AIR MOVEMENT & VENTILATION CONTROL WITHIN BUILDINGS

12th AIVC Conference, Ottawa, Canada
24-27 September, 1991

POSTER 20

A Demonstration of Low Cost DCV Technology on Five Canadian Houses

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Abstract

Field investigations were undertaken on five houses to determine the potential for improved performance and lower costs through the use of a demand controlled ventilation (DCV) systems. All 5 houses were energy efficient, low toxicity construction, and were chosen to reflect a range of mechanical systems consistent with Canada's new ventilation standard (CSA F326). Three of the test houses were extensively monitored and, after 90 days of conventional operation, were converted to DCV using a wide variety of sensors and controls. A fourth house with a previously installed DCV system was submitted to a series of "activity scenarios" to evaluate the performance of a DCV system based on extractors and inlets that respond to indoor relative humidity. The fifth house was a new house, designed to demonstrate DCV technology, and to validate the insights obtained from the other 4 houses. Commissioning of the new DCV house showed the suitability of using low cost sensors for detecting VOCs, absolute humidity, air flow and activity levels. A low-cost but sophisticated computerized control and monitoring system was used to analyze the ventilation needs and to switch fan motor windings and speeds to create a range of "operating modes" for the ventilation system. A video monitor display with occupant control added a further measure of demand control. The result was a successful demonstration of how currently available and affordable sensors and controls can be used to improve the performance of typical ventilation systems.

1.0 Introduction

This research project was completed for the Research Division of Canada Mortgage and Housing Corporation, and is part of Canada's contribution to an international research effort on Demand Control Ventilation (DCV). The research took place between September 1989 and December 1990.

The primary objective for the project was to determine if DCV can improve the way in which Canadian houses are ventilated, while lowering the operating or capital cost of ventilating systems. A further objective was to provide guidance for home builders and ventilation system designers on what DCV strategies might be most appropriate for near term applications.

The project was completed in five separate phases described in Table 1.

Table 1: Phases of CMHC Funded DCV Research

Phase 1	Literature Survey
Phase 2	Preparation of a Primer for Builders and Designers
Phase 3	Field Research on Five Canadian Houses
Phase 4	Computer Simulations of Ventilation Rates
Phase 5	Economic Analysis of DCV

The results of the first two phases have been combined into a separate publication - A DCV Primer for Builders and System Designers, which provides a popular explanation of ventilation strategies, and identifies many types of sensor technologies and DCV hardware that are currently available or under development. This paper summarizes the findings from the field investigations on the five research houses. A companion paper, also prepared for AIVC 1991, summarizes the results from the computer simulations and economic analysis.

Field investigations were intentionally designed to test ventilation systems compatible with the new CSA F326 Ventilation Standard for Canadian houses. Four of the five research houses were energy efficient, low toxicity construction. The houses were located in both coastal and interior climatic zones. The variety of systems was intended to reflect the most common approaches applied in new energy efficient Canadian housing.

Table 2: Description of ventilation systems in the Five Research Houses

Sue house	HRV with recirculating system
Jones house	HRV without a recirculation system
Smith house	Exhaust only ventilation with recirculating system
Morewood house	Exhaust only ventilation without a recirculating system
Helma house	Multiple sensor DCV system, HRV with recirculating system

The Sue, Jones and Smith houses were extensively monitored and retrofitted as part of the research. The Morewood house had an existing DCV system which was tested as found. The Helma house was new construction, and incorporated ventilation design specifications prepared as part of this project.

Field investigations began with extensive commissioning tests on existing ventilation systems, followed by minor up-grades and installation of long term monitoring equipment. After three months of monitoring house performance and air quality without DCV, each house was retrofitted with a new DCV system.

The new DCV systems employed a variety of sensors, to permit continuous measurement of such parameters as CO2 levels, pressure differentials, temperatures indoors and out, relative humidity, absolute humidity, air flow through the ventilation system, activity levels within the house, operation of heating equipment and clothes dryers, and air flows through variable exhaust equipment and furnace blowers. Several patented devices for gauging air quality measurement were also employed in the houses, including the Massawa Vital Air Purity meter (with sensors for oxygen, particles and humidity), and the Halitech Sensor (for odours and combustibles). Different combinations of sensors were used in each house, as dictated by the type of systems. Spot measurements were also conducted for measuring formaldehyde, organics and other pollutants.

