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# PERFORMANCE ANALYSIS OF DEMAND CONTROLLED VENTILATION SYSTEM USING RELATIVE HUMIDITY AS SENSING ELEMENT

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# PERFORMANCE ANALYSIS OF DEMAND CONTROLLED VENTILATION SYSTEM USING RELATIVE HUMIDITY AS SENSING ELEMENT


## SYNOPSIS

This paper evaluates the suitability of humidity-controlled house ventilation system to determine (i) the effectiveness of relative humidity as a sensing element, and (ii) the operating and performance characteristics of such ventilation strategy. The ventilation system consists of continuously running "mechanical" air extractor units and "passive" air inlet units equipped with humidity sensors. The ventilation system was installed in two single storey houses which were monitored during November 1989 to April 1990. Results showed that the changes in the relative humidity did not appear to track the levels of normal human activity accurately. The difference in air in-flow through each passive air inlet due to changes in RH (2 to 10%) varied from 0.8 L/s to a maximum of 1.7 L/s, which was found to be insufficient based on high $CO_2$ levels ( > 1200 ppm) in occupied rooms. The humidity-controlled mechanical exhaust system was found satisfactory in maintaining the level of exhaust air-flow with changes in RH. The air in-flow and out-flow analyses showed that the air leakage though the house envelope remained as a predominant form of fresh air supply to the house, thus defeating the purpose of demand controlled ventilation. The energy consumption of these two houses reduced by more than 8% by cutting down the fresh air provided to house during un-occupied periods. Relative humidity as an exclusive sensing element may not be sufficient enough to achieve required quality ventilation in houses.


## 1. INTRODUCTION

Modern houses have significantly improved building envelopes in terms of insulation and airtightness to improve energy efficiency and human comfort. Given the current trend towards increased airtightness of house envelopes, it is recognized that houses now being built in North America will have to incorporate some form of controlled mechanical or passive ventilation. The controlled ventilation should assist in removing the moisture source as well as providing sufficient fresh air to occupants [CMHC 1990].

In Canada, the CSA Standard F326 - *Residential Mechanical Ventilation Requirements* - defines the requirements for mechanical ventilation systems for providing minimum controlled rates of ventilation air to habitable spaces by using continuous or intermittent air supply and exhaust devices [CSA 1989]. It is likely that the F326 Ventilation Standard will be referenced, as mandatory, in the upcoming 1995 National Building Code and in those provincial codes based on it. The minimum mechanical ventilation requirement is 0.3 air changes per hour (ach), which is similar to ASHRAE Standard 62-1989 [ASHRAE 1989].

One such controlled ventilation strategy is based on humidity sensing passive air inlets and humidity-controlled mechanical exhaust system. The humidity-controlled ventilation (HCV) systems rely on humidity levels generated by the occupants as being the controlling variable determining the necessary ventilation rate. In this way it attempts to follow a "demand-controlled ventilation" strategy (DCV): ventilate the house when and as needed. The HCV system was installed in two single storey detached houses located near Ottawa, Ontario which were monitored during the winter months of November 1989 to April 1990. The study objectives were to (i) to gauge how well the ventilation system responded to changes in indoor humidity, and (ii) to determine the response of air inlets and extractors to indoor RH and occupancy. The ventilation system was evaluated using two criteria: (i) the occupant related pollutants dominate house related pollutants; and (ii) the house envelope is sufficiently air-tight that some form of passive or mechanical ventilation is required.

## 2. HUMIDITY-CONTROLLED HOUSE VENTILATION (HCV) SYSTEM

The indoor humidity levels depend on the following factors: (i) the number of people in the house (a person at rest emits roughly 40 grams of water vapour per hour); (ii) the occupancy level in the room (a vacant room will have a lower humidity level than when occupied); (iii) the utilization of each room (level of human activity, laundry, cooking, bathing, dishwashing, etc.); and (iv) the effect of air infiltration and ambient air temperature and humidity. The indoor humidity level seems to vary according to occupancy and level of utilization of space. Therefore, a ventilation system designed to respond according to the changes in indoor relative humidity have seemingly good potential to supply fresh air and exhaust stale air according to occupancy when and as needed.

The humidity sensor in HCV system is composed of polyamide tissue (nylon strips) which responds to changes in humidity with shrinking or stretching. The movements of the nylon strips are amplified and transmitted by a system of actuator to the movable shutter. The air-inlets and extractor units are composed of humidity sensor, actuator, movable shutter and deflector. Fresh air is introduced through air-inlets into the main rooms such as the living and dining areas, family rooms, and bedrooms according to the relative humidity in each room. The exhaust outlets are located close to the source of pollutant generation such as kitchen, bathrooms and laundry room.

