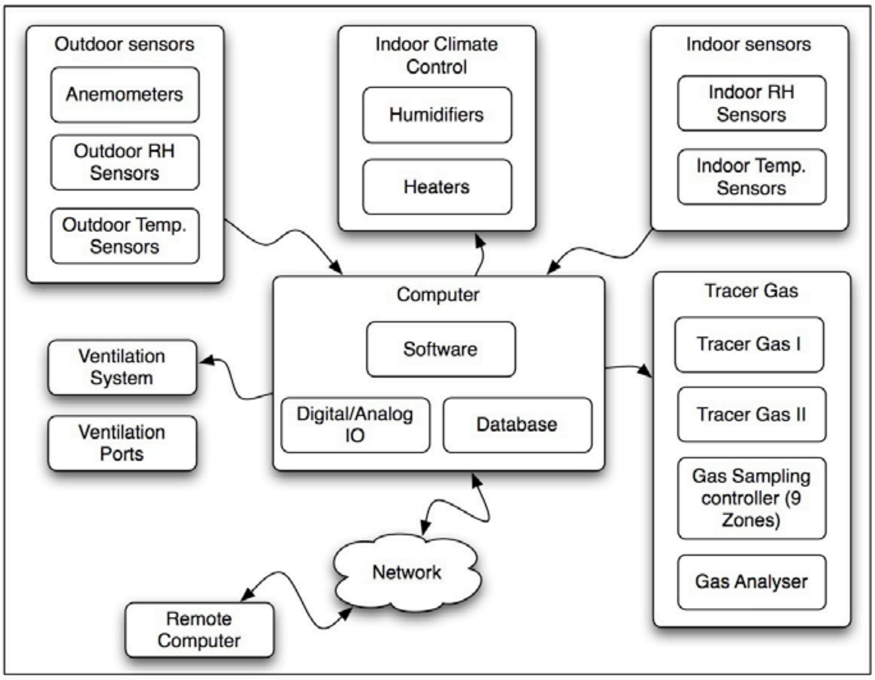

Figure 3: Instrumentation scheme used in the house.

The tracer gas injection rate is manually controlled at this point in time. Flow controllers used in gas chromatography are used to adjust the injection rate of the tracer gases from a few millilitres to hundreds of millilitres a minute. The flow controllers are kept at a few degrees above ambient temperature to minimise drift of the tracer gas injection rate. The flow rate is measured using simple bubble flow meters. An Innova 1412 photo acoustic gas monitor is equipped with filters to detect CO_2, Freon, sulphur hexafluorid (SF_6) and water with detection limits of 3.4 ppm, 0.02 ppm, and 0.006 ppm, respectively. The dynamic range of the gas monitor is typically 4 to 5 orders of magnitude. The target working concentrations of the tracer gas in the zones is usually at least 10 times the detection limit or, in case of CO_2 10 times the background concentration. The tracer gases are sampled from the zones by means of a computer controlled manifold that can switch each of the possible 9 sampling locations onto the gas monitor. Each room, including the attic, is equipped with a number of sampling and dosing tubes. In the living area these tubes are located at approximately 1.5m off the ground. Before the gas monitor analyses the air sample it purges the tubes and the sampling chamber to avoid cross contamination. Measuring each location in turn takes about 10 minutes to process, thus allowing 6 samples to be taken from each location per hour. Wind velocities are obtained from the weather station located next to the house.

INFILTRATION MEASUREMENTS

Before we can determine the performance of various ventilation systems, the infiltration characteristics of the house at different airtightness levels in the absence of a ventilation system had to be established. Our intention is to measure the ventilation effectiveness at the four airtightness levels of 1, 3, 5 and about 9 N_{50}. Various ports in the walls, the ceiling and the floor are opened to achieve these levels of airtightness. A ventilation port plan is used to make sure that only those ports are opened at a given airtightness level that allow for an even distribution of air leakage paths throughout the building. The injection rate of the tracer gas is adjusted in accordance with the set airtightness level to reach a tracer gas concentration of at least 10 times the detection limit, thus allowing for enough dynamic range and lower signal to noise ratio.

