INTEGRATED HEATING AND VENTILATION SYSTEMS: AN AIR MANAGEMENT MODULE AND CONTROLLER FOR USE WITH GAS-FIRED BOILERS

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Canada Mortgage and Housing Corporation, the Federal Government's housing agency is responsible for administering the National Housing Act

This legislation is designed to aid in the improvement of housing and living in Canada. As a result, the Corporation has interests in all aspects of housing and urban growth and development.

Under Part IX of this act, the Government of Canada provides funds to CMHC to conduct research into social, economic and technical aspects of housing and related fields, and to undertake the publishing and distribution of the results of this research. CMHC therefore has the statutory responsibility to make widely available, information which may be useful in the improvement of housing and living conditions.

This publication is one of many items of information published by CMHC with the assistance of federal funds.

NOTICE TO READER

This project was designed to develop an integrated heating and ventilation system in accordance with Preliminary Standard CSA F326 Requirements for Mechanical Ventilation - May 1988.

Since that time, CSA F326 has gone through a number of changes that are not reflected in this project or the design. The simplifications reflected in the most recent version of the standard may provide opportunities for simplification of the design presented in this report. Nonetheless, the approach and data collected in this project provides valuable information that will help to direct the development of appropriate technologies to facilitate compliance with CSA F326.

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SUMMARY

In the fall of 1988 Canada Mortgage & Housing Corporation (CMHC), proposed to fund demonstrations of integrated heating and ventilation systems capable of satisfying requirements for air quality, ventilation and combustion safety in Canadian houses. The integrated systems were to be designed to satisfy requirements for the CSA Preliminary Standard on Residential Ventilation (CSA F326), which requires the distribution of fresh air to all living areas, and the control of indoor/outdoor pressures within prescribed limits.

Sheltair Scientific Ltd., in partnership with Allied Engineering Ltd., proposed to develop and demonstrate a system which combined a gas-fired boiler serving a radiant heating system, an indirect-fired water storage tank, and two air management module (AMM1 & AMM2) fitted with heat exchange coils for air tempering. All ventilation devices would be linked to a central controller to ensure a relative balance between supply air & exhaust air under all operating conditions.

The prototype system was built, installed, tested and monitored in a demonstration house on Clearwater Ave, in Coquitlam, B.C. commencing the winter of 1988. The Clearwater house is a large custom built two story home with a full basement, framed with 2" X 6" walls. A computer monitoring system was installed in the boiler room and recorded data for a 5 month period from Sept/89 to Mar/90. The house was pre-wired to facilitate convenient location of sensors in remote locations. Supply air flows, temperatures, indoor RH, CO_2, house pressures and fan status were monitored.

In the initial design of the Integrated System, consideration was given to all possible exhaust appliance interactions in order to assure that the system would manage house pressures. The overall concept, interlocking of exhaust appliances to assure management of house pressures by managing supply and exhaust flows, fared exceptionally well technically, though proving very expensive to build and maintain. The central control box was almost as large as an electrical service panel, and contained a surprisingly complex system of bulky induction coil relays. Much more time and money was spent in its design and construction than anticipated.

The indoor/outdoor pressure management strategy evolved from an empirical exercise in control logic based on hypothetical exhaust appliance interactions, building airtightness, and flow capacities. With pressure decrease and increase limitations set by F326 for the house at -5 Pa and 10 Pa, the objective was to minimize air flow imbalances and stay within these limits. To do this practically, a lock-out

system was employed whereby only one major exhaust appliance could be used at one time. In order to use others a 60 minute manual override timer was provided.

As expected the system managed without significant pressure imbalances. Some unlikely events occurred where numerous major exhaust appliances were in use and pressure spikes were recorded exceeding limits for decrease by 2 - 3 Pa. Much repeated use of exhaust equipment was recorded and the value of an integrated and balanced ventilation system was confirmed. In general, the data confirms that the interlocking method was effective at avoiding depressurization.

Wind & stack pressures combined to create pressure differentials as great as -10 Pa and averaging -7 Pa over 30 minutes in the most extreme case.

Occupant controls (fan speed control, dehumidistat, thermostat, override timer) were provided but were rarely used and in the case of the dehumidistat, largely ineffective at controlling air quality.

The long term average mechanical ventilation rate was 0.28 ACH for the 125 day monitoring period. The rate was reduced by a technician from 0.35 ACH to 0.20 ACH for the second half of the period.

A supply temperature setpoint of 25 °C was chosen for supply air leaving the AMM units, so as to avoid any sensation of cold drafts by occupants. The heat exchange coils chosen provided sufficient heat although the single coil AMM unit was limited to a 30 °C temperature rise while the 2 coil AMM, at twice the capacity, was slightly oversized. The thermostatic control valves chosen performed well in regards to air tempering under all given situations up to -10 C and were the most economical of the alternatives at less than $100 (including temperature sensors). The slow response time of these low-cost valves did not present a problem since thermal storage in the metal ducting reduced any sudden air temperature drops at the coil to minor drops at the supply registers.

No serious air quality problems were found. However, carbon dioxide levels measured in the master bedroom were surprisingly high with 900 PPM on some nights despite 8 L/s fresh air supply, & 25 L/s exhaust from the ensuite.

Relative humidity proved hard to measure because of sensor drift. Corrected data revealed occasional high levels of indoor RH. The dehumidistat however, rarely triggered ventilation system high speed operation. Reasons for this include slow response, drift from setpoint, and inadvertent occupant adjustment of the control.

Total fuel costs at the Clearwater house were higher than estimated. This was mostly due to the air-leakiness of the building envelope. The average mechanical ventilation cost was 13.5% of the total fuel cost (not including electrical costs) averaged over the 5 months monitoring period.

A functional and marketable air management module and interlock control system should be designed that can perform the basically the same functions of the system demonstrated in the Clearwater house, but it should be simplified by reducing the number and complexity of some components and made more affordable to the typical homeowner.

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1.0 INTRODUCTION

1.1 Background

In August, 1988, the Project Implementation Division of Canada Mortgage & Housing Corporation (CMHC) proposed to fund demonstrations of integrated heating and ventilation systems capable of satisfying requirements for air quality, ventilation and combustion safety in Canadian houses. CMHC's objective was to encourage manufacturers in Canada to undertake research and development to adapt their products to new and upcoming standards for ventilation systems in housing. Most significantly, CMHC was looking for integrated systems that could satisfy the CSA Preliminary Standard on Residential Ventilation (CSA F326), which requires the distribution of fresh air to all living areas, and the control of indoor/outdoor pressures within prescribed limits.

Sheltair Scientific Ltd., in partnership with Allied Engineering Ltd., proposed to develop and demonstrate an integrated heating and ventilating system by combining a gas-fired boiler and indirect-fired water storage tank, with a new air supply and tempering system and an all-purpose controller. With support from CMHC, a prototype of this integrated system was built and installed in a demonstration house in Coquitlam, B.C. in the winter of 1988. Sheltair tested and monitored the prototype system over an 18 month period. The results of this demonstration project are summarized in the following report.

1.2 Concept In Brief

The central concept behind the integrated heating and ventilating system was the use of a single gas-fired burner to accomplish space heating, domestic hot water heating, and tempering of fresh air. The components and general layout of the systems are illustrated in Figures 1a and 1b. This system is built around a conventional natural draft gas boiler manufactured by Allied - the Super Hot ™ ,Saturn series. The boiler heats the house by means of radiant floor heating. Connected to the boiler, on a separate loop, is a 160 litre free standing stainless steel water tank for domestic hot water use. On another loop are two (2) pipe-fin heat exchangers for tempering fresh air.

The heat exchangers are enclosed in sheet metal casings which also house a fan and air filter. These supply air tempering systems are referred to as *Air Management Modules* (AMM's).

Each AMM is connected to a supply air duct system. The AMMs are operated by a central control box

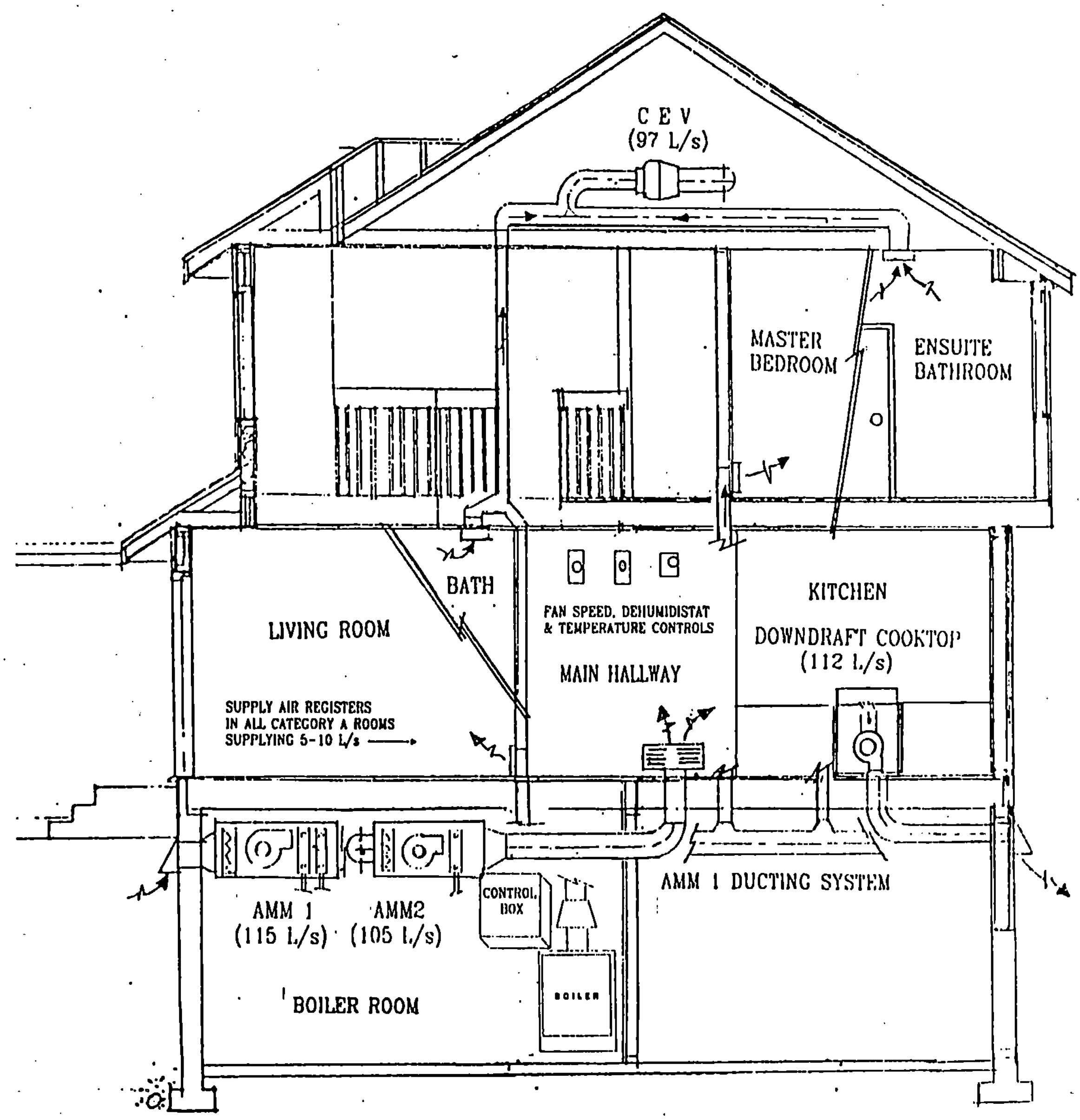


Figure 1a: Cross section of Clearwater House showing main components of system.

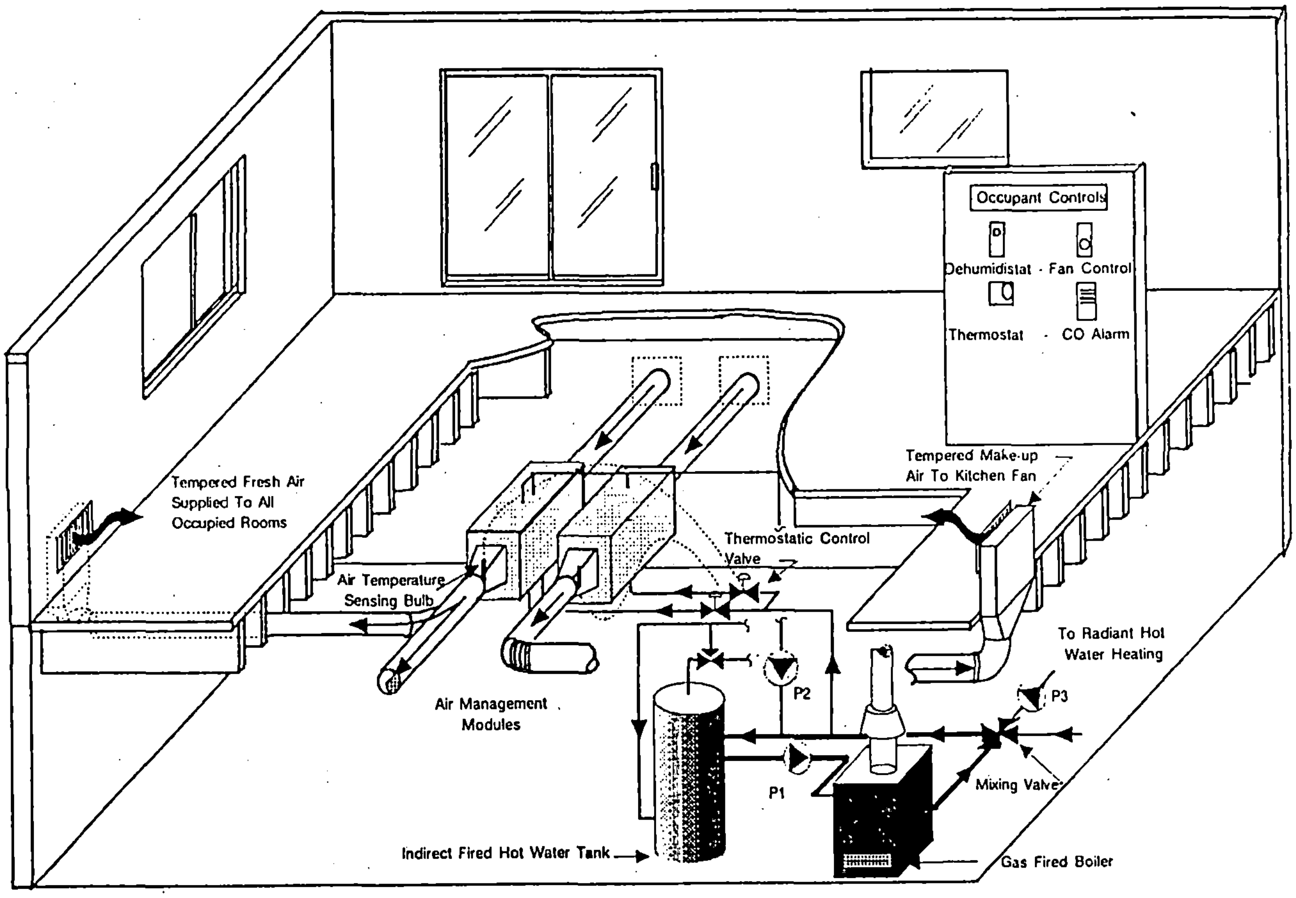


Figure 1b: Conceptual drawing of Integrated Heating & Ventilation System

which is designed to maintain a balance of indoor/outdoor air pressures. Balance is achieved by increasing air flows through one or both of the units, or by locking out powerful exhaust fans elsewhere in the house.

AMM 1 provides fresh air (tempered and filtered) to each room in the house in accordance with the CSA F326 Standard. Household air is extracted from the bathrooms through a Central Exhaust Ventilator (CEV) located in the attic. Since they share the same speed control, *AMM 1* and the *CEV* are relatively well balanced in regards to air flow.

AMM 2 is electrically interlocked with the kitchen exhaust fan, and delivers air to the central hallway as required to make up for air exhausted.

1.3 Special Features and Benefits of the Integrated System

The use of a single gas burner to satisfy space heating, domestic hot water, & requirements for tempering fresh air offers the obvious advantages of lower capital costs, improved operating efficiency, and reduced maintenance. The system was designed to offer a number of additional features appropriate for a quality housing market. Some of these features are listed below:

- **Tempering of fresh air to at least 25°C during the heating season.** This feature offers improved comfort over more conventional approaches such as an HRV or a fresh air duct connected to the return side of a forced-air system.

  HRV's can present a problem because they deliver only partially tempered air. Low-velocity air 'falling' onto sitting occupants from high wall supply air registers can lead to a cold draft sensation and complaints of discomfort. Fresh air ducts tied into return air plenums have also caused discomfort for occupants. Cold air can easily pool on to floors below the duct opening (if the duct is not tightly connected to the plenum), or in the circulating ducts and plenums during the furnace off-cycles. These problems can be solved by the use of an electric duct heater but the extra cost of electricity and equipment need also be considered.

- **Automatic balancing of supply and exhaust air.** By operating the central air supply (AMM 1) and the central exhaust fan (CEV) on the same speed control, the whole house ventilation is kept in balance. And by interlocking all the exhaust and ventilation systems in the house through a central controller, the pressure balance can be maintained for any operating configuration. This *interlocking* approach is particularly attractive because it eliminates the need for additional monitoring of indoor/outdoor pressure differences - a difficult and (at present) expensive task.