Extractor Units: The extractor units control the rate of exhaust by automatically varying the size of the extractor opening in proportion to the level of indoor relative humidity (RH). The extractor opening contains an inflatable rubber tube/spring assembly, which controls the dimension of the opening pneumatically. As the relative humidity in the room rises, the pneumatic circuit closes, causing the tube to lengthen and allowing greater air flow through the extractor. As the relative humidity drops, the tube shortens and widens, reducing air flow through the extractor. In this way, the exhaust rate is proportioned according to the relative humidity. Air extractors are hooked to the 100 L/s (208 cfm) central exhaust fan, which are placed in rooms where humidity is produced such as bathrooms, kitchens and laundry rooms. The exhaust fan runs 24 hours a day at slow speed and continually maintains a slight negative pressure across the building envelope.

Air Inlets: The air inlets are installed with through-the-wall supply diffusers, placed in each bedroom and the main living area in the house. The air flow into the house through the supply diffusers is controlled by the relative humidity of each room or space. The air inlets provide a variable free opening of 5 to 30 $cm^2$ (0.78 to 4.65 $in^2$), adjusting the opening by means of a humidity sensing element that sets the damper position. Two humidity ranges can be selected on the fixture: 25% to 60% RH, for cold climates, and 40% to 70% RH for milder climates. The humidity sensor is located in the fixture, but away from the incoming fresh airstream, so that it senses the average room humidity level [Baets and Dietz 1986]. Figure 1 shows the schematic of an air inlet.

## 3. HOUSE DESCRIPTION AND CHARACTERISTICS

Two test houses are located near Ottawa, Ontario. These houses are designated as House A and House B.

House A: This house is a split entrance, raised bungalow with three bedrooms, a dining room, living room, kitchen and unfinished basement. The electric baseboard heaters are controlled by individual wall mounted thermostats. This house has 109.7 $m^2$ (1,137 $ft^2$) of heated floor space and volume of 460.2 $m^3$ (16,243 $ft^3$). The estimated airflow to cause at 10 Pa pressure difference is 88 L/s (184 cfm). The measured airtightness was 3.18 air changes per hour at 50 Pa.

House B: This house is a three bedroom bungalow with eat-in kitchen, and living room as shown in Figure 2. It has a floor area of 101.8 $m^2$ (1,056 $ft^2$) and volume of 414.9 $m^3$ (14,644 $ft^3$). The estimated airflow to cause at 10 Pa pressure difference is 84 L/s (175 cfm). The electric baseboard heaters with wall mounted thermostats are located in each room and wherever necessary. The measured airtightness was 3.03 air changes per hour at 50 Pa.

## 4. RESULTS AND DISCUSSION

Monitored data was examined and "typical" snapshots of three to four days were selected to determine the performance of the HCV components and system as a whole. The following operating conditions were used in evaluating the HCV system: (i) periods of normal house occupancy and non-occupancy; (ii) the outdoor temperature: below -10 C (14 F), between 0 (32 F) and -10 C (14 F), between 0 C (32 F) and 10 C (50 F); and (iii) surge loads such as when several people enter (or leave) a room at the same time.

### 4.1 Relative Humidity and Air Inlet Response

Analysis of air inlet response to relative humidity was performed for two scenarios using several snapshots: (i) during the normal occupancy periods, and (ii) surge loads.

Normal Occupancy: With variation in human activity, in most cases, the RH changes by 1 to 10%. The HCV system is a humidity-controlled system and in its current configuration the air inlets do not show *instant* response of air inlet to the changes in room humidity. When there is a small increase in RH (1 to 3%) due to normal human activity, as shown in Figure 3, the air inlet response times are slow and the resulting increases in ventilation rates are very slight; however, $CO_2$ level indicate increase by more than 15%. Air flow through the individual air inlet vary from 0.8 L/s (1.7 cfm) to a maximum of 1.7 L/s (3.5 cfm). The time-referenced data on RH and air inlet position did not necessarily followed each other, for example, a slight increase in RH might have been followed by the closing of the air inlet rather than the opening. The relative humidity levels do not appear to track the levels of human activity in any significant way during normal occupancy.

Surge Loads: Several snapshots were observed to see the effect of "surge" loads on the HCV system to evaluate its "quick" response. The ventilation system showed quick response to changes when several people entered the room at the same time; however, it was sluggish to respond to changes when several people left the room at the same time as shown in Figure 4. The quick response of the air inlets opening when a sudden increase in the occupancy increased the air flow from 0.8 (1.7 cfm) to 3.5 L/s (7.3 cfm) in most cases. The $CO_2$ levels increased heavily during "surge" loads and remained high (more than 1000 ppm) for a period of more than 2 hours. This indicates that the air flow through the air inlets during sudden "loading" may not be sufficient to meet the ventilation requirements of occupants at that time.