Intensive monitoring of activity scenarios was conducted in four of the research houses, to measure how the systems responded to very different kinds of activities within the home. The intensive monitoring included: a tracer gas growth test in each house, to measure ventilation effectiveness; a tracer gas decay test, to measure ventilation efficiency; a mass balance moisture test, to measure the capture efficiency of the exhaust inlets; and a multi-point absolute humidity test, to measure the moisture absorption and desorption rates of the entire house.

During the intensive monitoring, Co-pilot, a program designed for MSDOS computers, was successfully used as a sophisticated controller and data acquisition system. A new version of Co-pilot, written for this project, was capable of simulating many different DCV control strategies.

An additional two months of monitoring was conducted on the Sue, Jones and Smith houses, following the installation of DCV systems. This approach provided extensive data for comparison with the earlier pre-DCV configurations.

2.0 Results

The results of field monitoring on three of the research houses is presented in the following table.

Table 3: Summary of Low Level Monitoring - Before and After DCV

	Sue house		Jones house		Smith house	
DCV Control Strategies	Before RH	After Activ.	Before RH	After CO2	Before RH	After AbsH
Hours of Monitoring Data	856	580	1168	189	1385	846
Outside Temperature (C)	3.8	10.5	2.7	n.a.	7.1	13.4
Inside Temperature (C)	20.9	21.4	21.2	22.1	24.4	24.0
Relative Humidity (%)	40	42	38	n.a.	31	n.a.
Average CO2 (ppm)	571	544	584	558	542	472
Max. Hourly CO2 (ppm)	2250	948	996	726	2767	1028
Ventilation Flow Rate (L/s)	80	75	62	49	25	32
Ventilation - Time Off (%)	0	23	0	34	0	0
Activity Counts Family Rm	75	67	39	35	79	68
Activity Counts Bedroom	4	4	15	13	4	5

Note: n.a. - not available due to data collection problems

With demand control, ventilation reductions of 6% to 21% resulted for the period monitored. This will result in a corresponding reduction in energy required to heat the ventilation air. In addition, fan electrical energy was reduced from 23% to 34%.

While generally reducing energy use, all three DCV systems achieved slight reductions in average CO_2 levels, and significant reductions in peak CO_2 levels.

3.0 Jones house

Three figures from the Jones houses are presented as an example of the data that was analyzed prior to choosing a DCV strategy for this house. A similar procedure was followed for the Sue house and the Smith house.

Figure 1: Typical Working Day presents a typical working day in the Jones house. The house has 335 square meters of living area and is rated as a super energy efficient home under the Canadian R2000 Program. The house is heated with a hot water radiant boiler and is ventilated with a fully ducted HRV running continuously. Two adults and four children live in the Jones house. The mother works at a nearby school and the children are all school age.

CO_2 levels slowly rise during the night with 6 people sleeping with a ventilation rate at 62 L/s. CO_2 levels are constant through the night and peak at 8:30 AM as the family prepares to start the day.

The HRV is activated either by relative humidity sensors or by manual controls. The maximum HRV flow is at 7:30 AM and likely corresponds to showers. CO_2 levels decay slowly over the day but begin to rise when the children first arrive home from school at 3:00 PM. The maximum peak for CO_2 (850 ppm) is reached at 11:00 PM just before bedtime. Activity Sensors detect some slight movement during the night as occupants use the washroom and a burst of activity in the morning. Activity sensors detect the arrival home of the youngest children in the early afternoon. Weekends were found to only vary slightly from this typical working day.

Figure 2: Evaluation of Absolute Humidity Sensor for DCV Control presents intensive monitoring of the same house at the same time of year, but over several days. Absolute humidity and CO_2 are being sampled every 5 seconds and averaged and stored on a 3 minute basis by the data acquisition system. Only a rough visual correlation exists between peaks in CO_2 and absolute humidity. Humidity and CO_2 peaks tend to coincide, however the CO_2 peaks are usually one to three hours later. During unoccupied periods, CO_2 concentrations drop from peaks of 800 - 900 ppm to 500 - 600 ppm (about 35%). For the same period, absolute humidity drops about 15% to 20%. At night, when the six occupants are sleeping, CO_2 concentrations remains relatively stable, while the absolute humidity tends to fall.