- **Minimum make-up air capacity**. The total exhaust capacity in a house can often exceed 500 L/S (incl. clothes dryer, downdraft kitchen fan, bathroom fans, fireplaces etc.). It is unreasonable to install a make-up air system to match such high flows, since they occur only on those rare occasions when all exhaust systems are operating. A more practical approach is to lock-out *some* of the exhaust fans whenever other powerful exhaust systems are operational. Although the locking-out of some exhaust fans may occasionally inconvenience the occupant, this is more than compensated by a ventilation system that is practical and affordable.

- **A fully ducted distribution system**. A centralized, fully-ducted supply system provides effective distribution of fresh air to all rooms in the house. An exhaust only system, on the other hand, with outlets in bathroom and kitchen only, does not guarantee effective ventilation in rooms with closed doors or in basements and corner bedrooms. Noise transmissions to rooms is low, and filtration and tempering of air is economical and convenient. It is easy to install an HRV in-line with the *AMM 1* for added energy efficiency in colder climates, or wherever the savings might warrant such an investment. Depending upon the HRV design, the system may still benefit from only a single fan to supply air to the house.

1.4 CSA Standard F326 - 1988: Residential Mechanical Ventilation Requirements

In response to increasing concerns of combustion safety and inadequate ventilation in new houses, a draft standard, CSA F326 "Residential Mechanical Ventilation Requirements" has been developed to fulfil the need for a national set of residential ventilation requirements. The requirements go well beyond what is required by the National Building Code. While not enforceable, it is proposed that this standard will remain in its preliminary form to give industries involved an opportunity to develop appropriate systems to meet these requirements before issuing the requirements as a formal standard. As with the National Building Code Requirements, the standard does not make any specific reference to how the system be operated, or that it be operated at all. While the intent is to encourage the use of ventilation systems to ensure adequate indoor air quality, the primary goal is to ensure houses will have ventilation systems that adequately address issues of combustion safety and have the "capacity" to provide the requisite amount of fresh air to the house. The flow requirements set out in the standard are derived from a number of sources including the R2000 program and ASHRAE. In general, it has been found that for most houses the ventilation rates equate to approximately 0.3 to 0.4 ACH. Again, while not trying to oversimplify the standard, a summary of the flow requirements as set out in the standard are presented in Table 1a. Recirculation systems must supply or exhaust a minimum of 20L/s to each Category A room and 5L/s to each Category B room with a minimum recirculation rate of 1 ac/h. Fresh air delivered to the recirculation system must satisfy the Base Flow Rate for the dwelling calculated from Column 1.

Table 1a: Minimum Ventilation Air Requirements

Space Classification	Column 1 Base Supply Flow Rate	Column 2 Intermittent Exhaust	Column 3 Continuous Exhaust
Category A			
Double/Master Bdrm	10		
Basement	10		
Single Bedrooms	5		
Living Room	5		
Dining Room	5		
Family Room	5		
Recreation room	5		
Other	5		
Category B			
Kitchen	5	50	30
Bathroom	5	25	15
Laundry	5		
Utility room	5		

In order to ensure safe operation of combustion appliances, specific depressurization limits have been established for combustion appliances. In addition, to minimize the potential detrimental effects of moisture exfiltration, positive pressure limits have also been established. These limits are based on extensive research and field documentation conducted by Canada Mortgage and Housing Corporation (CMHC) and other public and private organizations. These limits are outlined in Table 1b below.

Table 1b: Dwelling-Unit Pressure Design Requirements

	Category I	Category II	Category III
Pressure Increase Limits	10 Pa	10 Pa	10 Pa
Pressure Decrease Limits	5 Pa	10 Pa	20 Pa

Category I: Naturally Aspirated fireplaces and furnaces
Category II: Induced draft furnaces
Category III:Condensing combustion appliances.

Pressure Decrease Limits based on the sum of:
Net exhaust flowrate of ventilation
system under base flow rate condition
+
clothes dryer
+
next two largest exhaust appliances

In order to address issues related to of entry of radon and other soil gases, ventilation systems designed to operate continuously in a negative pressure mode must not exceed 10 Pa.

The standard also has requirements on tempering outdoor air and temperatures for delivered air to habitable spaces.

The requirements section of the standard is only one component of the standard. Two additional sections of the standard are included. These are "Requirements for Installation" and "Requirements for Compliance".

To complete the standard, a design manual will be included. A preliminary version of this design manual has been developed and is available for review by industry.

The Challenge for Industry

CMHC's objective is to encourage manufacturers in Canada to undertake the requisite research and development to adapt their products to new and upcoming standards for ventilation requirements in housing. Ideally, this will facilitate the emergence of commercially available heating and ventilating systems that: i) reflect a systems approach to house operation; and, ii) provide builders and trades with appropriate, cost effective solutions to satisfying the requirements that new codes and standards are trying to promote.

In general, satisfying the air flow requirements do not present an unsurmountable problem for the industry, with the possible exception of the baseboard heating industry; the flow requirements implied a fully ducted distribution system, which would put their industry at an economic disadvantage. Nonetheless, with a combination of good duct design, good installation practice and proper selection of fans, the flow requirements for CSA F326 could be adequately addressed.

The Issue of Pressure Control

The pressure control requirements to prevent backdrafting and/or spillage of combustion products from heating appliances, however, presented a more substantial challenge, particularly to naturally aspirated heating appliances which are limited to only 5 Pa of house depressurization.

The most obvious approach to overcome or relieve excessive negative pressure caused by exhaust fans would be to install a suitably sized make-up air plenum ducted to a non-habitable zone of the house. However, a recent study commissioned by CMHC indicates that passive make-up air ducts are limited in their ability to compensate for even moderate exhaust flow rates. When one considers tighter houses and the propensity for larger exhaust fans (i.e. down draft cook tops), it becomes clear that a passive make-up air duct becomes both unacceptable and impractical as a solution to pressure control. The alternative then is a forced make-up air system. It would also be desirable from an energy perspective, to provide make-up air only in those circumstances where the critical pressure limits are likely to be exceeded. This became one of the central themes in the development of the integrated heating and ventilation designs, presented in this report.

2.0 SYSTEM DESCRIPTION & INSTALLATION

2.1 HOUSE CHARACTERISTICS

2.1.1 Building & Occupancy

The demonstration house was custom built by the owner, and is located on Clearwater Way in the River Heights subdivision of Coquitlam B.C. (A photograph of the house is provided in Appendix 1). It is a large house, with a floor area of approximately 330 m^2, and a volume of approximately 740 m^3. The house faces north-west, and has a panoramic view and large deck on the south-east side.

The house is occupied by a couple and their two children. It is a two story building with a full basement, and an attached two-car garage. The house includes three (3) bathrooms, three (3) bedrooms, a living room, dining room, family room, kitchen, and an unfinished recreation room in the basement.

2.1.2 House Assembly

The exterior, above-grade walls are 2" x 6" construction. The foundation is poured concrete. The basement is unfinished, except for the exterior walls which are clad with 2 x 4 framing and drywall, with window returns taped & drywalled as well. Because the lot is on a relatively steep slope, the back of the home is fully exposed to the foundations. At the front of the house the north-west wall foundation sits below grade. The exterior veneer is constructed from black tar paper with stucco, over particle-board sheeting. Roof trusses are site-built. A long, narrow storage room located above the garage is unheated, and has not been considered to be within the house envelope.

2.1.3 Airtightness

The air-tight drywall approach was employed, with gasketing applied to all exterior walls, and with foam-board cut and caulked into box ends, and caulking applied around the entire foundation wall. Airtightness test results for the Clearwater house are presented in Table 2.

Table 2: Clearwater House Air-Tightness: Actual Measured Results & F326 Optimal Values

		Measured Values	CSA F326 Default Values
* ELA @ 10 Pa	cm^2	766	281
ACH @ 50 Pa	ACH	2.37	1.07
NLA @ 10 Pa	cm^2/m^2	1.36	0.5
Constant (C value)	$L/s/Pa^n$	35.61	14.02**
Exponent n value		0.7278	0.70

* Test was performed with combustion air supplies sealed.

** House exponent based on empirical average.

Since the execution of the original fan-door test, some measures were taken to increase the tightness of the building. For instance the combustion air supplies to both the boiler and the fireplace in the family room, were blocked off. The intention was to simulate conditions in a house approaching R-2000 tightness levels and thus challenge the house to maintain *safe* pressure differences across the envelope during operation of exhaust and ventilation appliances. Table 2 also compares the optimal F326 air tightness values with the actual measured results. The value of 0.5 cm^2/m^2 for the house NLA (Normalized Leakage Area) is taken from the F326 - M1989 Appendix A 6.1.

2.2 HEATING & VENTILATION SYSTEM DESCRIPTION

2.2.1 Boiler & Hot Water Storage Tank

A large and separate boiler room was built in the Clearwater house to facilitate the installation of integrated appliances and the monitoring system. (The layout of the boiler room can be seen from the photograph in Appendix 1.)

The boiler installed is a conventional, natural draft appliance. In accordance with the design criteria in CSA Preliminary Standard F326 Section 6.3.2, the boiler is considered a Category I appliance (see Table 1b).

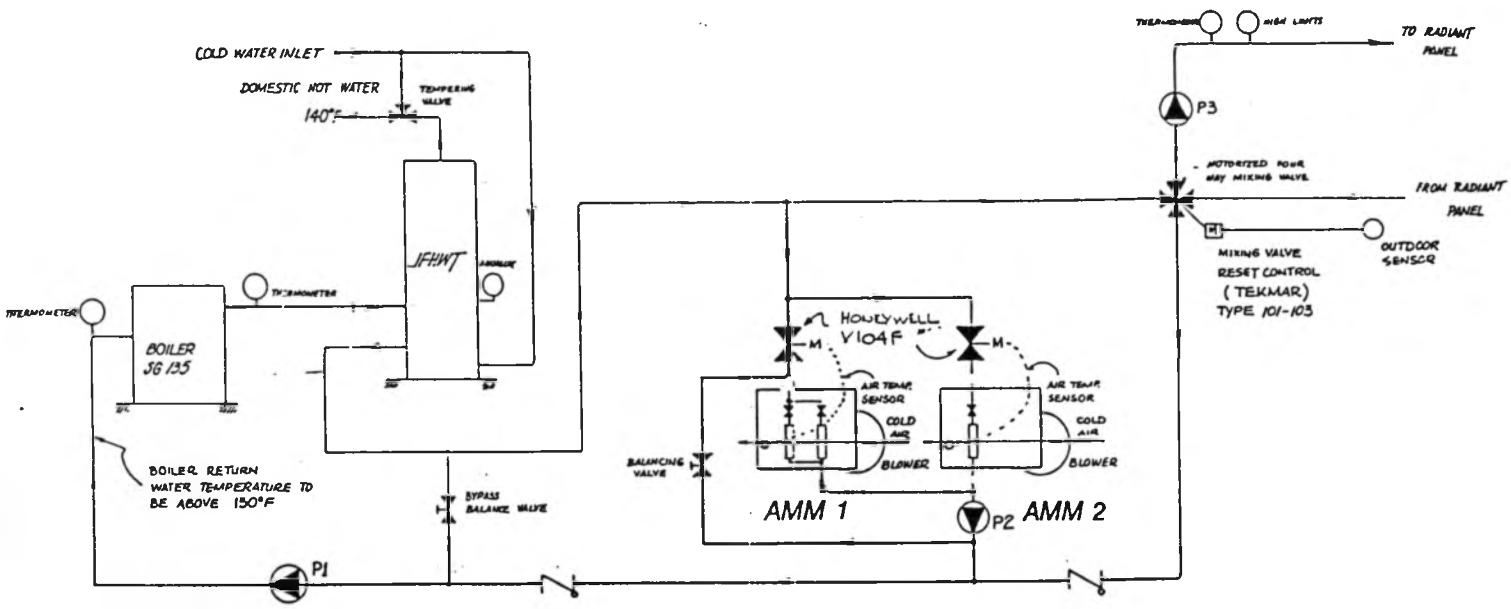


Figure 2: HV System Piping Diagram

The boiler output rating is 135,000 BTUH, seemingly high for any energy efficient home, but sized for heating three different loops:

1) to all zones in the in-floor radiant heating loop;
2) to the indirect-fired *DHW* tank; and
3) to the *AMM* units for air tempering.

The Domestic Hot Water tank is a stainless steel water storage tank currently manufactured by Allied, and categorized as an *Indirect-fired Hot Water Tank* (IFHWT). Its storage capacity is 160 L (40 US gal.). Operation is by means of heat transfer from the boiler loop to the storage tank through a heat exchange coil in the IFHWT. The term indirect-fired means that the tank is fired indirectly by the boiler. When the temperature in the tank falls below the setpoint, the primary circulation pump (P1 in Figure 2) is activated. The boiler, however does not fire until its own low limit has been reached.

• **Energy Increase Due to Installation IFHWT Problem:** During the course of the monitoring, it was found that the boiler short cycling and that gas consumption seemed higher than expected. The *IFHWT* was intended to energize the primary circulation pump (P1) when the tank temperature dropped below the setpoint (80 °C) measured by the aquastat. (See illustration in Figure 2). At the time of installation, the aquastat was mistakenly omitted and P1 ran continuously. This resulted in increased radiation losses from the boiler and system piping as high temperature water/glycol was continuously circulating through the primary piping loop. This also increased *standby* losses of heated air since the chimney remained at higher temperature with a stronger draw.

The aquastat was correspondingly installed towards the end of this project, and the pumping arrangement re-configured as per specifications. Hopefully, the coming winter, 1990/91 will provide proof that the situation has improved.

• **Energy Increase Due to Oversizing of Boiler :** The sizing of the boiler was difficult to anticipate because of the presence of the *IFHWT* and the *AMM* loops along with the radiant heating loop. In retrospect, we realize that a smaller boiler, 80,000 BTUH (23.5 kW) would have been adequate. A size reduction would probably increase overall system efficiency for reasons similar to those cited above. Also, during the shoulder seasons and in the summertime, when the boiler need only furnish the domestic hot water needs, the large boiler may also suffer from lower than expected efficiency since it will rarely reach steady state conditions.

2.2.2 Radiant Heating System

The radiant floor heating uses a Polytherm system that runs through the first and second floors of the house. On the first floor, hot water pipes are embedded in a concrete slab. On the second floor, piping is affixed to the sub-floor within reflective metal channels.

Since the integrated system provides tempered make-up air to rooms (@ 25 °C) on the second floor, it is unlikely that the radiant heating on the second floor will be required for much of the heating season. However, despite extensive analysis of the heating requirements, and a HOT 2000 run on the house, Sheltair could not determine whether it would be safe to avoid any heating system - other than tempered make-up air - on the second floor. Consequently, in-floor radiant heating was installed on the second floor as a precaution against poor heat distribution.

2.2.3 Valves, Pumps, & Controls

• **Radiant Heating System Control:** The heating medium to the radiant system is channelled through a four-way mixing valve to a manifold consisting of zone control valves that can be manually adjusted for optimum system balancing. The control unit for the system is a Tekmar ® that includes a programmable setback timer and boiler control. The heat supplied to the zones is regulated according to both outdoor and room temperature by means of two resistance type temperature sensors. A change in the resistance of the sensors effects the modulation of the mixing valve increasing or decreasing the flow of heating medium to the zones. When there is no heat required and the 4-way valve is shut, an automatic by-pass valve stays open to assure continued circulation.

• **Circulation Pumps:** There are three circulation pumps in the system (refer to Figure 2). Pumps are operated in the following manner:

Pump 1 (P1): is the primary pump which cycles on and off with boiler operation. It circulates fluid through the primary supply and return headers and through the hot water storage tank (IFHWT). P1 is energized by both the IFHWT and the boiler high-limit switch, depending on which reaches the set temperature first;

Pump 2 (P2): circulates fluid through the ventilation air tempering loop and runs continuously; and,

Pump 3 (P3): serves the radiant heating loop and is also continuously energized.

• **Air Tempering Loop Control Valves:** The key elements in the air tempering loop are the heat exchanger coils, the circulation pump, and most importantly - the control valves. Some consideration was given to the choice of the most suitable and economical valves. Two problems that had to be considered were:

1. how quickly the control valves would respond to sudden load changes; and,
2. which valves are available in a price range suitable for a low-budget residential system.

One important criteria for selecting a reasonable valve response-time. The time required for the heating coil to raise supply air temperature 35 C should be less than five minutes. That would allow for AMM 2 to be energized @ -10 C and recover to 25 C quickly enough to avoid cold drafts at the outlet. A more precise criteria for this was not established. Manufacturer specifications on valve response time were difficult to acquire for low cost control valves. A representative for the manufacturer of the valves chosen, assured adequate response time but offered no guarantees due to lack of technical support data. Trial seemed to be the best alternative.

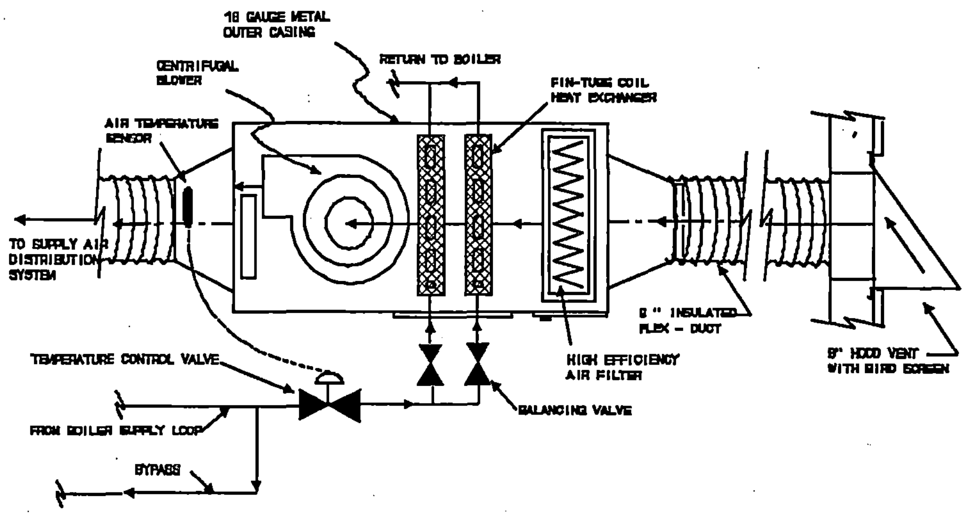
Control option costs ranged widely, from $45 to $1000, to achieve identical results. Danfoss valves (recommended by Allied Engineering) were not available with an appropriate air temperature duct sensor. It was decided to use the Honeywell V104F Thermostatic valves which satisfied both considerations very well. The final cost was less than $100 for both units, including valves and duct sensors. Normally these valves are used for zone control of large radiators in hydronic heated buildings. Such sensors can be air sensing or they can be immersed in the heating medium. More detailed information concerning the valve can be found in Appendix 2.