Figure 4 and 5 show the hourly averaged infiltration measurements of a single zone i.e., one tracer gas, over 2 - 4 days at different airtightness levels. The measurements were completed during a calm period with average wind speeds of only 2 m/s measured at 10 metres height.

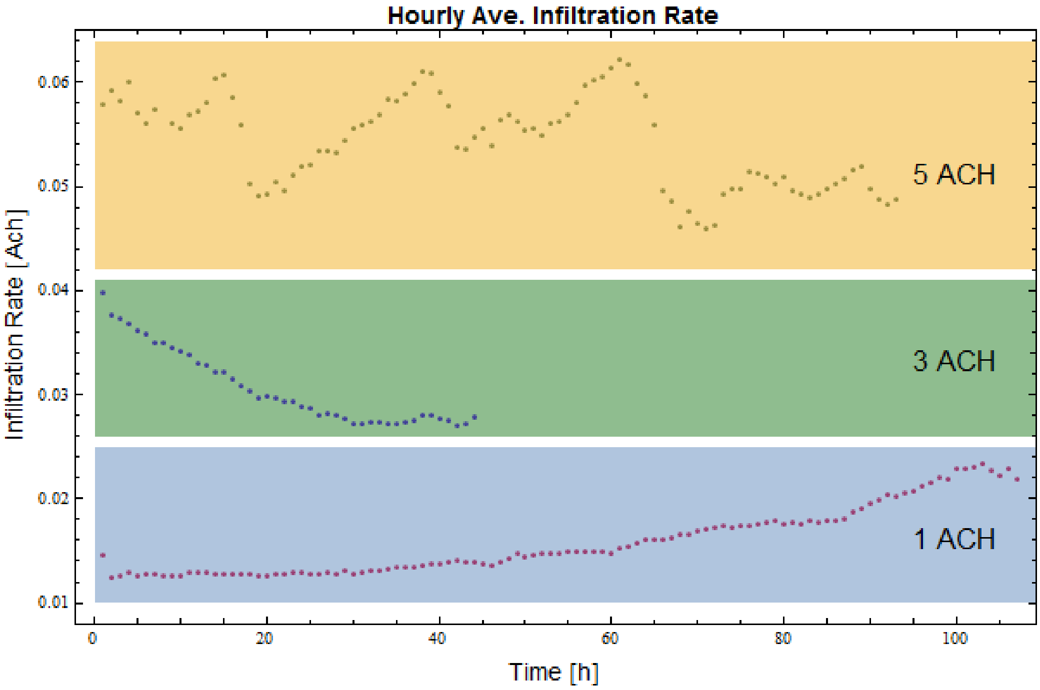

Figure 4: Single zone infiltration rate of the living area at different N_{50} airtightness levels. The graph for the airtightness level of 9 ACH has been moved to Figure 5 due to scaling.