Figure 3: CO-Pilot CO_2 DCV Control shows the Co-pilot data acquisition control program acting as a DCV controller in the Jones house. This trial of the software shows that the feedback gain set for the ventilation system controller was to high,

causing an erratic fluctuation in the ventilation rates. Further experimentation was required to obtain a smooth transition. With a CO_2 set point of 650 ppm the DCV system was unable to match the load during breakfast. However, during most of the night flows of either 40 L/s or 88 L/s were able to control the load.

4.0 New DCV House

The Helma house was a new house, designed to demonstrate DCV technology, and to validate the insights obtained from the other 4 houses. Commissioning of the new DCV house showed the suitability of using low cost sensors for detecting VOCs, absolute humidity, air flow and activity levels. The Helma house DCV system has five main features that are presented in Table 4.

Table 4: Features of DCV Control Strategy in Helma House

Feature 1	The system automatically turns on when people are at home and cycles on and off when people are away. The ventilation rate is calculated by the software program based on activity levels and the number of people at home. (Alternatively, a CO_2 sensor could have been used.)
Feature 2	An air quality sensor will detect when pollutants are produced and will increase ventilation rates. The Figaro semi-conductor sensor operating in AC mode with a breather will sense toxic cleaning chemicals, off-gassing from construction materials and cigar smoke.
Feature 3	The system automatically monitors moisture levels in the home and outdoor temperatures. The system will automatically lower humidity levels to prevent condensation form occurring on window surfaces if outdoor temperatures drop.
Feature 4	The information that is being monitored is continuously displayed on a video monitor in the living room. The occupant can always be aware of how the system and the house is performing.
Feature 5	The software written to control the system is able to achieve any ventilation rate by switching between two motor windings and four motor speeds. Moving averages are used to dampen variability and slowly target a given ventilation rate.
Feature 6	The occupant can override the system at any time to set minimum and maximum ventilation rates by turning a dial and flicking switches. The occupant can choose when to rely on the automatic system.

5.0 Conclusions and Recommendations

A number of useful guidelines for designing DCV systems in Canadian housing were discovered by analyzing data from the before and after low level and intensive monitoring. The guidelines apply to the 5 research houses and we believe can be safely applied to other Canadian homes.

- DCV offers benefits only when time-varying occupant generated pollutants exceed building related pollutants

- Source control of building generated pollutants at the construction stage is essential for applying DCV control strategies in new Canadian homes.

- CO2 is an excellent indicator of occupancy and ventilation requirements in residential buildings. A small, moderately priced passive CO2 gas analyzer performed well in three research houses. However, the cost of the technology is too expensive for the bulk of Canadian houses.

- Activity related pollutants are best controlled by special purpose high capacity, directly vented, exhaust fans with high capture efficiencies.

- Relative humidity is a poor indicator of occupancy. Response times are slow and often there is no discernable change in RH despite major changes in occupancy and CO2 concentrations. Absolute humidity is a much better indicator of occupancy than relative humidity but still displays a lag time that is due to absorption and desorption characteristics of the house. Ventilation control based on absolute humidity is limited to the heating season, and is best combined with a window inside surface temperature to provide condensation control.

- The dehumidistats commonly employed for RH control were found to be grossly inaccurate as supplied by the manufacturers, subject to drift over time, and lacking any convenient means for re-calibration.

- Passive Infra red (PIR) activity sensors proved low cost and reliable during the field trials. They have a poor short term correlation with CO2 but excellent long term correlation. The poor short term correlation is due to the fact that activity is sensed instantly whereas pollutant concentrations rise over time. Short term correlations could be improved with more sampling points, and a software program that is able to gauge the level of activity over time and allow the system to respond to the rhythms of the household.

- Semi-conductor sensors (e.g. Figaro T68800) appear to have potential as an overall IAQ indicator if used in alternating operation with a breather that periodically flushes the sampling chamber to automatically zero the sensor.

- High mixing rates in residential houses are preferable to zoning and can greatly reduce the ventilation requirements on a room by room basis. In an energy efficient home, the ventilation requirements - not the heating load - should dominate the design specifications for air moving and distribution systems.