2.2.4 Air Management Modules

• **Design of the Air Management Module:** The AMMs consist basically of five (5) components:

1) a high efficiency air filter;
2) a fin-tube coil heat exchanger capable of generating 3 kW of heat @ 70 L/s for a single coil system (AMM 1 has 2 coils and twice the capacity);
3) an relatively inexpensive centrifugal blower (approx. 100 L/s @ 60 Pa). The blower has a measured power consumption of 125 Watts on maximum speed;
4) a metal outer casing with dimensions 14" X 19" X 30" designed to hang from joists using flexible straps; and,

5) a modulating thermostatic control valve that requires no electrical power and can be set to regulate air temperature from 9 °C to 25 °C with a remote sensing bulb placed in the airstream. In the summer time the valve can be set to a minimum temperature for conservation purposes.



AIR MANAGEMENT MODULE
(AMM)

Figure 3: Schematic of Air Management Module

Figure 3 is a schematic diagram of *AMM 1* showing all the components listed above. The AMM is fitted with a panel to access the heat exchangers and fan, and a hinged access door for changing the filter. The AMM also contains a pressure switch for proving the flow. If the blower motor fails, a fail light located on the speed control on the main floor will extinguish, cautioning the homeowner.

• **<u>Sizing of Coils:</u>** Allied Engineering investigated the availability of fin-tube heat exchangers for incorporating into the modules and selected an appropriate model. The most important criteria for sizing the coils were:

a) the maximum air temperature drop across the coil;
b) the range of air flow passing through the coil;
c) the amount of restriction to air flow & fluid flow caused by the coil;

Appendix 2 contains detailed graphs projecting the performance of the heat exchangers, including variations determined by the number of rows of heat exchangers in the AMM, and parameters such as air speed, glycol temperature, air flows, BTU per hour output, and pressure drops.
Graph 1 in gives the output in BTU/hr of a single coil. For the AMM on high speed @ 115 L/s (230 CFM) the heat output would be near 25,000 BTU/hr (7.35 kW) with 2 coils which would support a temperature drop of 50 °C. Outdoor temperatures could reach -25 C and the supply air would be maintained at 25 C. Further details accompany the performance graphs in Appendix.

Figure 4 presents the principle dimensions of the heat exchangers and the materials used. A manifold was used to link two (2) banks of coils inside *AMM 1*. *AMM 2* was fitted with only one (1) bank of coils. (Photographs in Appendix 1 show the AMM installation).

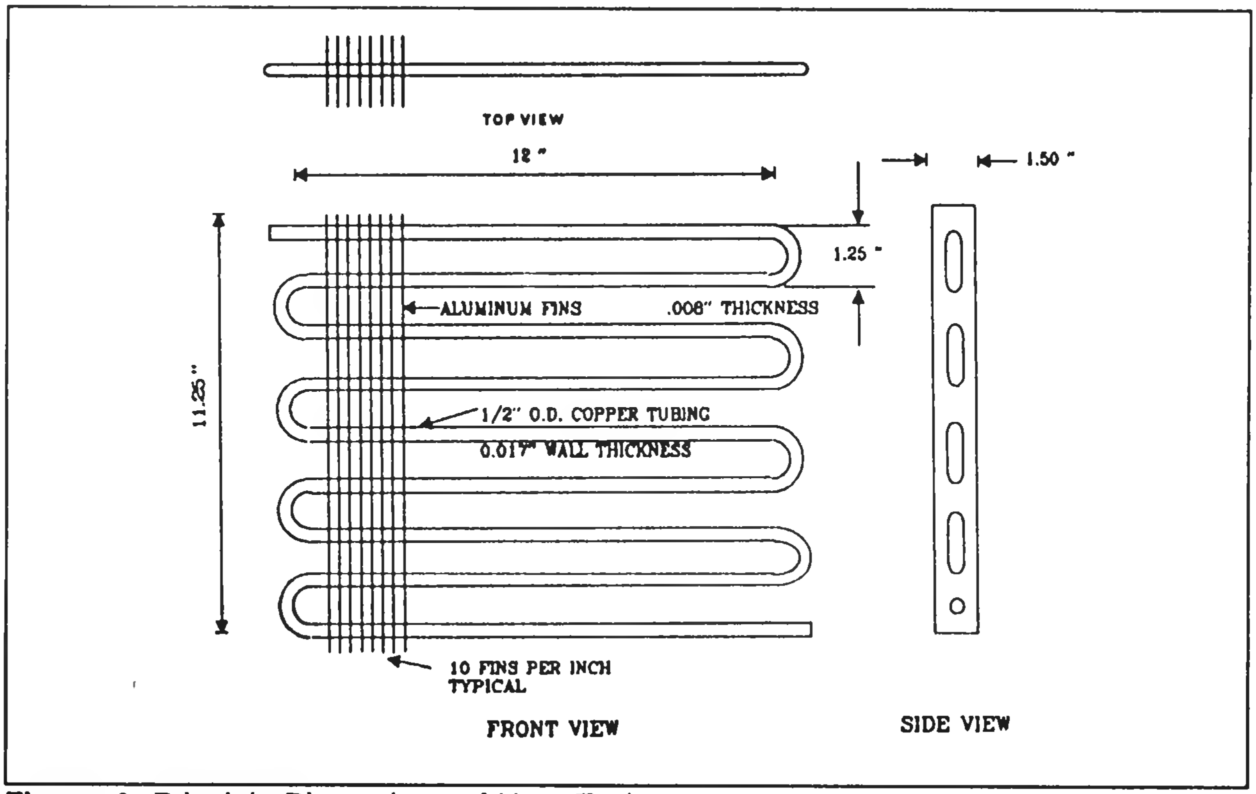


Figure 4: Principle Dimensions of Heat Exchanger

2.2.5 Air Distribution System

Separate specifications were developed for installation of a ventilation system in the Clearwater residence. The owners original plans were for a separate stand-alone ceiling exhaust fan in two of the bathrooms, with no provision for make-up air supply. The final installation was somewhat more elaborate.

• **Supply Air Duct System:** The supply air duct system was designed to be as unrestrictive as possible, using 8" round main trunk, branching off with 5" feeder ducts or through wall cavities with standard rectangular 4" x 10" ducts (see photos in Appendix 1).

The system was designed to distribute, more or less evenly, to all supply outlets except the Master bedroom which required slightly more ventilation air and was given priority in the ducting arrangement. Adjustable butterfly dampers were installed in some duct runs.

• **Supply Registers:** Supply registers are standard 4" X 10" sliding louvre type. They have been placed in a low wall position about 6 " from the floor. They are positioned to ensure effective distribution without short circuiting to any exhaust outlets.

• **Balancing of Supply Air:** To assure accurate distribution of the supply air in accordance with F326, the system would require fine tuning or *air balancing.* (Unfortunately, such small air flows are very difficult to measure, and at present no contractors have the means with which to perform such a task.)

2.2.6 Central Exhaust Ventilator

The *CEV* components include an 8 inch Kanalflakt EBM centrifugal fan, and a system of ducting from all four bathrooms, including the unfinished basement bathroom. Figure 5 is a schematic drawing showing the CEV and its major components.

• **Duct System:** The ducting from the upstairs bathrooms is 6 inch diameter sheet metal. Exhaust ducting from the first floor and future basement bathrooms, is 4 inch diam. and 3.5 x 10 inch rectangular respectively. These branches join in to an 8 inch trunk line which joins a 5 foot long flexible duct adjacent to the fan. Flexible ducting and rubberized suspension straps are design features intended to dampen fan noise. Attached to the exhaust end of the fan is another short length of flexible ducting and a 5 foot by 8 inch diameter straight length of rigid metal ducting. The exhaust duct

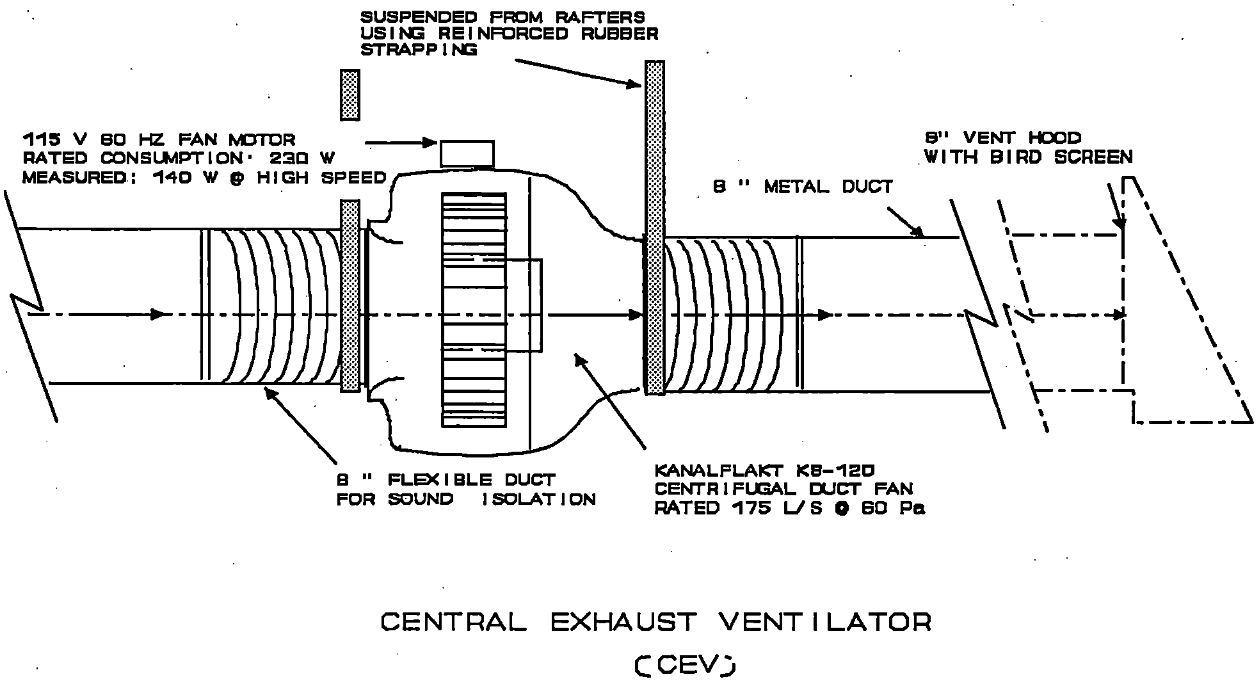


Figure 5: Schematic of Central Exhaust Ventilator

terminates directly at the gable wall through a custom made 8 inch hood with a bird screen.

• **Exhaust Grills:** Exhaust inlets, were fitted with whisper grills. The inlets are located at the centre of the bathroom ceilings. The 6 inch grills are rated for 60 CFM (28 L/s) @ 25 Pa and the 4 inch grills for 40 CFM (14 L/s) @ 25 Pa.

There were some complaints registered by the occupants about excess noise from the CEV which emanated mainly from the ensuite bathroom outlet. This will be reduced by installing a *"silencer"* type noise reduction muffler, now available from local HVAC equipment suppliers.

2.2.7 Downdraft Kitchen Fan

A central issue for the performance of an integrated heating and ventilation system is its ability to prevent excessive house depressurization during operation of a downdraft kitchen fan. Although a fireplace at full burn can draw as much air from a house, it is used rarely and does not impose a constant threat as does the downdraft kitchen fan, used every day.

The kitchen fan in the Clearwater house is a downdraft kitchen fan rated for 135 L/s (286 CFM) @ 160 Pa static pressure. Sheltair measured the flow to be about 112 L/s (220 CFM) +/- 5% in its installed condition. The fan is ducted through the basement using a 5" dia. metal flex duct. The manufacturer suggests the a 6" duct be used but approves the use of a 5" duct as long as the equivalent length is 3 m or less. (The installed equivalent length is 4 m.)

2.2.8 Whole-House Vacuum System

Unfortunately, the owner of the house did not purchase the vacuum system until February/1990, near the end of the monitoring phase of the project. The 2 inch diameter plastic ducting system for the vacuum, however, was installed during initial house construction. The estimated flow for the system is 30 - 40 L/s. The central vacuum unit, is located outside the envelope in the garage. It is vented outside through the garage wall.

2.2.9 Clothes Dryer

The clothes dryer is located on the second floor in a closet beside the master bedroom. The air flow has not been measured because of the precarious placement of the exhaust outlet, high on the northwest gable of the house. The estimated air flow for the appliance 40 - 50 L/s.

2.2.10 Passive Combustion-Air Supply

According to the existing installation code for gas-burning appliances (Can1-B149.1-78), a combustion air supply duct was still required in the Clearwater house. Consequently a 6 inch diameter rigid metal duct was installed, terminating 18 inches above the boiler room floor, immediately beside the boiler.

In order to simulate *tighter* conditions in the house, it was decided to block the duct temporarily. With the monitoring and control system operating and a carbon monoxide alarm active on the main floor, it was not considered a dangerous proposition. In late February of this year the owner reopened the air supply.

2.2.11 Fireplaces

There are two (2) fireplaces in the residence: a gas-fired fireplace in the family room and a conventional wood-burning fireplace, in the living room. At full burn, these fireplaces can exhaust 50-75 L/s each, adding significantly to house depressurization.

The combination of fuel types was requested for research purposes. We had numerous discussions with the fireplace installers and the owner about the best alternatives for the house. Although an air-tight, zero-clearance fireplace was too expensive, we selected a reasonably efficient alternative. The owner was dissuaded from using an air-bathed chimney system, which would have even further sabotaged the air sealing of the residence.

Subsequently, the occupants complained on more than one occasion about the cold drafts emanating from the family room fireplace combustion air supply. Eventually the outside intake was blocked off deliberately by the owner for the winter.

During the monitoring period both fire places were used on occasion. The wood burning fireplace was used more frequently than the gas model.

3.0 SYSTEM DESIGN

3.1 Design Requirements

Air flow design requirements are listed below:

1. Minimum required base flow rate: 70 L/s (0.34 ACH)
2. Minimum required exhaust capacity:

Kitchen	50 L/s Intermittent	-	30 L/s Continuous
Bathrooms(4)	100 L/s Intermittent	-	60 L/s Continuous

3. Allowable net supply flow rate - 86 L/s
4. Allowable net exhaust flow rate - 49.4 L/s

3.2 Summary of Ventilation & Exhaust Appliances

Table 3 below gives a summary of the system flow capacities for the installed appliances in the Clearwater house.

Table 3: System Flow Capacities

Ventilation System	Flow Capacity (L/s)	Est. Static Pressure (Pa)	Source of Data
AMM1 (supply)	115	60	measured
AMM2 (kitchen fan make-up air)	105	60	measured
CEV (exhaust)	100	50	measured
Additional Exhaust Appliances			
Down Draft Kitchen Fan	112	150	measured
Clothes Dryer	40-50	75	estimated
Central Vacuum	30-40	200	estimated
Fireplace 1 @ full burn (wood)	75	5	*
Fireplace 2 @ full burn (gas)	50	5	*

* From "Fireplace Air Requirements" prepared for CMHC by Ortech Intl, Scanada Consultants, & Sheltair.

3.3 System Specifications

3.3.1 Minimum Required Base Flow Rate

The minimum required base rate was satisfied when both AMM1 and the CEV were running continuously in a balanced state. The selected flow ratings for the fans @ 50 Pa. of static ensure adequate capacity to satisfy the 70 L/s base flow rate (0.34 ACH). The design of the air distribution system; (ducting, supply & exhaust grills, according to F326 requirements), was completed by an independent HRAI contractor. Sheltair verified distributed capacities in the field by direct flow measurement (see section 5.1).

3.3.2 Minimum Required Exhaust Capacity

For the kitchen, intermittent capacity was selected requiring a minimum of 50 L/s. The down draft appliance had a capacity of 175 L/s - more than sufficient.

For the four bathrooms, continuous exhaust was anticipated, and 60 L/s is the minimum total flow. The installed capacity of the CEV serving all four (4) bathrooms was anticipated to be 150 L/s @ 50 Pa. and was to be interlocked with AMM1 set to 70 L/s base flow rate. This assures bath capacity to be adequate. The intermittent capacity requirements could also be met for the bathrooms and activated by bathroom timers or dehumidistat. Intermittent requirement for the bathrooms is 100 L/s (4 * 25 L/s) with the CEV capable of delivering 150 L/s.

3.3.3 Allowable Net Supply Flow

The system is designed to run balanced so no problems were anticipated.