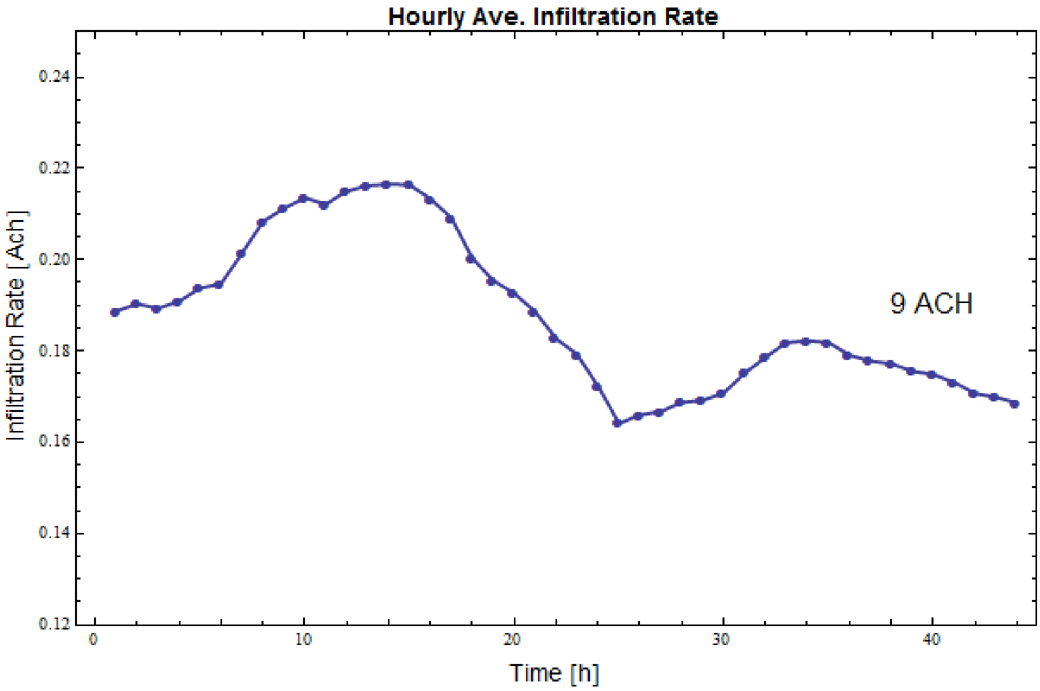

Figure 5: The graph shows the single zone infiltration rate of the living area at about 9 N_{50}. All ports are open at this level of airtightness but windows and doors are closed.

The hourly averaged infiltration rate of a short 2 zone infiltration experiment is shown in Figure 6. One of the bedrooms (Zone 2) of the house was filled with CO_2 while the remaining living area (Zone 1) of the house was filled with SF_6. Both zones were at an airtightness level of about 2 N_{50}. Only wall ports were open during this experiment, therefore, there was no cross infiltration between the two zones via the roof apart from through adventitious openings. Most of the inter zonal infiltration would have taken place through openings under the closed door. The average wind speed during this period was about 1.5 m/s at a height of 10 metres.

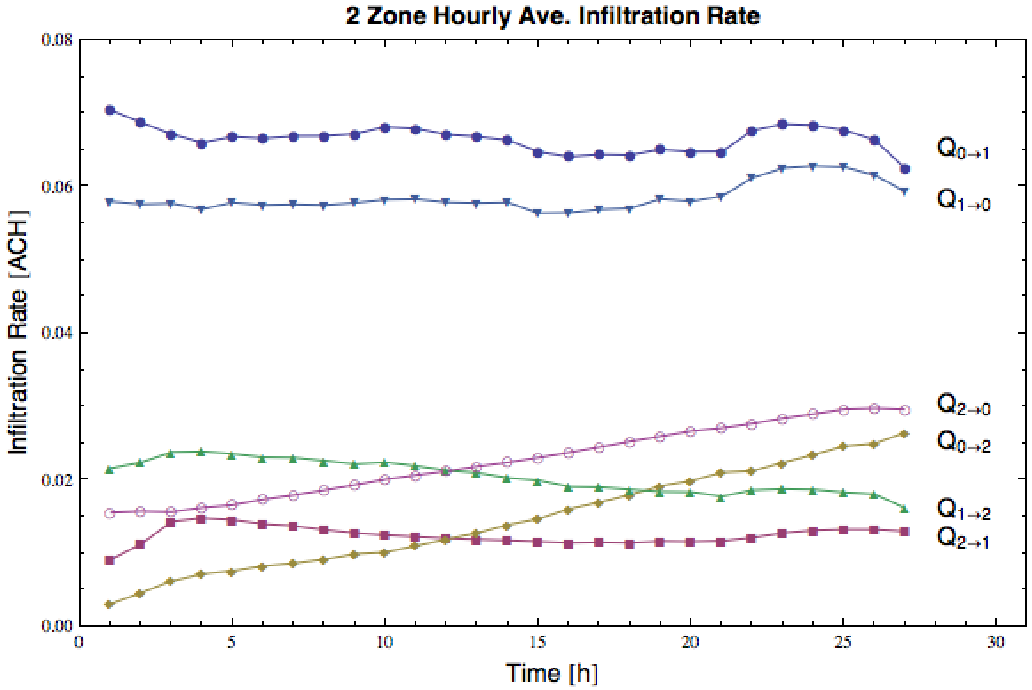

Figure 6: Infiltration rates for two zones - A bedroom (Zone 2) and rest of the house (Zone 1). Zone 0 refers to the outside of the building.