- DCV systems are particularly effective at reducing peak pollutants concentrations. This offers improved health and comfort, even if the mean level of pollutants are similar for systems without DCV.

- Further research, including theoretical work and chamber testing, is needed to develop a simple and reliable performance test capable of describing the effectiveness of fresh air distribution, and the response time of systems to fresh air demands. The development of these tests could greatly facilitate the evolution of ventilation systems and the incorporation of minimum standards within the building code.

- Inlets equipped with humidity controlled bladders were found to be particularly ineffective for DCV application, both in coastal climates and in central Canada.

- DCV system design can be simplified by defining the most common operating modes for the house, and configuring the air mixing and air change rates accordingly. Typical operating modes could be: standby (with timer activated intervals of operation); occupant arrival; high activity; odour control: and sleep.

- A potential exists for lowering the capital costs of sophisticated DCV systems by using a multipurpose home computer.

- Occupants should not be relied upon to optimize the operation of ventilation systems, although occupants must have the ability to interpret and override automatic controls

- DCV systems have the potential to become highly visible sales features in new homes, especially if occupants are provided with continuous feedback on their indoor and outdoor environments.

References:

1. Moffatt, P., Moffatt, S., and Cooper, K. "Demand Controlled Ventilation", Final Report - March 1991, Canadian Mortgage and Housing Corporation, Ottawa, Canada.