Relative humidity is found to be a poor indicator of occupancy. Response times are slow and often there is no discernable change in RH despite major changes in occupancy and $CO_2$ concentrations. Relative humidity displays lag time with changes in occupancy due to absorption and desorption characteristics.

### 4.2 Carbon Dioxide and Air Inlet Response

The carbon dioxide ($CO_2$) is commonly used as an indicator of air quality in buildings. The time-referenced snapshots of $CO_2$ are shown in Fig 4 and 6. Unlike relative humidity, $CO_2$ levels do appear to track the human presence and levels of activity very well during normal occupancy and for the "surge" loads. A rise in $CO_2$ consistently occurs at the times of maximum activity. During unoccupied periods, $CO_2$ levels decay, as indoor air is continuously exhausted from house by the extractor units. Presumably, $CO_2$ can be a good indicator of occupancy and indoor air quality with demand-controlled ventilation systems.

In both houses, the $CO_2$ levels in the master bedrooms peaked at more than 1200 ppm and remained above this level for a period of three to seven hours during the night time. The higher $CO_2$ levels indicate the lack of supply of fresh ventilation air to the house. It is probable, therefore, that the current air inlet system is not providing adequate fresh air supply to the house.

Since $CO_2$ appears to be a good indicator of occupancy, the demand-controlled ventilation systems, like HCV, might require a combination of $CO_2$ and indoor relative humidity sensors to provide good air quality and moisture control in cold climate houses.

## 4.3 Comparison of Indoor Carbon Dioxide and Relative Humidity

Figure 5 shows the comparison of $CO_2$ and RH. It shows that variations in RH are more stable and smaller than changes in $CO_2$. The $CO_2$ tends to indicate *instant* changes in the occupancy while the RH lags about 15 to 30 minutes behind changes in occupancy. The time-referenced comparison of $CO_2$ and air inlet response do not track each other well. However, one or two hour averaged variations in $CO_2$ and RH response can be compared well in either increasing or decreasing trends. This observation raises the question regarding whether the humidity-controlled air supply inlets are effective in demand-controlled situations where the supply of fresh air is supposed to be provided on a room by room basis when necessary.

## 4.4 Performance of Humidity-Controlled Ventilation System

In both houses, an intentional opening area (IOA of air inlets) to the total house leakage area (ELA) ratio varied approximately from a minimum of 12% (all air inlets in minimum position) to a maximum of 35% (inlets in maximum position). This suggests that a significant amount of ventilation air is entering the house through non-intentional openings.

The in-flow and out-flow calculations showed the following results for both houses: The fresh air flow through air inlets varied from a minimum of 12% during non occupancy periods to a maximum of 27% of the total air in-flow during full occupancy. Estimated total air flow through all air inlets varied from 6.5 L/s (13.5 cfm) to 16 L/s (33.3 cfm). The air leakage through the house envelope remained as a predominant means of supplying fresh air to the house. Therefore, even if all air inlets were fully opened (say 90 to 95%), it would not substantially increase the fresh air supply to the rooms. The air inlets do not seem to have control over where fresh air is supplied. The fresh air will most likely be supplied to the basement where the majority of the leaks occur. In this regard, the air inlets are of questionable value except where the air leakage patterns are uneven and require additional leakage in a specific applications such as in a small isolated room.

The performance analysis of exhaust system showed that the continuous air exhaust was maintained adequately by the air extractors. The flow measurement results showed that these units were working according to their settings and on an average provided required 37 L/s (77 cfm) of exhaust in both houses. These extractors were constantly exhausting air from the house and kept the house depressurized.

The energy consumption monitoring and data analysis showed that the HCV system reduced the energy consumption by more than 8% when compared to forced air system. The energy efficiency of the HCV system is achieved by cutting back the fresh air provided to the house occupants, presumably at times when it is not required). However, the results of air quality monitoring ($CO_2$) in both houses raise questions about the suitability of humidity control as an exclusive control for ventilation rates.

## 5. CONCLUSIONS

This paper has attempted to describe the performance of the most recent approach to house ventilation using the indoor humidity level as a sensing element. The following conclusions are drawn from the monitoring results of humidity-controlled ventilation system installed in two houses:

- In most cases the indoor relative humidity changes by 1 to 10% with the changes in occupancy. The change in air in-flow through individual air inlet varies from 0.8 L/s (1.7 cfm) to 1.7 L/s (3.5 cfm), which was found to be insufficient based on high $CO_2$ levels in occupied rooms.
- Air inlets supply approximately 12 to 27% of the total fresh air. Remaining fresh air supply is through the envelope leaks.
- Air extractor units were working according to their settings and on an average provided the necessary 37 L/s (77 cfm) of exhaust.
- Relative humidity does not appear to reflect the levels of human activity accurately. Hence, the use of humidity as an exclusive sensing element for ventilation control may not be suitable in cold climates.
- Carbon dioxide levels do appear to track human presence and activity very well. Since $CO_2$ appears to be a good indicator of occupancy, the demand-controlled ventilation systems, like HCV, might require a combination of $CO_2$ and indoor relative humidity sensors to provide good air quality and moisture control in cold climate houses.