3.3.4 Allowable Net Exhaust Flow Rate

On a continuous basis, exhaust and supply were expected to be balanced much of the time. However, with the many possible combinations (See Truth Table Section 3.5) of appliance interactions, special consideration was required in the system design. The calculations for the design were based on the net exhaust bias (theoretically = 0 with balanced system) + Dryer exhaust + next two largest exhaust When the CEV switches to high AMM1 also goes to high thus net bias = 0. Therefore Allowable Exhaust Flow was based on:

Exhaust Appliance	Air Flow (L/s)
Dryer	50
Downdraft Kitchen Fan	150
Central Vacuum	40
Total (Allowable 49.4 L/s)	240
Excess (Total-Allowable)	190.6

Based on these specifications a passive make-up air inlet of 14" diameter was required. This was unacceptable. The options were forced make-up air or an appliance lockout mechanism. For this project a combination of these was chosen. Although this required somewhat complex control logic the concept provided an attractive solution - forced make-up air for powerful exhaust fans combined with lockout of other exhaust fans on a first energized first served basis.

3.4 Control Logic & Devices

3.4.1 Central Control Box

• **Background:** The purpose of including a central control box was to detect the use of, and control power supply to exhaust appliances from a single control centre. Extensive discussion and planning was required to finalize the control strategy for the integrated system. This included several days of meetings with experts, including Thigh Ward, of Thew Products Ltd. in Vancouver and an electronics specialist, Paul Sobolev. A summary of the control strategy and the wiring schematics used by Paul can be found in Appendix 3.

• **Construction & Installation:** It was decided to construct the control panel box in a standard *12 x 14 x 4* inch NEMA enclosure, which was mounted in the boiler room near the proposed monitoring station. All external controls and sensors were wired back to this central box. The control box was constructed using 24 VAC - 115 VAC induction-coil relays for control, as opposed to low voltage solid-state integrated circuitry. Production line units would undoubtedly benefit from solid-state design.

• Problems With Switching Technology: The use of relays seemed most appropriate at the beginning of the AMM design process. The most important objective, once the preliminary logic was contrived, was to take the design from drawing board and build the working model as soon as it was feasible. This *make it work now* philosophy dictated the design. In retrospect a more efficient strategy could have been employed. For instance, half of the relays were normally-closed (NC) and therefore continuously drawing power - *from a large, inefficient power supply.*

• Control Logic for Major Exhaust Appliances: Since it was necessary both to detect the use of exhaust fans, and to control power supply to exhaust appliances, the final wiring schematic appears quite complicated. The complexity stemmed from the need to control a number of potentially overlapping scenarios concurrently. The controller was forced to address virtually all possible combinations including;

- locking-out powerful exhaust appliances, leaving only one running at a time;
- allowing the occupants to override the lock-out when required;
- balancing supply and exhaust by switching the *CEV* to idle if exhaust appliances were energized;
- warning occupants if the *AMM's* were malfunctioning; and,
- switching the system to high speed when either the dehumidistat or a bathroom timer was activated;

Operation of the kitchen fan switches *AMM 2* and *AMM 1* to high speed and the *CEV* to idle. The other powerful fans in the house (vacuum, dryer) are disabled when the downdraft kitchen fan is operating.

When the clothes dryer or central vacuum is in use, *AMM 1* switches to high speed, and the *CEV* switches to low or "idle" speed. As with the operation of the kitchen exhaust, operation of either the dryer or central vac will disable or lock-out the remaining exhaust fans. A manual overide allows the occupant to operate any of the fans that are locked-out.

Both fireplaces are integrated with the ventilation system so that when they are in use, a capillary and snap-thermodisc switch activates a relay causing *AMM 1* to run on high and the *CEV* to low idle, similar to the action taken when the dryer or vacuum are in use. Major exhaust fans are not locked-out when the either of the fireplaces are used.

A brief study of the flow diagram in Figure 6 will help to understand how the control logic is employed.

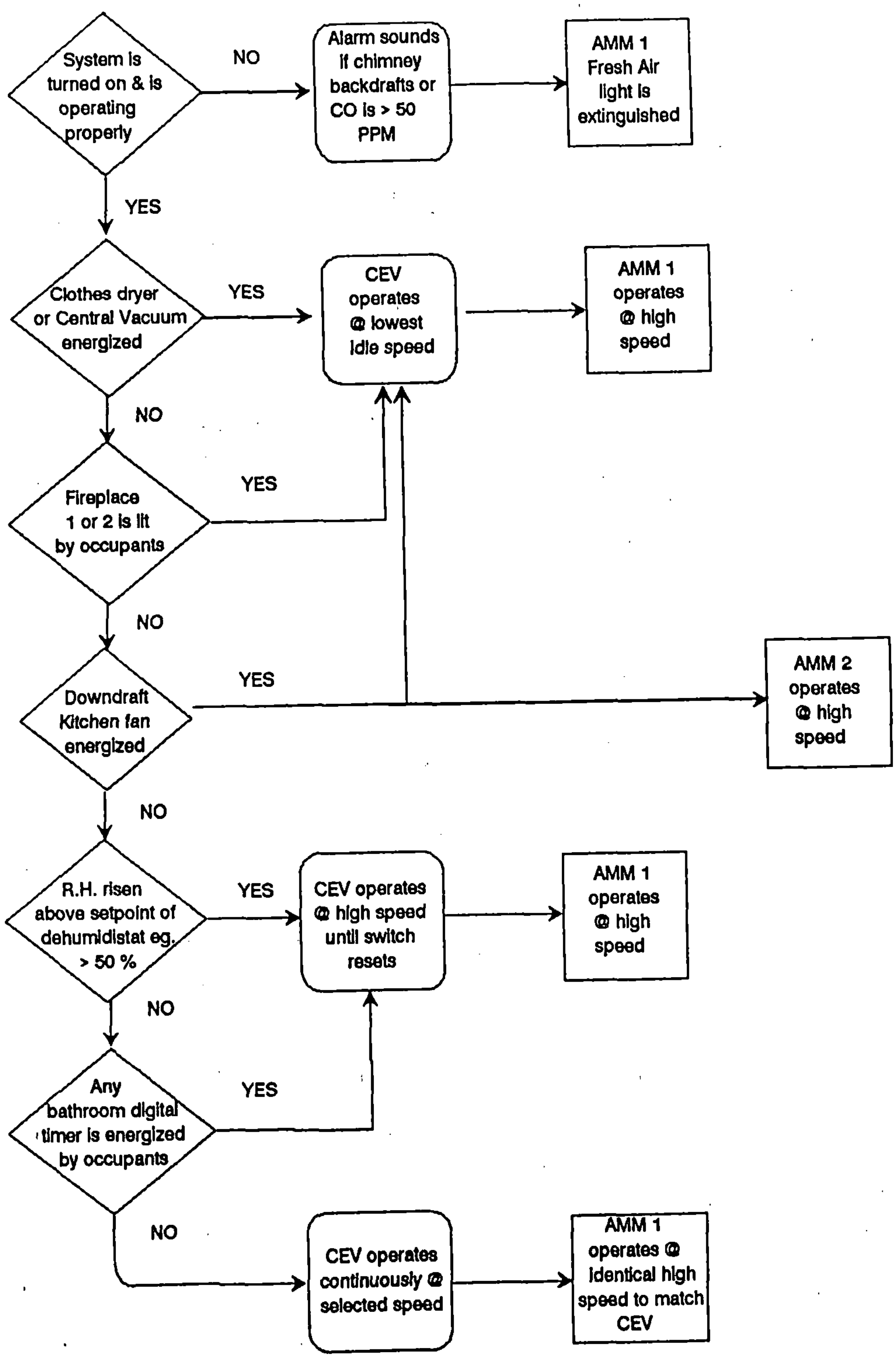


Figure 6: Flow Chart Illustrating System Operation

3.4.2 Occupant Controls

The original conceptual design proposed an occupant-friendly control panel with all controls mounted within. However the homeowner found that such a panel protruded too far into his already confined hallway. The compromise was to separate the control functions, and mount individual external controls along the wall of the central hallway, next to the house temperature control[1]. These individual controllers include the following:

- a speed control, to adjust the house ventilation rate by simultaneously altering the speeds of AMM 1 and the CEV;
- a dehumidistat, wired into the central control box;
- a 60-minute manual timer switch; and,
- a 50 PPM carbon monoxide alarm (powered from the central system).

3.5 CONTROL LOGIC & THE HOUSE PRESSURE ENVIRONMENT

In the initial design of the Integrated System, consideration was given to all possible appliance interactions in order to assure that the system would perform the objective of house pressure management. Three (3) general considerations were most important in pressure control objective:

1. *House Airtightness*: F326 requires ventilation system design to be based on a normalized leakage area for any house of 0.5 cm^2/m^2. This calculates to an ELA for the Clearwater house of 280 cm^2. This is the *default* value that is used in the design exercise;

2. *System Reliability*: In the case that any part the ventilation system should break down, and failsafes were ineffective or unheeded, the house would be subjected to excessive depressurization when exhaust appliances were in use. The assumption made here was that providing a fail light on the homeowner fan control and a CO alarm would be adequate.

3. *Possible Appliance Interactions*: Twelve (12) possible interactions of exhaust appliances were considered to be reasonably possible during normal and slightly unconventional family use.

[1] Not to be confused with a house thermostat, the Tekmar system uses a resistance device to modulate the mixing valve.

The criteria used for pressure limitations were taken from F326 Section 6.1 & 2, which specify a limit of 5 Pa pressure decrease and 10 Pa pressure increase.

Table 4a shows the theoretical depressurization(dPF326) that would have occured in the absence of any make-up air provisions and assuming and airtightness value of 0.5cm^2/m^2. As a comparison, the resultant depressurization using the measured airtightness values are also shown(dPHse). The data clearly shows the potential for combustion spillage even when a single fan is operated.

Table 4b shows the theoretical depressurization after installing AMM1, AMM2 and the control panel, complete with fan lock-out system and the manual overide. The data confirms that unless 3 or more major exhaust appliances were in use, the system passed the design exercise, even using the F326 optimal airtightness levels. Keep in mind also that the manual override timer would have to be activated in order for multiple exhaust appliances to be used.

Table 4c repeats the exercise shown in Table 4b, except actual fan flows are used as measured on-site.

The complete summary of all possible fan appliance combinations is included in Appendix 3.

Table 4a: House Depressurization Potential Without Use of AMM1 & AMM2(using manufacturer specified air flows)

Condition	dP F326	dP Hse	Imbalance	CEV	Dndrft	Dry	Vac	FP1	FP2
	(Pa)	(Pa)	(L/s)	L/s-->					
Downdraft In Use Only	-29.5	-7.2	-150	0	-150	0	0	0	0
Dryer Only	-11.0	-2.8	-75	0	0	-75	0	0	0
Vacuum Only	-4.5	-1.2	-40	0	0	0	-40	0	0
FP1 Only	-11.0	-2.8	-75	0	0	0	0	-75	0
FP2 Only	-6.2	-1.6	-50	0	0	0	0	0	-50
Dndrft+Dryer(Ventilation OFF)	-52.7	-12.6	-225	0	-150	-75	0	0	0
Dndrft+Dryer+Vac(Ventilation OFF)	-66.6	-15.8	-265	0	-150	-75	-40	0	0
Dndrft+Dryer+FP1(Ventilation OFF)	-79.5	-18.7	-300	0	-150	-75	0	-75	0
Dndrft+Dryer+Vac+FP1(Ventilation (OFF)	-95.1	-22.2	-340	0	-150	-75	-40	-75	0
Dndrft+Dryer+Vac+FP1+FP2(Ventilation OFF)	-115.7	-26.8	-390	0	-150	-75	-40	-75	-50
Dryer+Vac(Ventilation OFF)	-20.2	-5.0	-115	0	0	-75	-40	0	0
Dryer+FP1(Ventilation OFF)	-29.5	-7.2	-150	0	0	-75	0	-75	0
Dryer+Vac+FP1(Ventilation OFF)	-41.4	-10.0	-190	0	0	-75	-40	-75	0
Normal Operation	-9.9	-2.5	-70	-70	0	0	0	0	0
Normal Operation+Dndrft	-51.1	-12.2	-220	-70	-150	0	0	0	0
Normal Operation+Dryer	-28.1	-6.9	-145	-70	0	-75	0	0	0
Normal Operation+Vacuum	-19.0	-4.7	-110	-70	0	0	-40	0	0
Normal Operation+FP1	-28.1	-6.9	-145	-70	0	0	0	-75	0
Normal Operation+FP2	-21.5	-5.3	-120	-70	0	0	0	0	-50
Normal Operation+Dndrft+Dryer	-77.6	-18.3	-295	-70	-150	-75	0	0	0
Normal Operation+Dndrft+Dryer+Vac	-93.1	-21.8	-335	-70	-150	-75	-40	0	0
Normal Operation+Dndrft+Dryer+Vac+FP1	-124.3	-28.7	-410	-70	-150	-75	-40	-75	0
Normal Operation+Dndrft+Dryer+Vac+FP1+FP2	-146.5	-33.6	-460	-70	-150	-75	-40	-75	-50
Normal Operation+Dndrft+Dryer+FP1	-107.3	-24.9	-370	-70	-150	-75	0	-75	0
Normal Operation+Dryer+Vac	-56.1	-13.4	-235	-70	0	-75	-40	0	-50
Normal Operation+Dryer+FP1	-68.4	-16.2	-270	-70	0	-75	0	-75	-50
Normal Operation+Dryer+Vac+FP1	-68.4	-15.4	-260	-70	0	-75	-40	-75	0
RH>Setpoint	-21.5	-5.3	-120	-120	0	0	0	0	0
RH>Setpoint+Dndrft	-68.4	-16.2	-270	-120	-150	0	0	0	0
RH>Setpoint+Dryer	-43.0	-10.3	-195	-120	0	-75	0	0	0
RH>Setpoint+Vacuum	-32.4	-7.9	-160	-120	0	0	-40	0	0
RH>Setpoint+FP1	-43.0	-10.3	-195	-120	0	0	0	-75	0
RH>Setpoint+FP2	-35.3	-8.6	-170	-120	0	0	0	0	-50
RH>Setpoint+Dndrft+Dryer	-97.1	-22.7	-345	-120	-150	-75	0	0	0
RH>Setpoint+Dndrft+Dryer+Vac	-113.6	-26.3	-385	-120	-150	-75	-40	0	0
RH>Setpoint+Dndrft+Dryer+Vac+FP1	-146.5	-33.6	-460	-120	-150	-75	-40	-75	0
RH>Setpoint+Dndrft+Dryer+Vac+FP1+FP2	-169.7	-38.8	-510	-120	-150	-75	-40	-75	-50
RH>Setpoint+Dndrft+Dryer+FP1	-128.6	-29.7	-420	-120	-150	-75	0	-75	0
RH>Setpoint+Dryer+Vac	-73.9	-17.4	-285	-120	0	-75	-40	0	-50
RH>Setpoint+Dryer+FP1	-87.2	-20.4	-320	-120	0	-75	0	-75	-50
RH>Setpoint+Dryer+Vac+FP1	-83.3	-19.6	-310	-120	0	-75	-40	-75	0

Notes:

dP F326 - Depressurization predicted based on F326 airtightness values(AT=1.07@50Pa)

dP Hse - Depressurization predicted based on measured airtightness values(AT=2.37@50Pa)

Table 4b: House Depressurization Potential With Use of AMM1 & AMM2 and interlock system(using manufacturer specified air flows)

Condition	dP F326	dP Hse	Imbalance	OVERRIDE	AMM1	AMM2	CEV	Dndrft	Dry	Vac	FP1	FP2	
	(Pa)	(Pa)	(L/s)	USED	L/s->								
Normal Operation	0.0	0.0	0		70	0	-70	0	0	0	0	0	CSA F326 Base Flow
RH>Setpoint	0.0	0.0	0		120	0	-120	0	0	0	0	0	
Normal Operation+Dndrft	8.0	2.0	60		120	120	-30	-150	X	X	0	0	
Normal Operation+Dryer	1.1	0.3	15		120	0	-30	X	-75	X	0	0	
Normal Operation+Vacuum	6.2	1.6	50		120	0	-30	X	X	-40	0	0	
Normal Operation+FP1	1.1	0.3	15		120	0	-30	0	0	0	-75	0	
Normal Operation+FP2	4.5	1.2	40		120	0	-30	0	0	0	0	-50	
Normal Operation+Dndrft+Dryer	-1.1	-0.3	-15	Y	120	120	-30	-150	-75	X	0	0	
Normal Operation+Dndrft+Dryer+Vac	-7.0	-1.8	-55	Y	120	120	-30	-150	-75	-40	0	0	Reference Exhaust Flow
Normal Operation+Dndrft+Dryer+Vac+FP1	-24.1	-5.9	-130	Y	120	120	-30	-150	-75	-40	-75	0	
Normal Operation+Dndrft+Dryer+Vac+FP1+FP2	-38.3	-9.3	-180	Y	120	120	-30	-150	-75	-40	-75	-50	Worst Case
Normal Operation+Dndrft+Dryer+FP1	-14.2	-3.6	-90	Y	120	120	-30	-150	-75	X	-75	0	
Normal Operation+Dryer+Vac	-2.3	-0.6	-25	Y	120	0	-30	X	-75	-40	0	0	
Normal Operation+Dryer+FP1	-8.0	-2.0	-60		120	0	-30	X	-75	X	-75	0	
Normal Operation+Dryer+Vac+FP1	-16.6	-4.1	-100	Y	120	0	-30	X	-75	-40	-75	0	

Table 4c: House Depressurization Potential With Use of AMM1 & AMM2 and interlock system(using measured air flows)

Condition	dP F326	dP Hse	Imbalance	OVERRIDE	AMM1	AMM2	CEV	Dndrft	Dry	Vac	FP1	FP2	
	(Pa)	(Pa)	(L/s)	USED	L/s->								
Normal Operation	0.0	0.0	0		70	0	-70	0	0	0	0	0	CSA F326 Base Flow
RH>Setpoint	-1.4	-0.4	18		115	0	-97	0	0	0	0	0	
Normal Operation+Dndrft	11.6	2.9	78		115	105	-30	-112	X	X	0	0	
Normal Operation+Dryer	0.6	0.2	10		115	0	-30	X	-75	X	0	0	
Normal Operation+Vacuum	5.3	1.4	45		115	0	-30	X	X	-40	0	0	
Normal Operation+FP1	0.6	0.2	10		115	0	-30	0	0	0	-75	0	
Normal Operation+FP2	3.7	1.0	35		115	0	-30	0	0	0	0	-50	
Normal Operation+Dndrft+Dryer	0.1	0.0	3	Y	115	105	-30	-112	-75	X	0	0	
Normal Operation+Dndrft+Dryer+Vac	-4.0	-1.1	-37	Y	115	105	-30	-112	-75	-40	0	0	Reference Exhaust Flow
Normal Operation+Dndrft+Dryer+Vac+FP1	-19.5	-4.8	-112	Y	115	105	-30	-112	-75	-40	-75	0	
Normal Operation+Dndrft+Dryer+Vac+FP1+FP2	-33.0	-8.0	-162	Y	115	105	-30	-112	-75	-40	-75	-50	Worst Case
Normal Operation+Dndrft+Dryer+FP1	-10.4	-2.6	-72	Y	115	105	-30	-112	-75	X	-75	0	
Normal Operation+Dryer+Vac	-3.0	-0.8	-30	Y	115	0	-30	X	-75	-40	0	0	
Normal Operation+Dryer+FP1	-8.9	-2.3	-65		115	0	-30	X	-75	X	-75	0	
Normal Operation+Dryer+Vac+FP1	-17.8	-4.4	-105	Y	115	0	-30	X	-75	-40	-75	0	

dP F326 - Depressurization predicted based on F326 airtightness values(AT=1.07@50Pa)

dP Hse - Depressurization predicted based on measured airtightness values(AT=2.37@50Pa)

X - Appliance locked out by Controller

OVERRIDE USED - Occupants used manual override switch

4.0 MONITORING APPROACH

4.1 Monitoring Objectives

The main objective of the monitoring phase, was to determine whether the design and installation of the *AMM's* would resolve the five (3) issues stated below:

1. meeting existing and future ventilation standards;
2. tempering air;
3. managing air flows and associated pressure differentials;

Some other factors that were also of interest to the research were:

- the energy consumption of the ventilation system;
- the response time of system components (ie. control valves); and,
- management of indoor air quality.