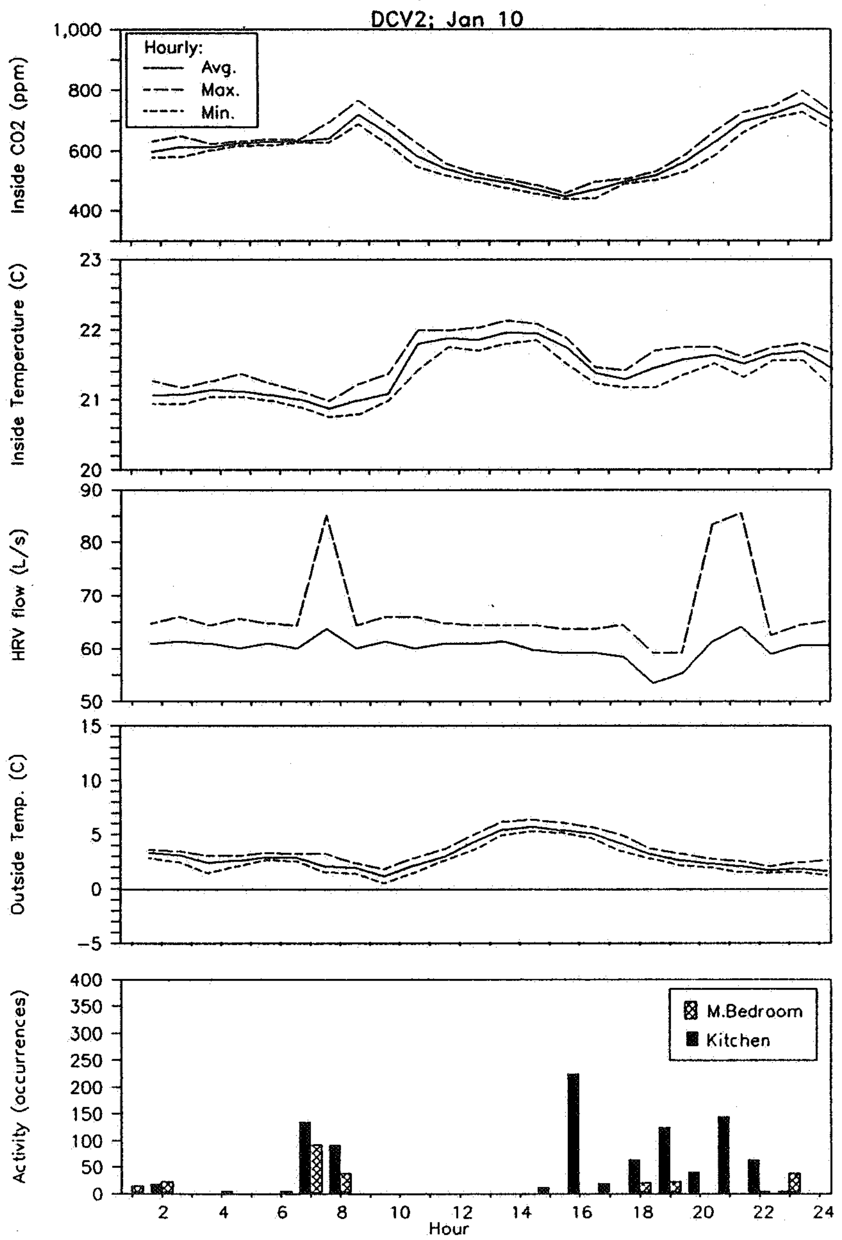

Figure 1: Jones house - Typical Working Day

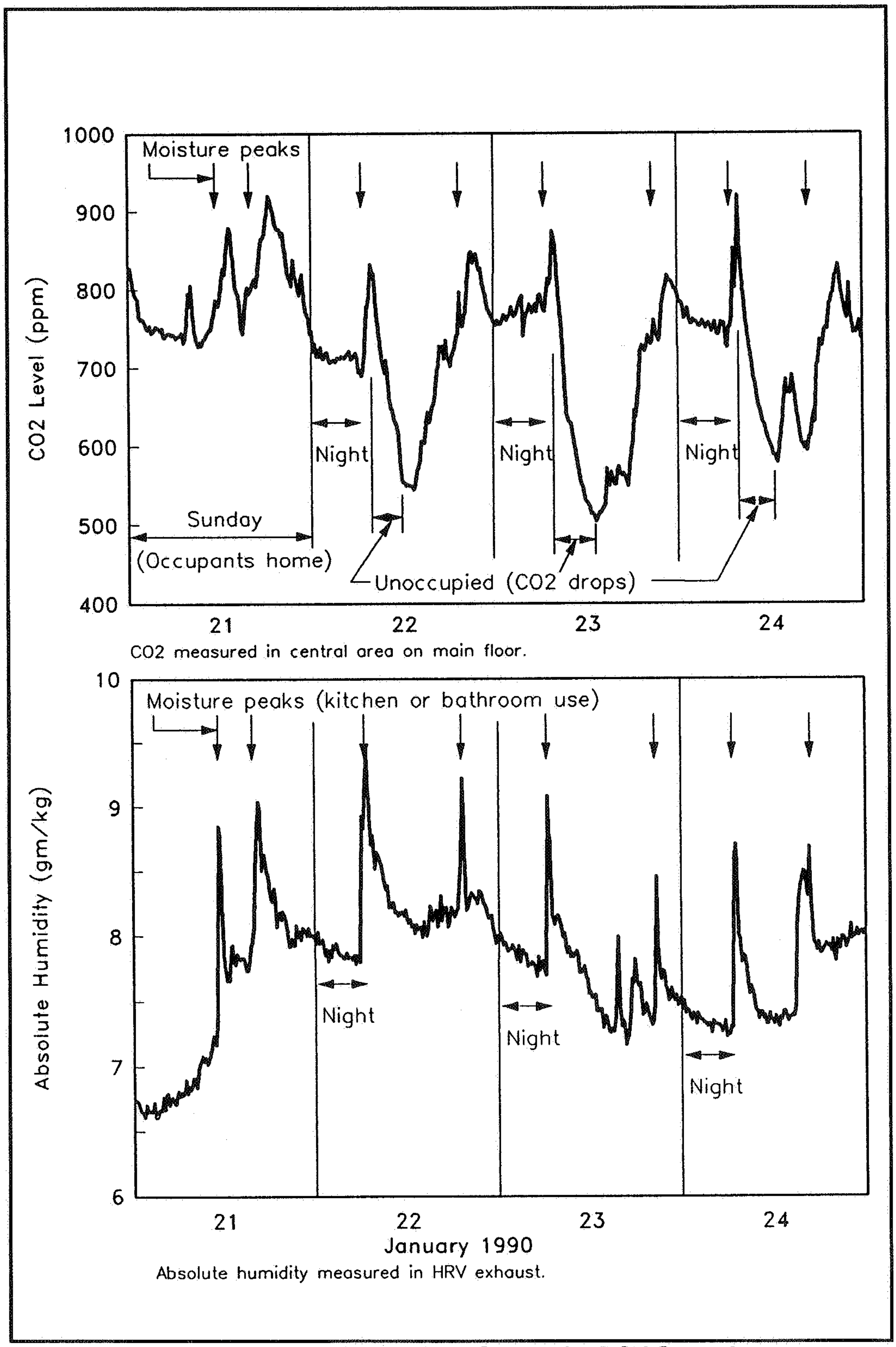