CONTAM MODEL

We have created a model of the infiltration characteristics using CONTAM. This model will be used later in the study to compare the measured performance with a ventilation system in place with what the performance would be without the ventilation system

At this point in time we have developed a single zone CONTAM [14] model using only the wall ports to simulate the ventilation in the living area of the test house. The pressure/flow characteristics of the wall ports (see Figure 3 and Table 1) have been used as parameters describing the flow paths in the model. Wind, outdoor and indoor temperature data were obtained from a weather station and the sensors in the test house. Pressure coefficient values for the building were derived from a wind tunnel measurements published by Tokyo Polytechnic University [15].

The tracer measurement was started on the 28th July and ran continuously till midnight of the 31st July. The hourly averaged simulated (dashed line) and the measured (continuous line) infiltration rate of the living area of the test house is shown in Figure 7. While the infiltration data is reasonable noisy it shows a good agreement between the simulation and the measurement. This indicates that the assumptions made in the model about the buildings pressure coefficients and the calculated pressure/flow characteristics of the wall ports are reasonable. Over time we will compare the simulation output of the model with other infiltration measurements to make the model more robust and show its validity under different wind and temperature conditions.

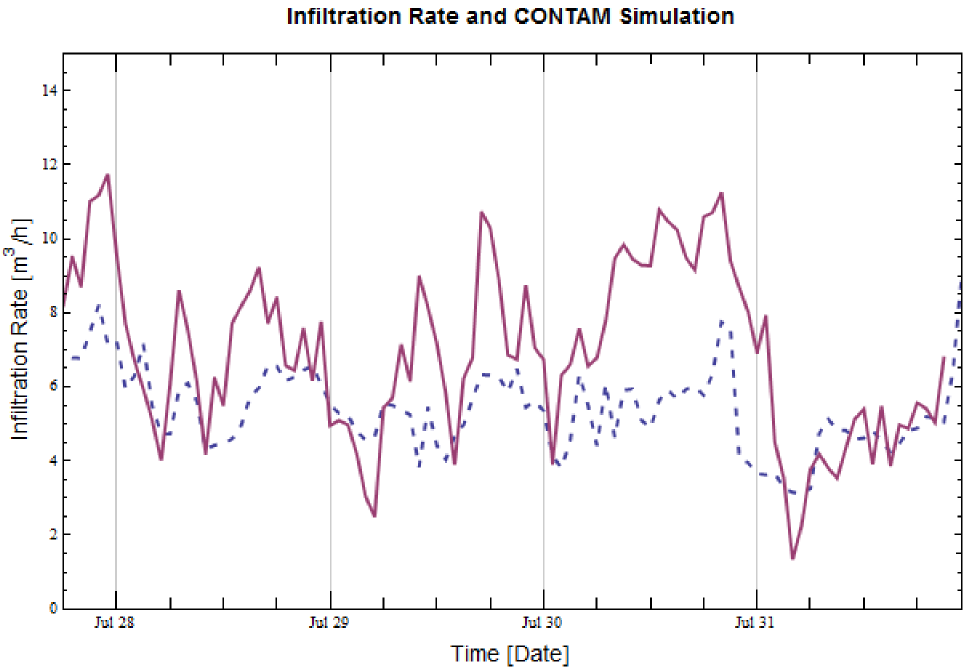

Figure 7: Good agreement is shown between the measured infiltration rate (continuous) and the rate simulated by use of a CONTAM model (dashed).

CONCLUSION

In this paper we have described the set up of a full scale experimental building to study the moisture removal effectiveness of ventilation systems and have presented initial measurements of infiltration data to characterise the building. The experimental setup can measure at up to 9 sample locations at a rate of 6 samples per hour. A single zone CONTAM model was developed and shows good agreement with a data set derived from an initial infiltration rate measurement.

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