Monitoring of the integrated heating and ventilation system included continuous low-level monitoring combined with some short-term monitoring and spot measurements.

The monitoring system was set up initially, to cover all parameters which might relate to the stated objectives. The performance of the heating system, and the energy consumption patterns of the house, were also monitored.

4.2 Long Term Monitoring

• House Pre-wiring to Sensor Locations: The Clearwater residence was pre-wired to facilitate convenient location of sensors in remote locations. Wiring and tubing were installed through the interior partition walls prior to applying the drywall in the house. Shielded, multiple-conductor Beldon cables were fished to the sampling locations from the boiler room, and brought into the specific rooms next to electrical outlet boxes or alongside ductwork.

• The Monitoring Task: The Sciemetrics™ data acquisition system, used for this project was driven by " *Pilot* " a monitoring software package (now named *Co-Pilot*) designed by Howell/Mayhew of Edmonton, Alberta and intended for use with Sciemetrics equipment. *Pilot* is a menu driven program that requires the configuration of monitoring *Tasks* which can then be customized and revised quickly and easily.

The programming of the monitoring task was coordinated with the addition and alteration of sensors. The task was given a new name each time a significant change was made in the structure of the program, for instance if the data save period for an *element*[2] was shortened or lengthened. For this reason, the monitoring task was revised on five occasions over the 5 1/2 months of intensive monitoring, and computer data has been stored under (5) different file names. The first clean data was collected at the end of September, 1989 and continued relatively steadily until March, 1990. The time-line bar chart in Figure 7 illustrates the chronology of the tasks and the segments of uninterrupted monitoring data. The task file names shown are acronyms - CWHM-012 is an abbreviation for Clearwater House Monitoring, 12th revision of the task. The most detailed monitoring task was designed, as one might imagine, for the last period, Feb-15-90 to Mar-06-90, coinciding with the coldest days of the winter. Design-day temperatures were experienced at this time. Also during the period, a time-averaged tracer gas test was performed.

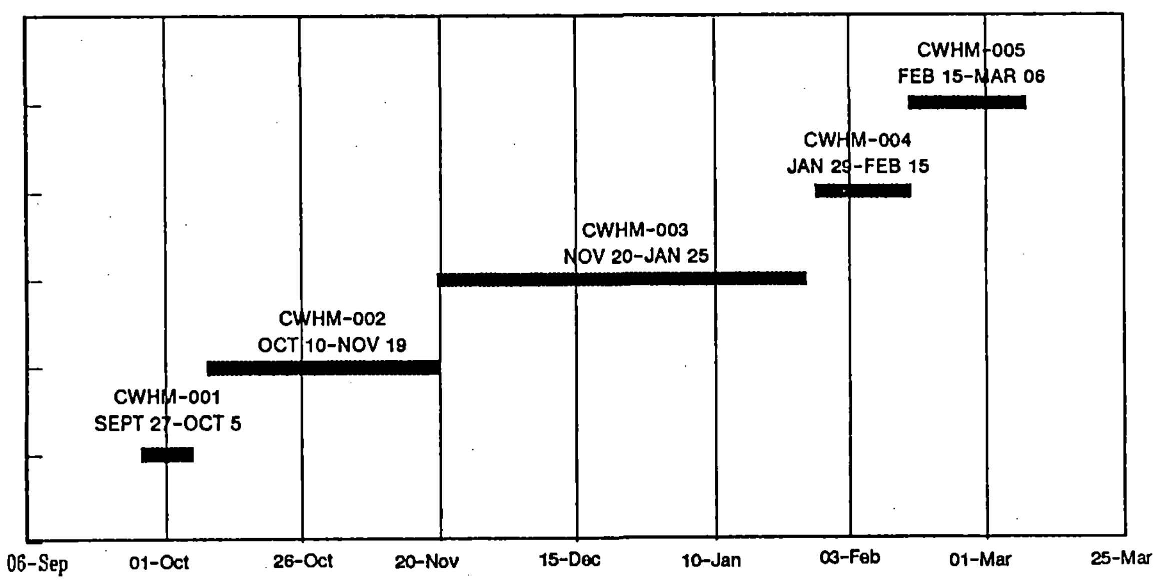


Figure 7: Time-line of monitoring task periods for winter 89/90 .

[2] An element is defined by Howell Mayhew as a record of characters and numbers which defines a specific portion of the monitoring task.

• **Continuously Monitored Parameters:** The monitoring sites are illustrated on house floor plans (see Figures 8a - 8c). All parameters of house performance relating to the mechanical systems were monitored continuously using the instrumentation cited below:

Parameters	Instrumentation
Temperatures in master bedroom, and basement.	AD590 I.C. Thermometer
Temperatures of the various supply air flows, family room, and in the farthest room from the AMM (south-east bedroom).	AD590 I.C. Thermometer
Relative humidity in front hall and family room.	Phillips humidity sensor
AMM 1 supply air flow.	Flow Cal Grid with Photohelic Pressure Transducer
Supply air temperature before & after the tempering coil.	AD590 I.C. Thermometer
Average pressure differential across the envelope.	Valodyne Pressure Transducer
Frequency of operation of various ventilation systems, including:	
- gas burner, and	Digital sensor
- exhaust equipment.	Relays
Operating times/status of all ventilation systems.	Digital Sensors
Carbon Dioxide levels (2-2 week periods only).	Nova CO_2 Analyzer (1 infra-red)
Combustion gas spillage events for boiler.	AD590 I.C. Thermometer
House fuel consumption.	Firing Rate Calculations
House electrical consumption.	Meter Reading
A weather station to monitor wind speed, direction, outdoor temperatures, and humidity.	Weathertronics

All continuously monitored data was stored on MS-DOS based storage media. The data has been exported from *Pilot* and formatted into *Lotus 1-2-3, Release 3*, three dimensional spreadsheets. The data was pre-processed into daily summaries, and Period summaries depending on the length of the monitoring task. Also, a summary was made of the entire period, with all known bad data excluded. These data summaries can be found in Appendix 3. The highlights are presented throughout the rest of the report.

• **Short-Term Monitoring:** Short-term monitoring and testing during the monitoring period was not confined to any definite period. At the beginning of the testing, and in the shoulder months of the autumn, continuous CO_2 was measured in the master bedroom. During the coldest part of the winter a time-averaged air change (PFT) was carried out over a two week period.

• **Spot Measurements:** The following measurements and/or tests were conducted periodically throughout the course of the project:

1. a chimney venting test and spillage check (Venting Systems Test) was conducted two (2) times during the monitoring period, once in the coldest part of the winter, and once in the fall; and

2. air flow measurements were taken of the delivered flows to each of the rooms and of exhaust systems, using the CMHC Duct Test Rig.

• **Additional Monitoring Completed:** The following measurements and/or tests were *not* conducted during the course of the project but have been completed as part of follow up work:

1. constant injection tracer gas testing to determine *room-by-room* ventilation effectiveness under varying operation modes;
2. tracer gas decay method testing to determine the efficiency of the ventilation system; and,
3. testing the effects of central-air distribution using AMM 2 as the continuous ventilation appliance, as an alternative to ducted *room-by-room* air distribution.

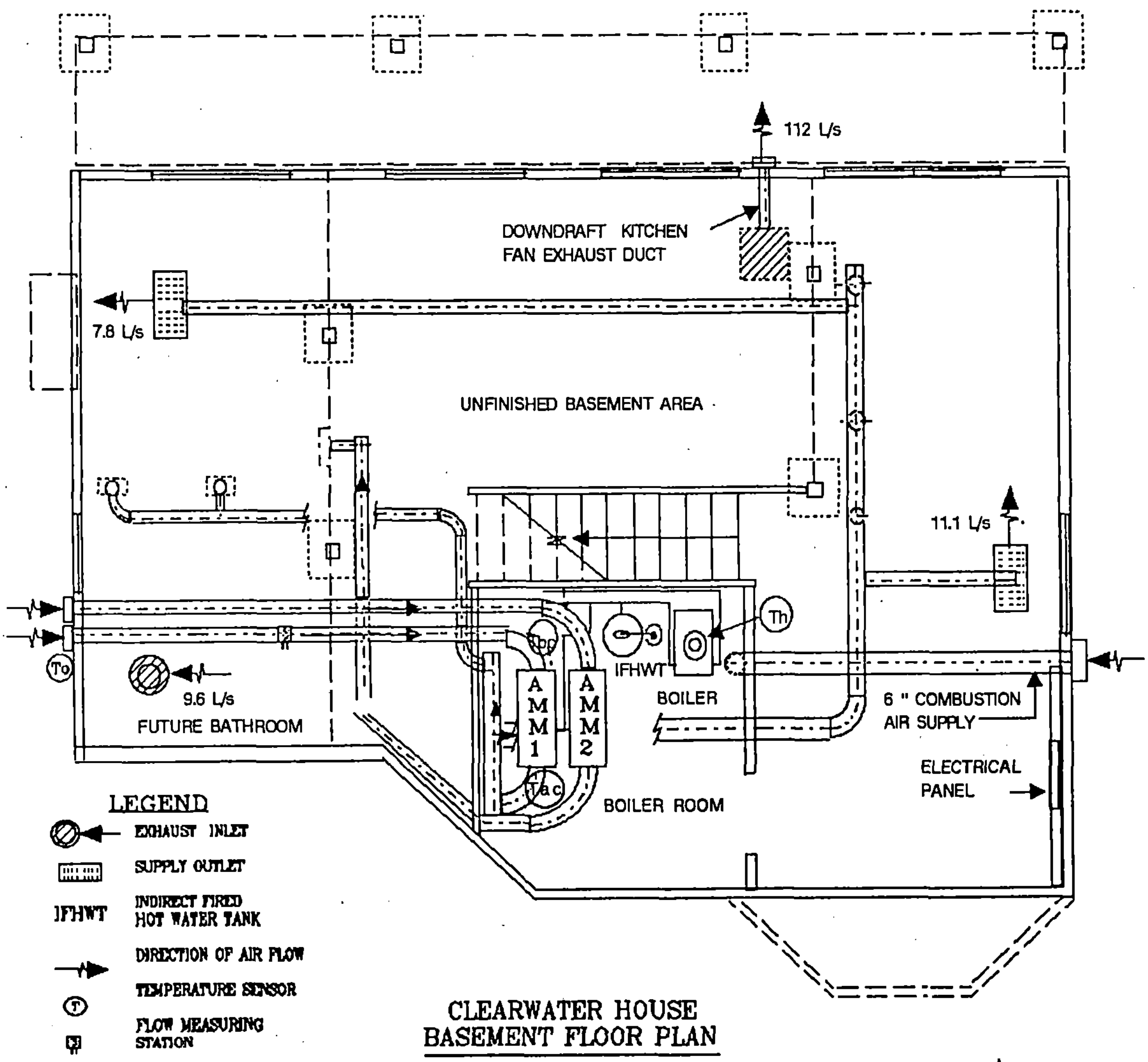


Figure 8a: Basement Floor Plan Showing Monitoring Sites & Air Distribution System