Figure 2: Evaluation of Absolute Humidity Sensor for DCV Control

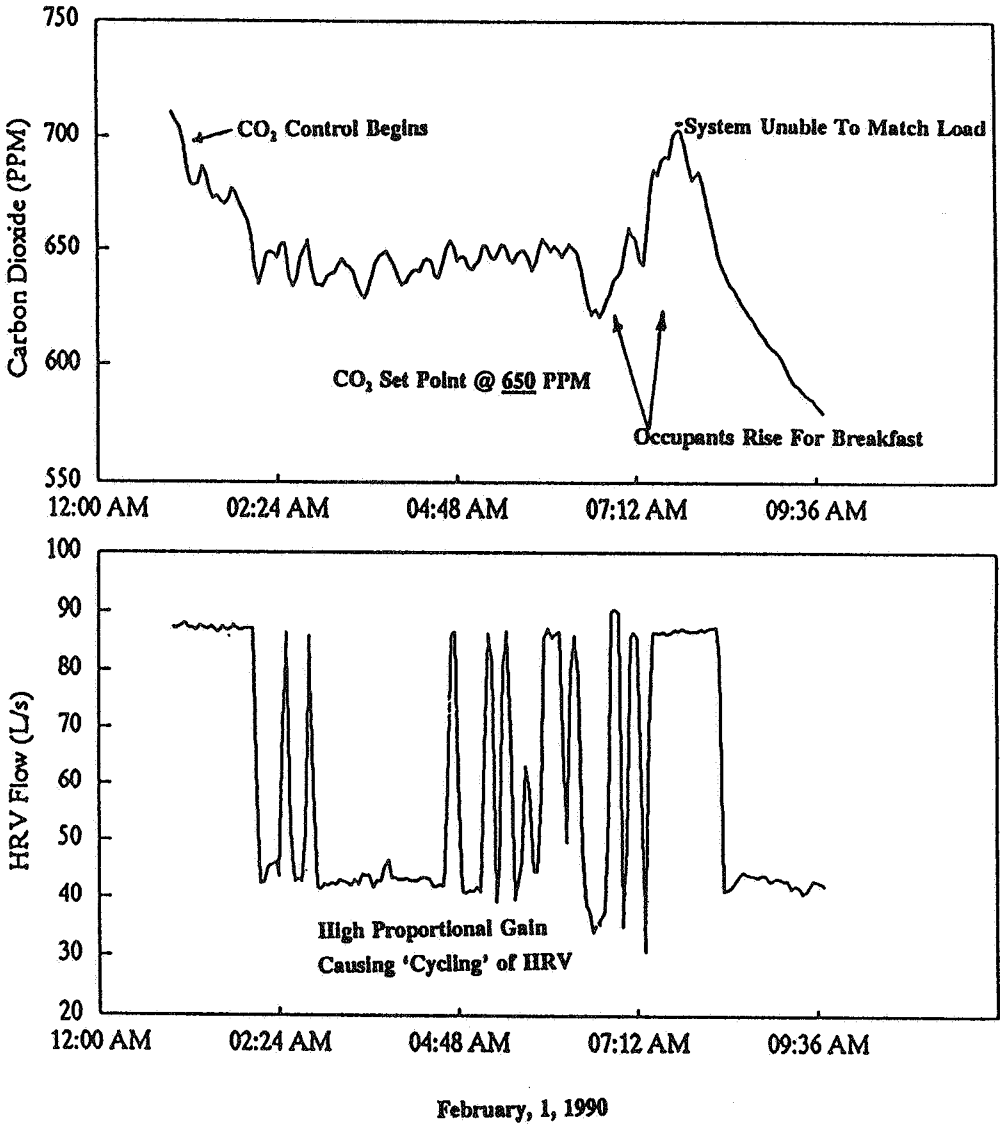

Figure 3: CO-Pilot CO2 DCV Control