## ACKNOWLEDGEMENTS

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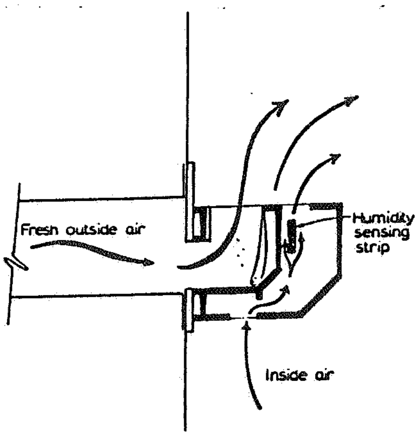



Figure 1: Humidity-controlled air-inlet.

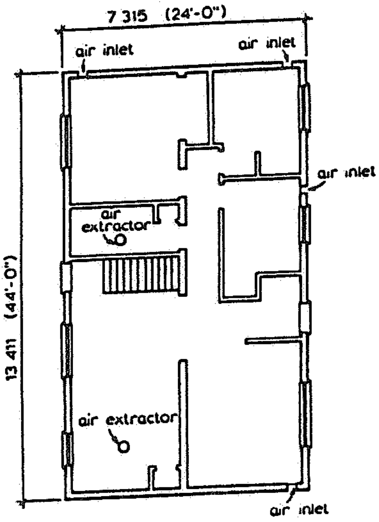



Figure 2: Description of house ventilation system.

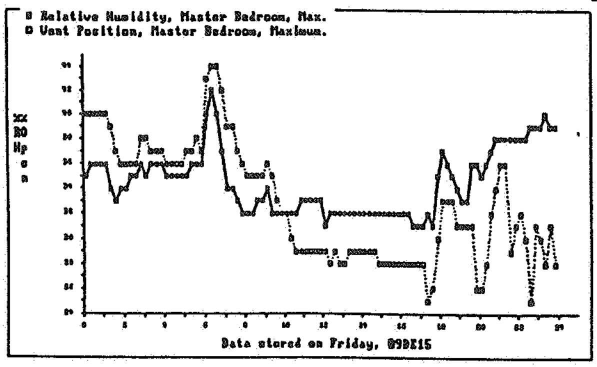



Figure 3: Relative humidity and air-inlet response.

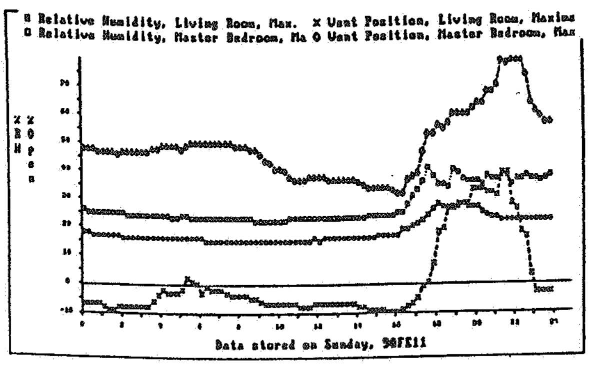
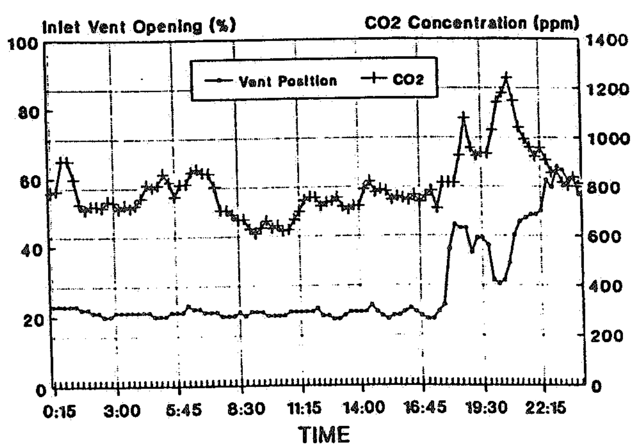



Figure 4: Effect of surge loads on RH and air-inlet opening.




Dec 15, 1989 - Living Room, Carleton

Figure 5: Response of air inlets to occupancy. Comparison of $CO_2$ measurements with air-inlet position.