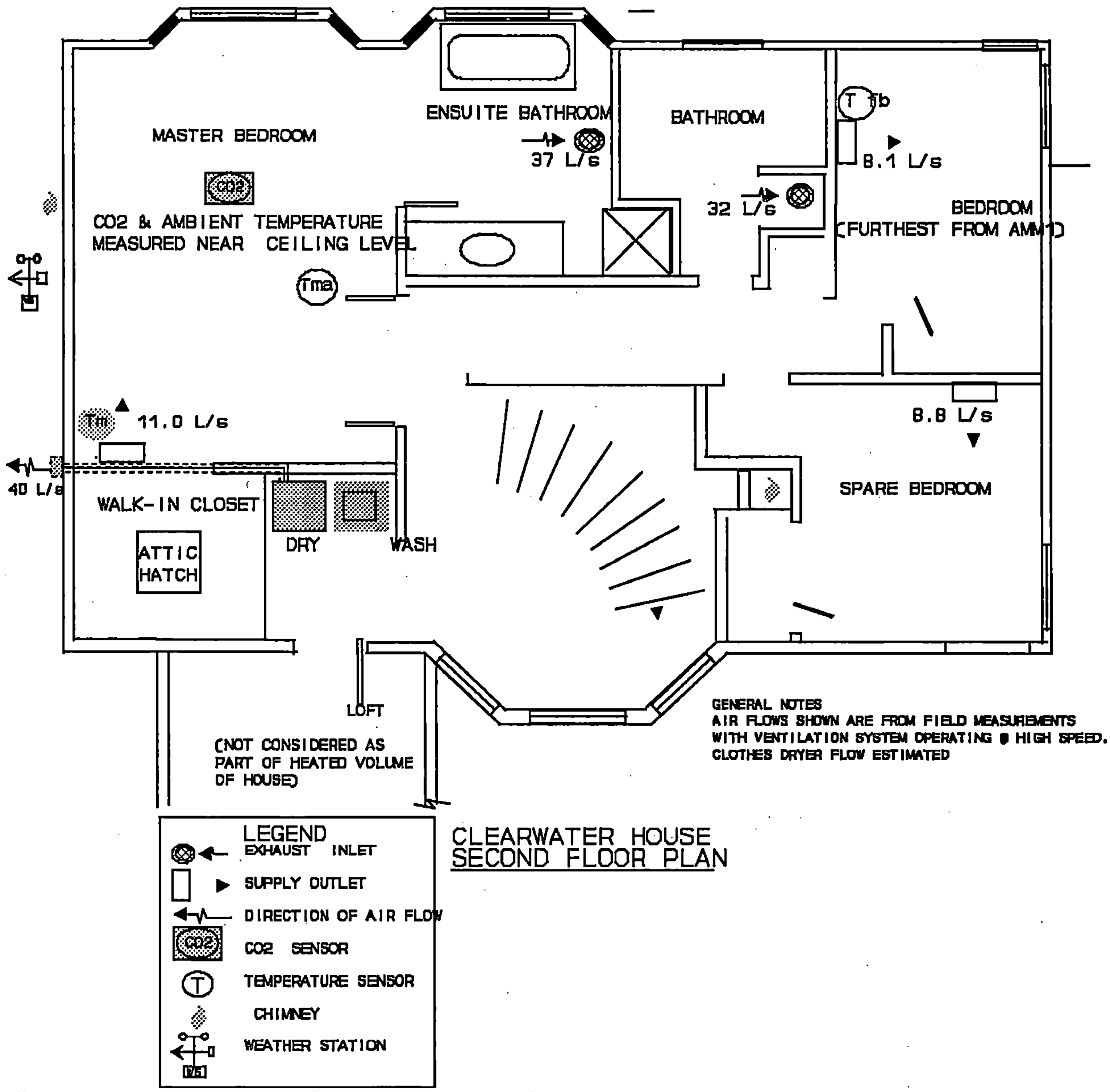


Figure 8b: Main Floor Plan Showing Monitoring Sites & Air Distribution

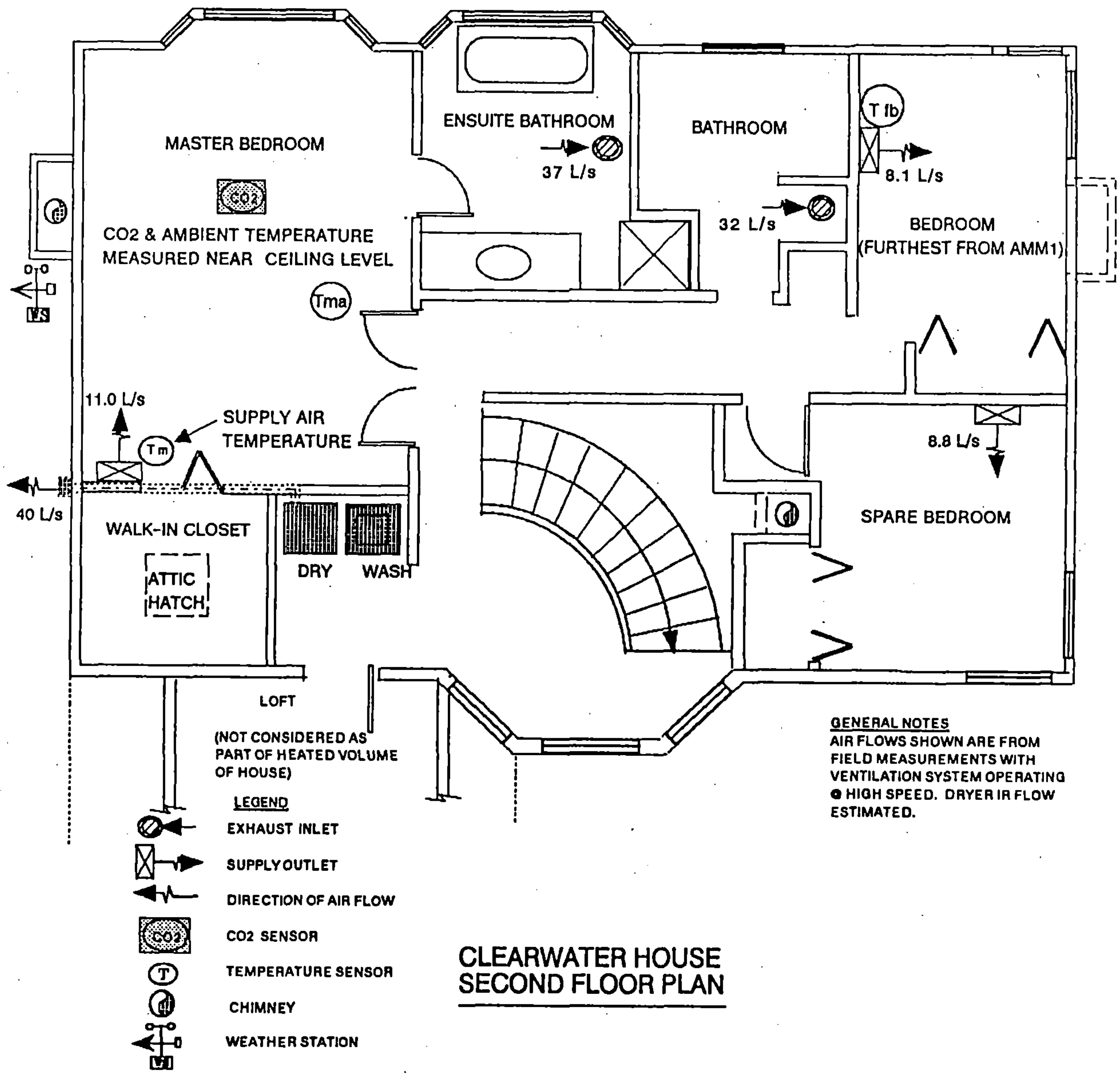


Figure 8c: Second Floor Plan Showing Monitoring Sites & Air Distribution System

5.0 RESULTS

5.1 MEASURED AIR FLOW RATES

Table 5 summarizes the basic flow rates of the installed appliances and the room-by-room measured flows compared to CSA F326 minimum requirements.

Table 5: Measured Air Flows & F326 Minimum Requirements (L/s)

Supply L/s	Measured	Estimated*	F326 Minimum	
Category A Rooms	**Continuous**	**Intermittent**	**Base Rate**	
Bsmt West side	7.8	4.9	5	
Bsmt East side	11.1	7	5	
Main Dining Rm	8.4	5.3	5	
Main Living Rm	6	3.8	5	
Main Family Rm	7.7	4.8	5	
2nd Flr. Master Br	11	6.9	10	
2nd Flr. Spare Room	8.8	5.5	5	
2nd Flr. Furthest Br	8.1	5.1	5	
Category B Rooms				
Bsmt Bathroom	–	–	5	
Main Bathroom	–	–	5	
2nd floor bath	–	–	5	
2nd floor ensuite bath	–	–	5	
Kitchen make-up (AMM2)		105	5	
Supply Total (Source)	**115**	**170**	**70**	
Supply Distribution	**68.9**	**148.1**	–	
Supply Leakage**	**46.1**	**21.9**	–	
Exhaust L/s	Measured	Estimated*	F326 Minimum	
Category B Rooms	**Continuous**	**Intermittent**	**Continuous**	**Intermittent**
Bsmt Bathroom	9.6	6.1	25	15
Main Bathroom	18.4	11.5	25	15
2nd floor bath	32	20	25	15
2nd floor ensuite bath	37	23.2	25	15
CEV Exhaust Total	**97**	**60.8**	–	–
Kitchen Exhaust	-	112.3	50	25
Exhaust Totals	**209.3**	**173.1**	**150**	**85**

* Intermittent flows were estimated because of measurement difficulty. Extrapolation assumes directly proportional relationship between leakage @ high & low air flow.

** Leakage includes all air flow into house not measured at registered. (ie some leakage occurred in basement near AMM installation) Also measurement error could be responsible for some apparent leakage.

5.1.1 Duct Leakage:

Although all accessible joints were sealed to avoid leakage, our air flow measurements revealed after commissioning, that 40% of the supply air did not reach supply registers (comparing flow in to flow out). Some air was found to be leaking into wall cavities; the remainder is likely spilling directly into the basement. Some duct leakage was expected but more in the order of 10% (measurement error may account for 5% -10% of the leakage measured, due to the difficulty of measuring air flows between 5 and 15 L/s).

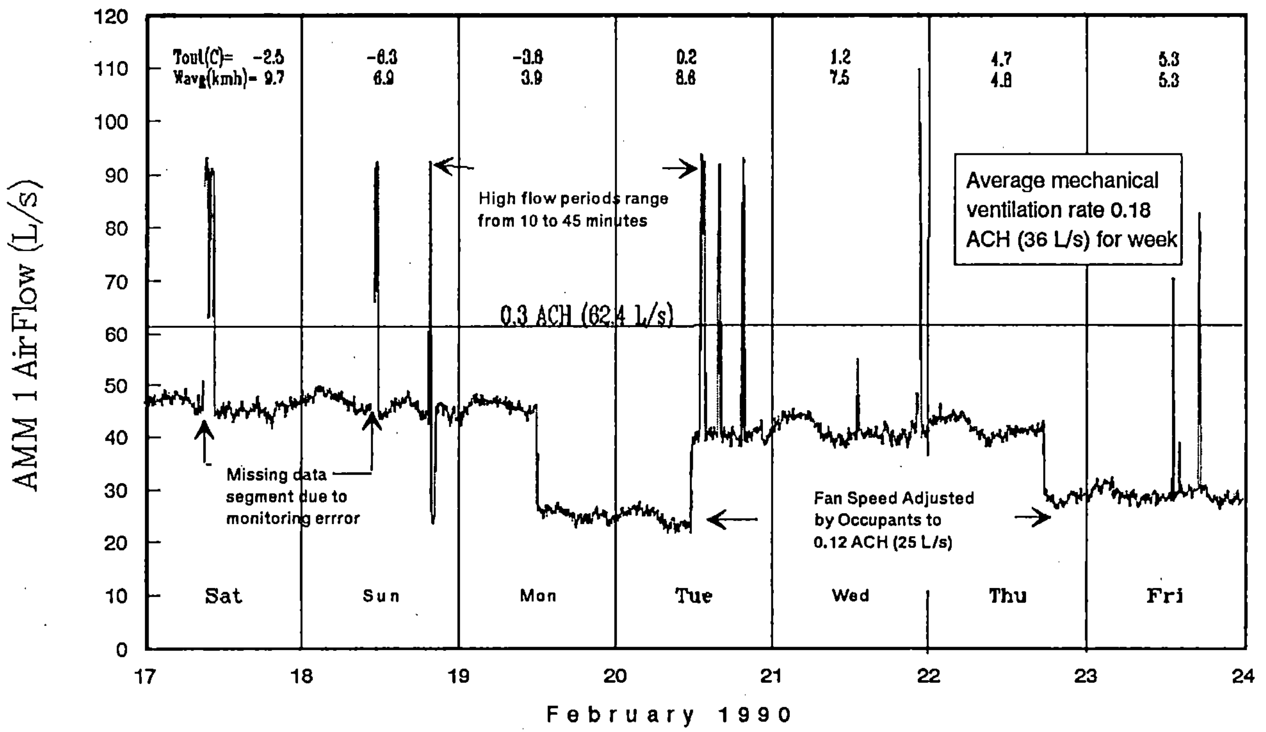
• **Measured Leakage:** The supply air measured at the inlet of the *AMM 1* was higher than the total supply measured at the registers . Total supply measured at the inlet was 115 L/s as compared with a total of 70 L/s delivered to the rooms. This suggests that there was leakage from ducting and into the wall cavities near the outlets of up to 45 L/s, or 40% of the total.

• **Leakage Sites:** The areas sited to contribute most to leakage are poor fittings. At one tee junction in the basement ceiling a feeder duct was loosely placed in the tee and had dislodged, leaving a 1 inch annular gap. This was detected only after all air flow measurements were made. The estimated contribution to leakage at that point was 5-10 L/s. Possibly the bulk of the remaining leakage was into the wall cavities around the outlets. Many of the openings in the drywall where the registers were to be placed, were roughly hewn and substantial leakage is suspected to be spilling behind grills.

• **Implications of Leakage:** The fact that duct leakage of this proportion may exist in many or perhaps most heating and ventilation ducting systems is quite serious when commissioning is conducted to determine compliance with room air supply requirement of CSA F326. F326 however, only requires that the air flow requirements be met at the source.

5.1.2 Variations In Ventilation Air Flows Over Long Term

During the monitoring period the amount of continuous ventilation from AMM 1 varied as a result of adjustments made to fan speed settings. Changes in base ventilation rates were made intentionally by the monitoring team and when required by the occupants, although occupant adjustment was infrequent. These continuous flow rates measured by the flow station, ranged from more than **65 L/s** to about **25 L/s**[3]. The long term average flow was **55.64 L/s** continuous over the 125 day monitoring period. Of course, this takes only ventilation air into account and disregards infiltration. (Section 5.4 looks at the results of time-averaged air change tests which give a clearer picture of the combined rates.)



Air flow measurements averaged over 10 minute periods

Figure 9: Example of Variations in Supply Air Over a One Week Period in Feb-90.

The influence of the AMM's high flow operation on the long term average flow rate was negligible. Of the 2480 hours of monitoring, *AMM 1* remained at base flow rate 2355 hours or 95 % of the time. This equates to a difference of 2.8 L/s, dropping the average base flow from 55.6 to 52.8 L/s[4].
The graph in Figure 9 shows how, during the mid February period, the base flow rate varied between

[3] Initially, the fan speed ratio allowed for a maximum decrease in flow to only 60 L/s but an adjustment made it possible to drop the speed and lower the air flow to about 25 L/s. This was intended to allow for more flexibility for experimental reasons and to conserve energy used for heating ventilation air which seemed to be high.

[4] Long term average does not include operation of AMM2 and associated air exchange.

25 & 45 L/s, possibly caused by occupant adjustment the speed control in the main hall. The spikes seen in the graph correspond to AMM 1 switching to high speed operation.

Most of periods in which AMM 1 was in high speed operation were due to use of the clothes dryer and kitchen fan or sometimes both. This implies that the 60 minute manual override timer was used to bypass the lockout system. Unfortunately, the status of the timer was not monitored. According to the homeowner however, the override timer was seldom used - perhaps 3 or 4 times over the 5 months monitoring period.

5.2 SUPPLY AIR TEMPERATURES: THERMAL COMFORT & AIR DISTRIBUTION

5.2.1 Supply Air Temperature Comfort Guidelines

The H.V.A.C. industry has recommended that unless air diffusers are intentionally designed and located so that cool supply air does not come in contact with occupants, supply air temperatures should not be less than 17 °C with floor or low wall diffusers and not less that 13 °C. with high side-wall diffusers. F326 Section 5.5 just recommends that the manner of introduction of supply air shall be as to avoid occupant discomfort. These comfort guidelines were easily satisfied by the ventilation system in the Clearwater house.

A supply temperature setpoint of 25 °C was chosen for supply air leaving the AMM units. Tempered air at much lower temperatures would potentially be felt as cold drafts to occupants seated or standing near the low wall diffusers. Actually, average for the season was nearer to 23.1 °C measured at the family room supply outlet. Figure 10 shows the temperature of the air leaving AMM 1 and outdoor temperature for the week of February 16th. During this mid winter period temperatures outdoors dropped to as low as -9 °C, the lowest normally experienced in the region and probably the best case for gauging AMM's ability to effectively temper the incoming air.

5.2.2 Design Day Thermal Performance of AMM's

On February 17, 1990 the temperature averaged -6.2 °C which for the Vancouver region could be considered a design day for heating system design (Vancouver heating design temp. is -7 °C). Spikes on the graph represent periods in which changes in air flow (AMM 1 to high speed) caused the air leaving temperatures to fluctuate while the control valve reset to match the load.

Figures 11a & 11b refer to the worst case conditions when *AMM 1 & AMM 2* were energized in response to kitchen fan operation. AMM 1 supply air was effected favourably since air temperature rose quickly indicating fast response from the control valve. The average temperatures over the 10 minute save period did not drop below 23 °C. There may have been noticeable cooling for the first minute but as will be seen in the next section, thermal storage in the supply ducting would have reduced this considerably. Figure 11a confirms this since the average temperature in the family room supply duct rose 0.6 °C during the 20 minute period of air temperature modulation.

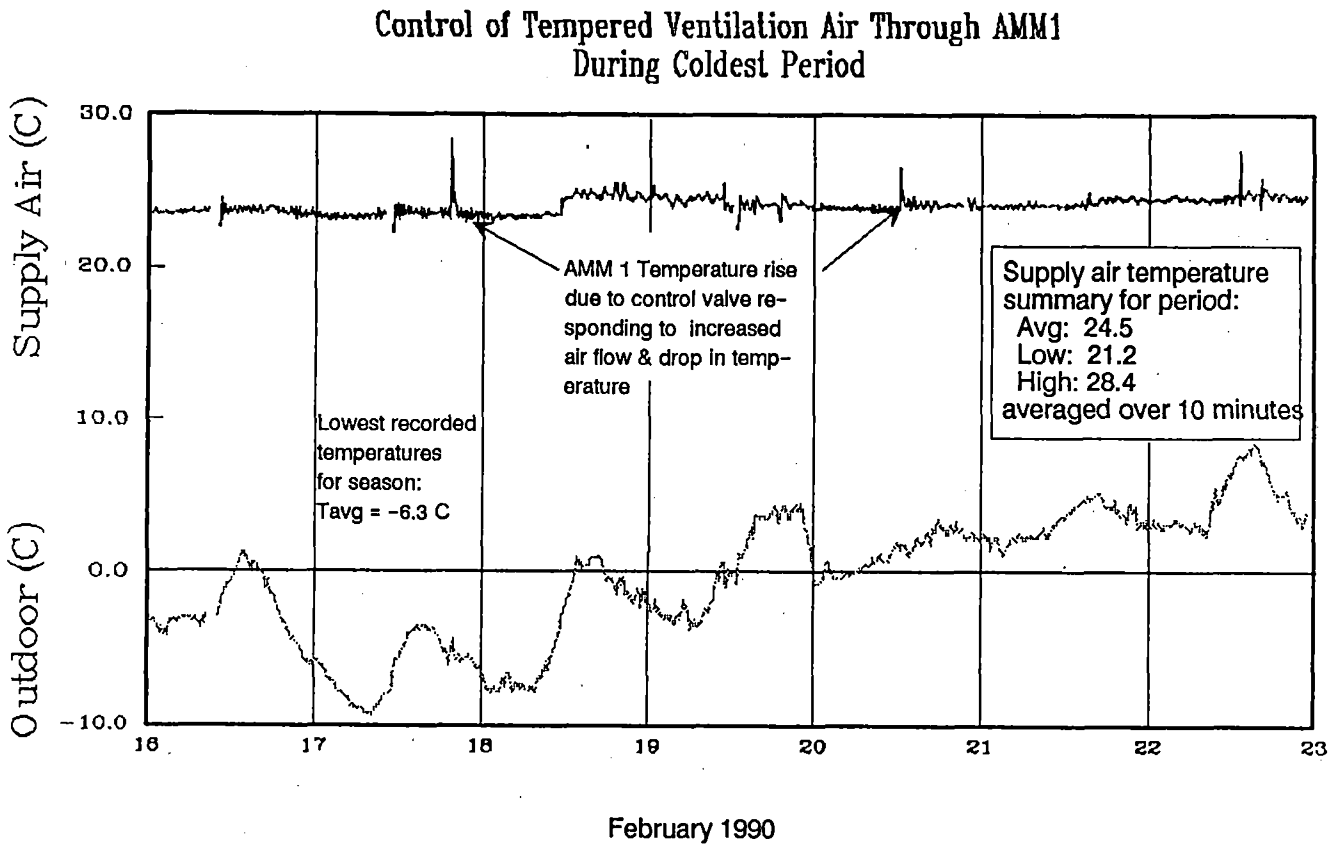


Figure 10: AMM 1 After Coil Air Temperature & Outdoor Temperature

AMM 2 is heavily taxed during kitchen fan operation in cold weather. In its off status stack pressure may cause air flows in the order of 3 - 5 L/s to pass through its single heating coil causing the temperature to drop to below 20 °C momentarily during any 10 minute period(see curve "After Coil Min"). Suddenly at high speed, its full capacity is demanded. When energized, incoming air at -7 °C would require 4 kW of heat to maintain 25 °C leaving air (105 L/s). The coil capacity from Graph 1 in Appendix 2 is only 12,500 Btu/hr (3.67 kW) @ 82 °C suggesting AMM 2 would fall slightly short of its setpoint temperature. Figure 11b tracks the coil response to a similar scenario with incoming air near -4 °C (allowing for some rise from outdoor ambient in the upstream ducting). A momentary drop was recorded to 11.6 °C but the average drop over the first 10 minute save period to only 20.9 °C suggests good recovery. The temperature at the supply outlet, though not monitored, most likely remained higher due to warming along the length of the duct.

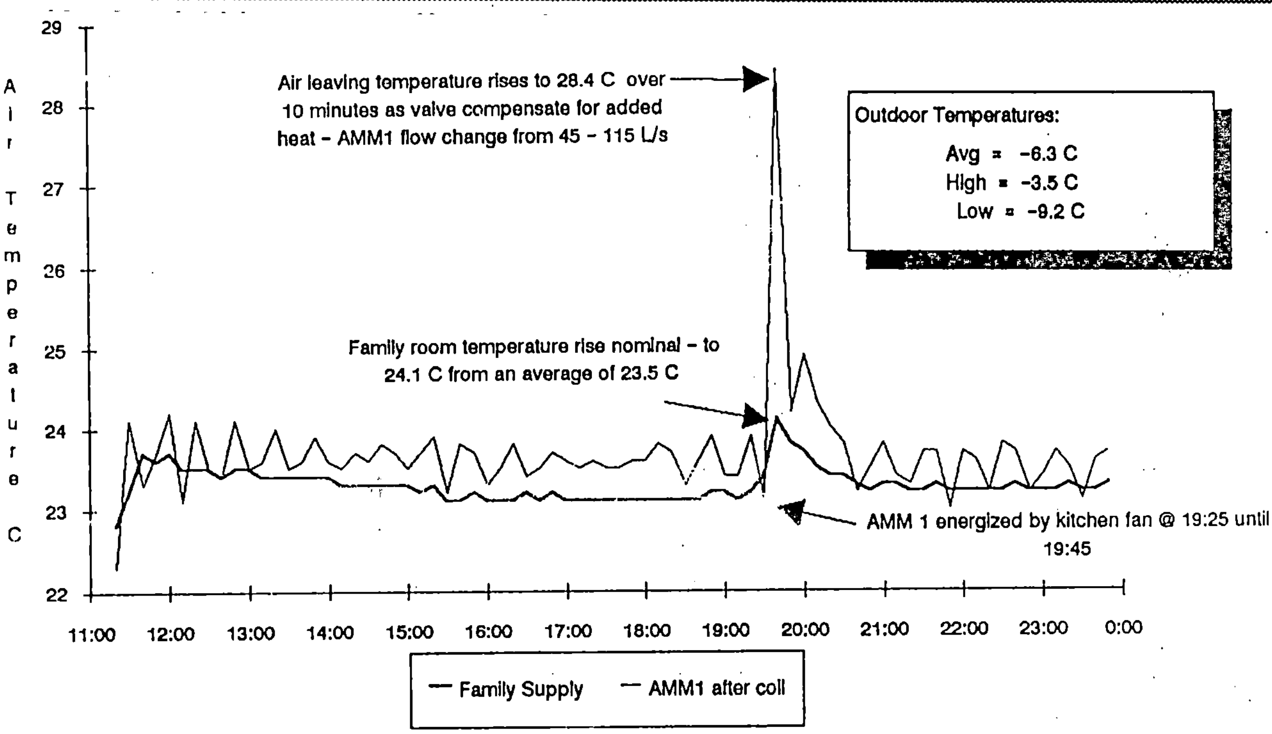


Figure 11a: Thermal Performance of AMM 1 At Design Day Temperatures

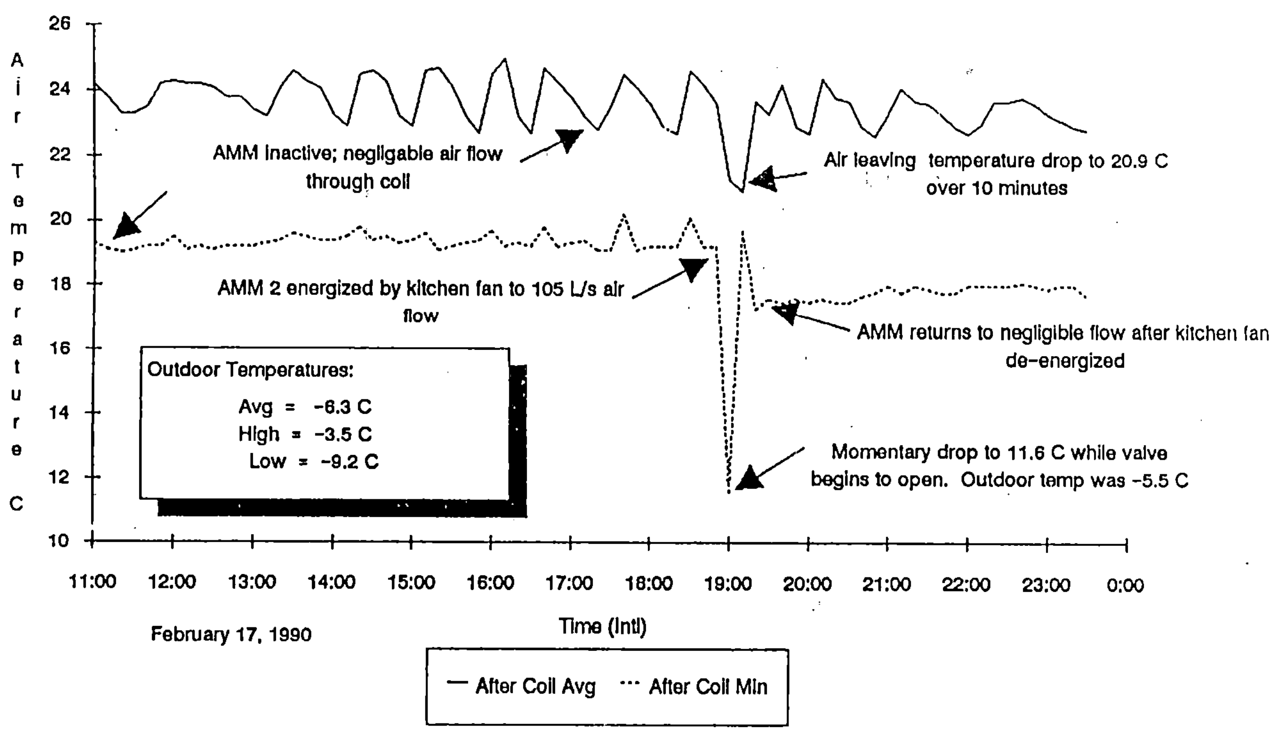


Figure 11b: Thermal Performance of AMM 2 Under Design Day Conditions

5.2.3 Thermal Storage of Ducting

The thermal storage of supply-air ducting was notably favourable. Figure 12 shows temperatures fluctuating +/- 7 °C at the coil face(due to heating demand as sensed by the downstream temperature sensor) during the first 5 minutes after AMM 1 returned to normal low speed operation. The incoming air temperature was approximately 7 °C on the day this data was collected. The second data series in the graph, family room air supply temperature, shows that these fluctuations were significantly dampened between the heating coil and the supply register. The scenario illustrated in Figure 12 was staged in an attempt to gauge the response of the control valve and data points correspond to 30 second intervals. *Pilot* screen data was saved manually for a 45 minutes period. In retrospect, this technique could have been used to answer many of the questions raised during the data analysis and the writing of this report.

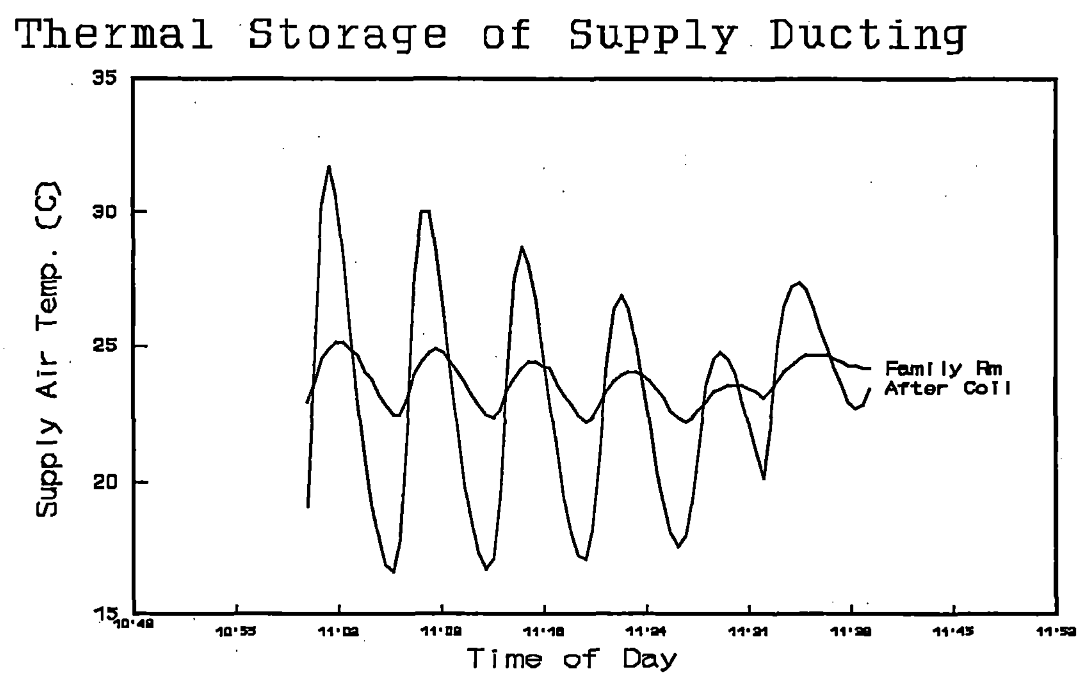


Figure 12 : Effects of Thermal Storage in Supply Ducting.

5.3 Managing Indoor/Outdoor Pressure Differentials

5.3.1 Overview

• **CSA F326.1 Dwelling Pressure Limits:** The two factors which most influence house pressure limits are:

1. the ability of fuel burning appliances to resist backdrafting of flue gases under negative house pressure; and,

2. the air leakage characteristics of the house (F326 assumes a default ELA for design purposes of 0.5 cm^2/m^2 of building envelope area).

Limits for pressure increase and decrease for the Clearwater house are +10 Pa and -5 Pa respectively. The Category I, natural draft boiler used in the Clearwater house limits decrease to *-5 Pa*. The pressure increase limit is set at +10 Pa in all dwellings for reasons cited below.

• **Effects of Excessive ΔP**

Pressurizing a dwelling can create problems by:

- inducing indoor air into wall cavities thereby increasing concealed condensation; and
- forcing moisture laden air through window frames and door hardware, increasing the possibility of frost damage or seizure.

Depressurizing a dwelling through the use of an exhaust appliance can cause:

- backdrafting of combustion products into the dwelling (possibly for extended periods of time);
- extinguishing of the pilot light;
- poor performance of fireplace (especially when stoking or burning down); and
- excessive cold drafts

The limits set by F326 are independent of stack pressures present in the house. For example, if stack present in the house is found to be *-3 Pa* before using an appliance such as a kitchen fan, then the ΔP when the fan is on should not exceed *-8 Pa*.

5.3.2 Interlocking of AMM's With Controller

Interlocking of exhaust appliances assures management of house pressures by managing supply and exhaust flows within a reasonable spread. In theory this is an easy task, but as the Truth Tables revealed, all possible combinations of appliance interactions cannot easily be accommodated for. The tables show the design process taken in the effort to balance air flows during any particular exhaust appliance interaction.

The data confirms that the interlocking method was effective at avoiding depressurization of the Clearwater house.

The graphs in Figure 13a show the response of house pressures to changes in AMM 1 air flow over several days. On November 12/89 the graph shows extensive activity in the house. AMM 1 high speed operation time totalled 3.1 hours for the day which is three times the average and pressure swings of up to 2.5 Pa over 10 minute periods were recorded. It can also be seen that, momentarily, house pressures dropped to less than -9 Pa. Some of those drops were caused by exhaust appliance interaction while some others do not. Quickly opening the basement door can cause a pressure shock wave which may fool the pressure sensor if the computer scan is concurrent and the drop is recorded.

Unfortunately, status sensors for all appliances were not installed, it is difficult to pinpoint the occupant activity and exhaust appliance interactions (ie. downdraft kitchen fan, fireplace, dryer, dehumidistat, boiler). The homeowner was questioned about the event and recalled using the fireplace and manual override timer on that day.

With so much repeated use of exhaust equipment, the value of an integrated and balanced ventilation system is confirmed.

Figure 13b demonstrates a case where where the kitchen fan and clothes dryer were in use simultaneously (assume override timer was activated by the occupant). Despite such high flows, house depressurization was controlled within **0.5** Pa consistent with expectations from the truth table.

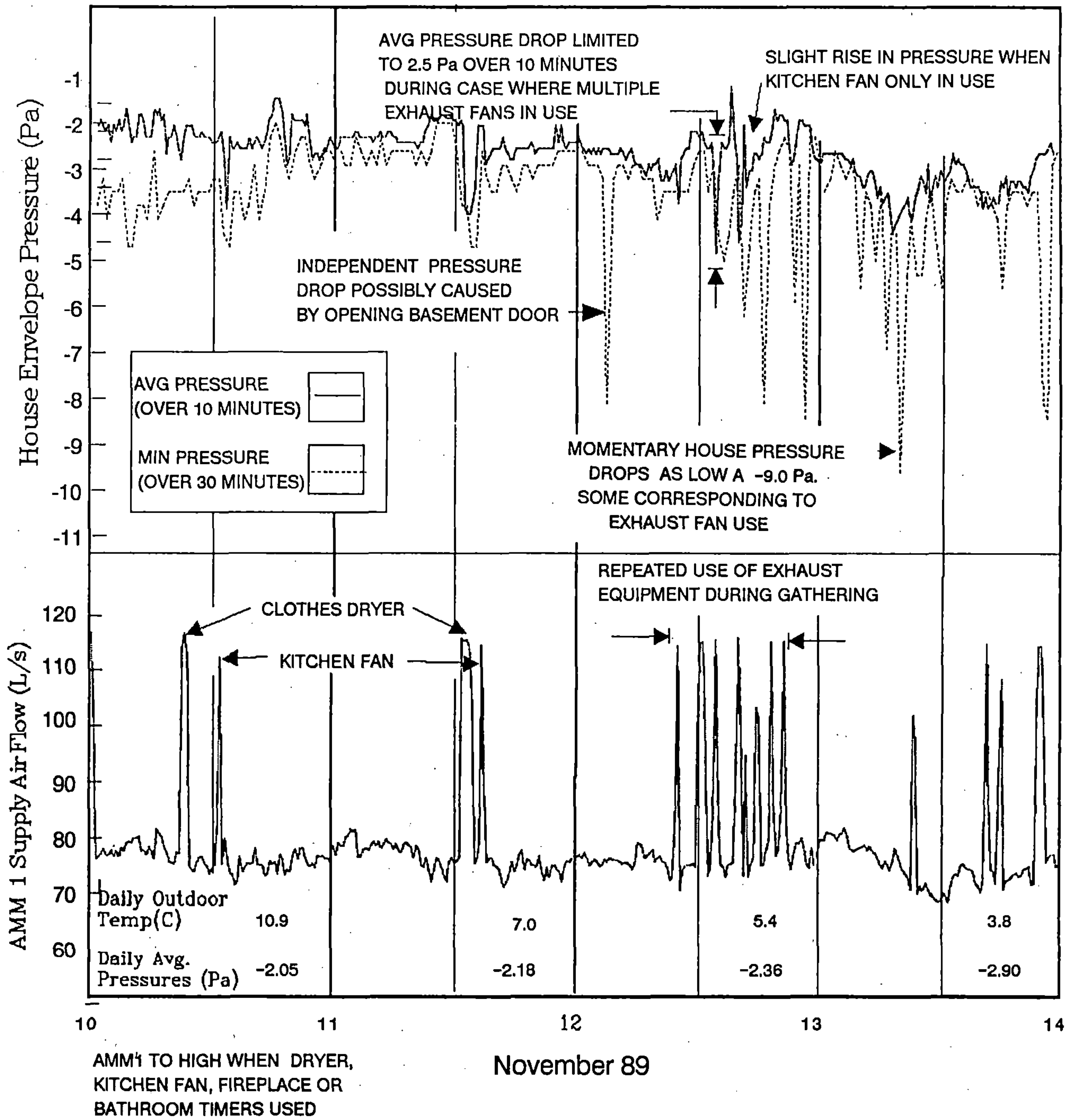


Figure 13a: Response of House Envelope Pressures to Supply Air Variations

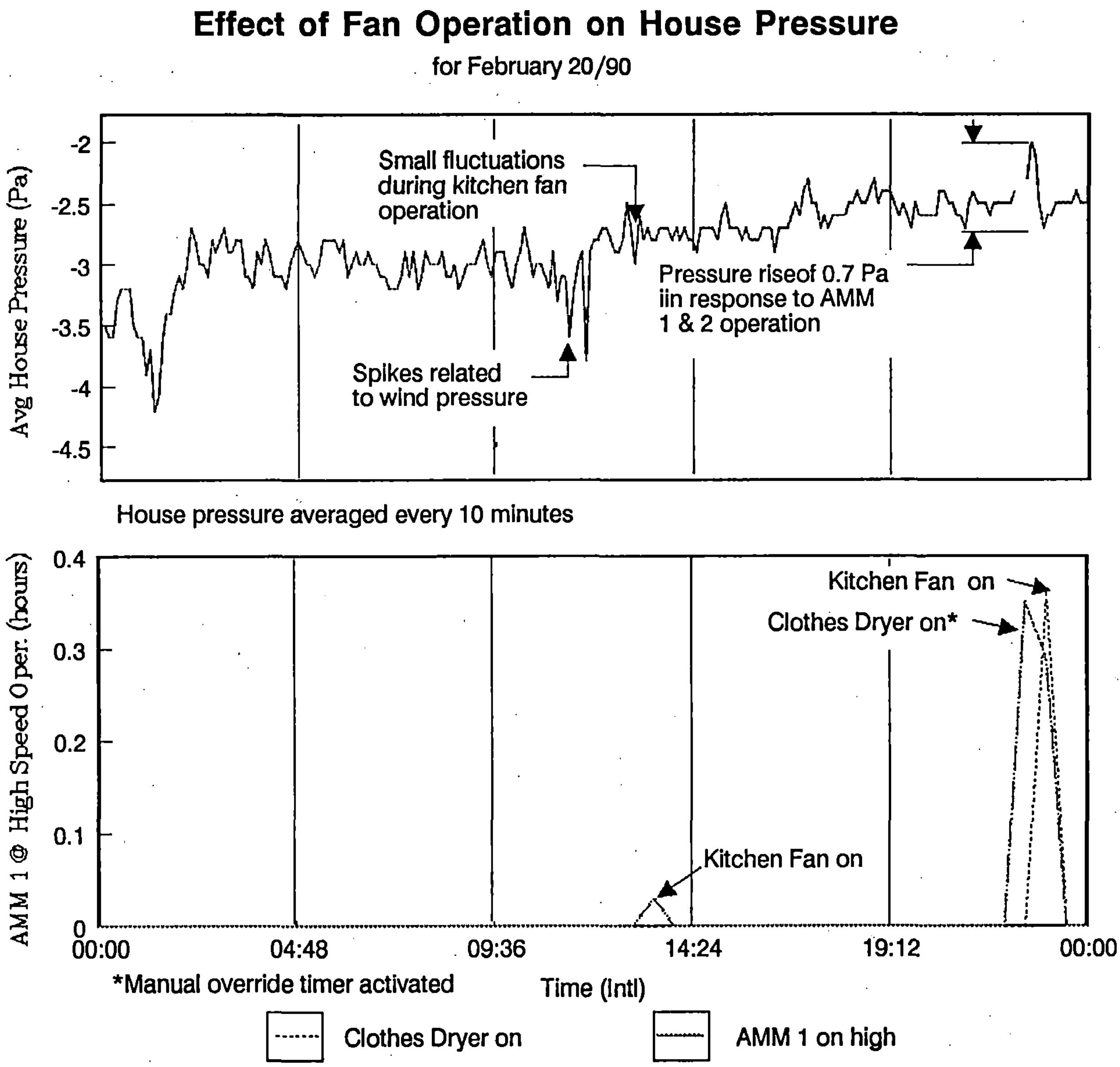


Figure 13b: Effect of Fan Operation on House Pressure

5.3.3 Effects of Wind and Stack Pressure

Fundamentally, the issue of house pressure control is simply a matter of choosing between two options:

i) monitoring the pressure differentials, and supplying air at critical points; or,

ii) installing an electrical interlock system for exhaust and supply fans in order to exclude hazardous combinations.

Both these approaches, however, can suffer from the unpredictable impact of wind and stack pressures.

Monitoring wind related pressure differentials in the Clearwater house revealed wide swings (more details below). The implications are that wind and stack related pressures can be so significant that any pressure sensor would be fooled by wind gusts and the resulting control actions would be erratic and inconsistent. At the same time the appliance lock out provide no guarantees.

• **Effects of High Stack Pressures:** Under normal operating conditions any building experiences a pressure gradient over its vertical elevation due to thermal buoyancy (stack pressure). When outdoor temperatures are lower than indoor, the basement ΔP is negative and the second floor is positive. Most infiltration modelling has assumed stack pressures of less than three Pascals.

Although no recorded combustion spillage events occurred in the Clearwater house as a result of the wind and stack pressures, house depressurization levels greater than the 5 Pa F326 limit were recorded that were unrelated to the use of exhaust appliances. These events are attributed to a combination of wind and stack pressures. Chimney draft is probably kept strong at these times, aided by the same wind and stack forces, which explains the absence of any recorded incidence of chimney backdrafting or combustion gas spillage.

Unusually high stack pressures were often measured in the Clearwater house, - up to 7 Pascals over 30 minute periods and momentarily up to 10 Pa. Pressure differentials were measured near ground floor level, (approximately at the height of the furnace draft hood). A pressure averaging kit was used to dampen wind effects on the ΔP.

• **Wind Effects:** The graphs in Figure 14 illustrate that the house pressures are markedly effected by winds. Pressure drops caused by the wind of 4 - 5 Pa for 10 seconds to 1 minute (minimum house pressure), and 1 - 1.5 Pa over 10 - 20 minute periods (average house pressures) were recorded.

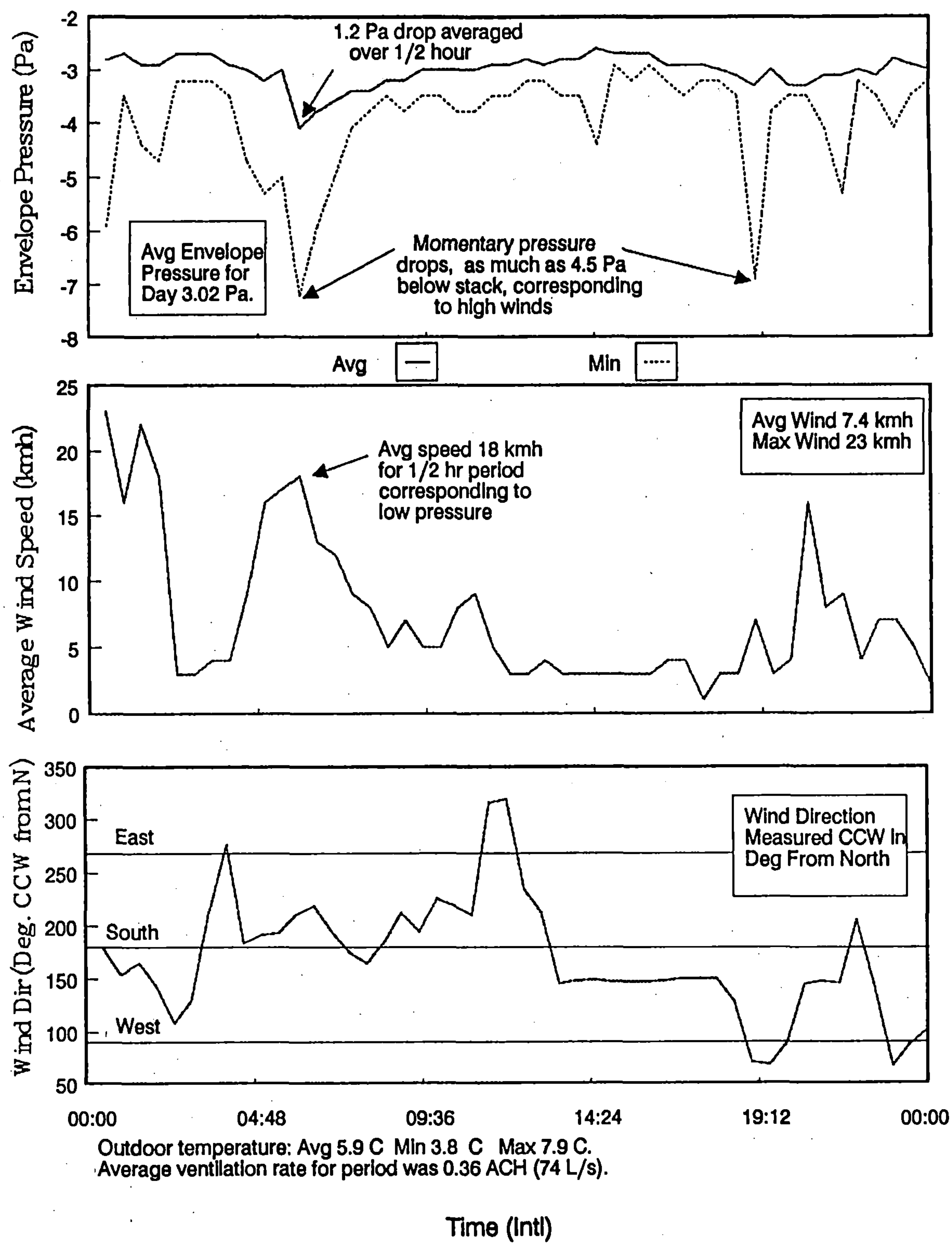


Figure 14: Wind Effects on House Envelope Pressures at Clearwater House

5.4 Time-Averaged Air Change Analysis

A time-averaged air change measurement was made using the NAHB AIMS tracer gas method. Gas emitters and collectors were placed on all three floors over the period from Feb-15 to Mar-06-1990. The result, in air changes per hour (ACH) was found to be **0.338 ACH** (68.6 L/s). The average mechanical ventilation rate for the same period was calculated to be **0.171 ACH** (34.8 L/s). The actual base rate varied during the period (refer to Section 5.1.2). The remainder air change is assumed to result from natural infiltration, which accounts for **0.167 ACH** (33.8 L/s), or almost half the overall air change.

Cold temperatures for the region presided during the air change period. The average outdoor temperature during this time was 3.45 °C; the average temperature indoor was 19 °C (see data summary in Appendix 3). The lowest temperature recorded was -9.4 °C on Feb. 17th. The wind speed average was 6 kmh close to the winter average.

As a cross check on these measured infiltration values, the infiltration air flows have been calculated for the Clearwater house, based on standard air flow equations. The amount of natural infiltration, driven by stack pressure, is a function of one half of the house ELA (ie. the leakage area is divided between infiltration and exfiltration air), the average stack pressure, and the ΔT between indoors and outdoors. As a check on the accuracy of the air change analysis, a general formula has been derived to calculate the infiltration rate in the Clearwater house. Using 1/2 the ELA value and a slight modification of the standard orifice equation (equation 1 below) the infiltration rate becomes:

$$Q_I = C_D * \frac{ELA}{2}\sqrt{2 * \frac{\Delta P}{\rho}}$$ **Equation 1:**

Where Q_I = Infiltration Air (m^3/s)

ΔP = Average House Pressure (Pa) (-2.75 Pa for period) measured across foundation wall

ELA = Estimated leakage area (m^2) from CGSB test (281 cm^2)

ρ = Standard air density 1.205 (kg\m^3)

C_D = Discharge coefficient for square edged orifice (0.61)

The resulting flow Q_i for infiltration is **49 L/s** or **0.241 ACH**. This result is 40% higher than the AIMS measured rate[5] cited earlier. Given that the AIMS result has an error of +\- 0.120 ACH, the hypothetical value is within the limits derived from field measurement. A summary of the measured and hypothetical air change values is presented in Table 6.

Table 6: Results of NAHB Air Change Testing & Est. Infiltration for Feb 16 - Mar 6, 1990

	Avg Overall Air Change Rate ACH(L/s)	Mechanical * Ventilation Rate ACH(L/s)	Infiltration Rate ACH(L/s)
NAHB AIM's Tracer Gas Test	0.338(68.6)	0.171(34.8)	0.167(33.8)
Estimated Air Change (Equation 1)	0.412(83.8)	0.171(34.8)	0.241(49.0)

* Calculated from field measurements @ flow station during period

5.5 Indoor Air Quality

The air quality parameters measured during the monitoring period included continuous measurement of relative humidity, carbon dioxide, and spot measurements of Formaldehyde and carbon monoxide.

• <u>Carbon Dioxide Measurements:</u> The long term air quality results showed that no excessive CO_2 levels were reached in the house. CO_2 levels were measured only during October and November during which time peak concentrations remained between 900 and 1100 parts per million (PPM).

The CO_2 sampling location was in the master bedroom at ceiling level. Tygon tubing was fed through the walls and down to a Nova 5000 PPM Carbon dioxide analyzer in the basement. The meter was zeroed at regular intervals and any corrections related to offset were made later during the data analysis.

[5] The overall air exchange rate was presented by NAHB AIMS as 0.338 ACH +\- 0.120 ACH

• Relative Humidity Measurements: There was some difficulty with RH measurement because the sensor that was used tended to drift from its set calibration regularly despite frequent recalibration. Most of the data shows humidity levels 5 % to 10 % RH higher than actual. In order to relate data to actual trends an assumption is made that on selected days, the data is correct but only shifted upward on average 7.5 % RH. As mentioned in Section 5.1.2 the calibrated dehumidistat was energized by high relative humidity levels for only 30 minutes during the entire season. This suggests that the RH levels in the house were lower than Figure 15 implies as no control action was recorded. The sensor was placed in the main hallway, at the top of the basement stairs (see floor plans Section 4.0) for the greater part of the period, and in February/90 moved to the Family room.

The uncorrected data, graphed in Figure 15, shows that the RH sensor drifted steadily from the a low daily average of 32% RH on February 16th (sensor calibrated on that day) to near 60% average on February 19th. After February 21st however, more stable results were recorded. The remainder of the data provides a long term record of the changes in RH occurring in the house, between average, minimum, & maximum levels over the Feb/Mar 90 monitoring period.

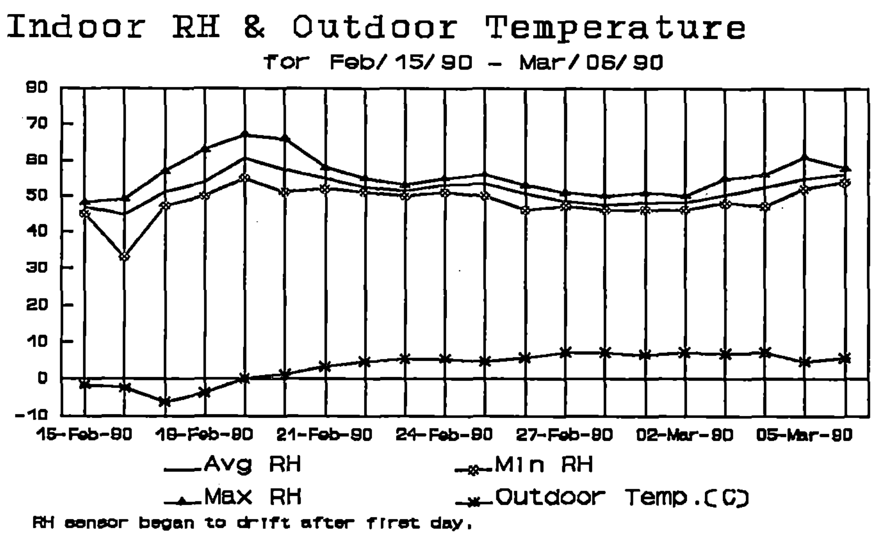


Figure 15: Indoor Relative Humidity & Outdoor Temperature

• Relationships Between RH, CO_2 & Occupancy: The set of graphs in Figure 16 illustrate how CO_2 and RH levels respond to occupant related pollutant generation. On the day the data was collected, October,25,1989, the base ventilation rate was set at approximately 0.34 ACH (70 L/s). A direct correlation is apparent between CO_2 and RH levels. The sharp rise in %RH in the early morning seems exaggerated and may be partly related to sensor error. It is also possible that because the location of the RH sensor was nearer to the kitchen, the rise reflects activities in the kitchen. The subsequent decay of CO_2 levels after the departure of the occupants (at approximately 13:00 hours on the graph time scale) was uniform and levels responded immediately when the occupants later returned (approx. 15:30). The RH graph, on the other hand, decays more erratically, showing some oscillation related to indoor temperature changes.

Unfortunately, no CO_2 was measured during the period when the house was operating under a lower air change rate. Such a comparison may have shown that carbon dioxide levels increased. Dehumidistat operation suggests that at least RH levels did not exceed the 45 % RH setpoint during this period of reduced air changes.

It is important to note that, in general, CO_2 was a better indicator of occupant activity than RH levels in the Clearwater house. This characteristic is also true of other houses monitored by Sheltair over a similar period.[6] Because relative humidity is effected by temperature changes, an increase in moisture levels due to increased activity is not necessarily detected quickly, or in proportion to the level of activity.

• Formaldehyde Spot Measurement: A spot measurement of formaldehyde concentration under normal conditions using an extra low range Gastec tube, was found to be below the 0.05 PPM detectable limit. A more precise time averaged measurement over a 1 or 2 week period was not felt to be warranted due to the almost complete absence of formaldehyde bearing building materials (ie. kitchen cabinets were constructed with solid oak as opposed to particle board).

No complaints of eye or throat irritation (ie. symptomatic of excess formaldehyde) were registered by the occupants.

[6] Sheltair; Demand Controlled Ventilation, Phase III Progress Report, submitted to CMHC Research division February 23,1990

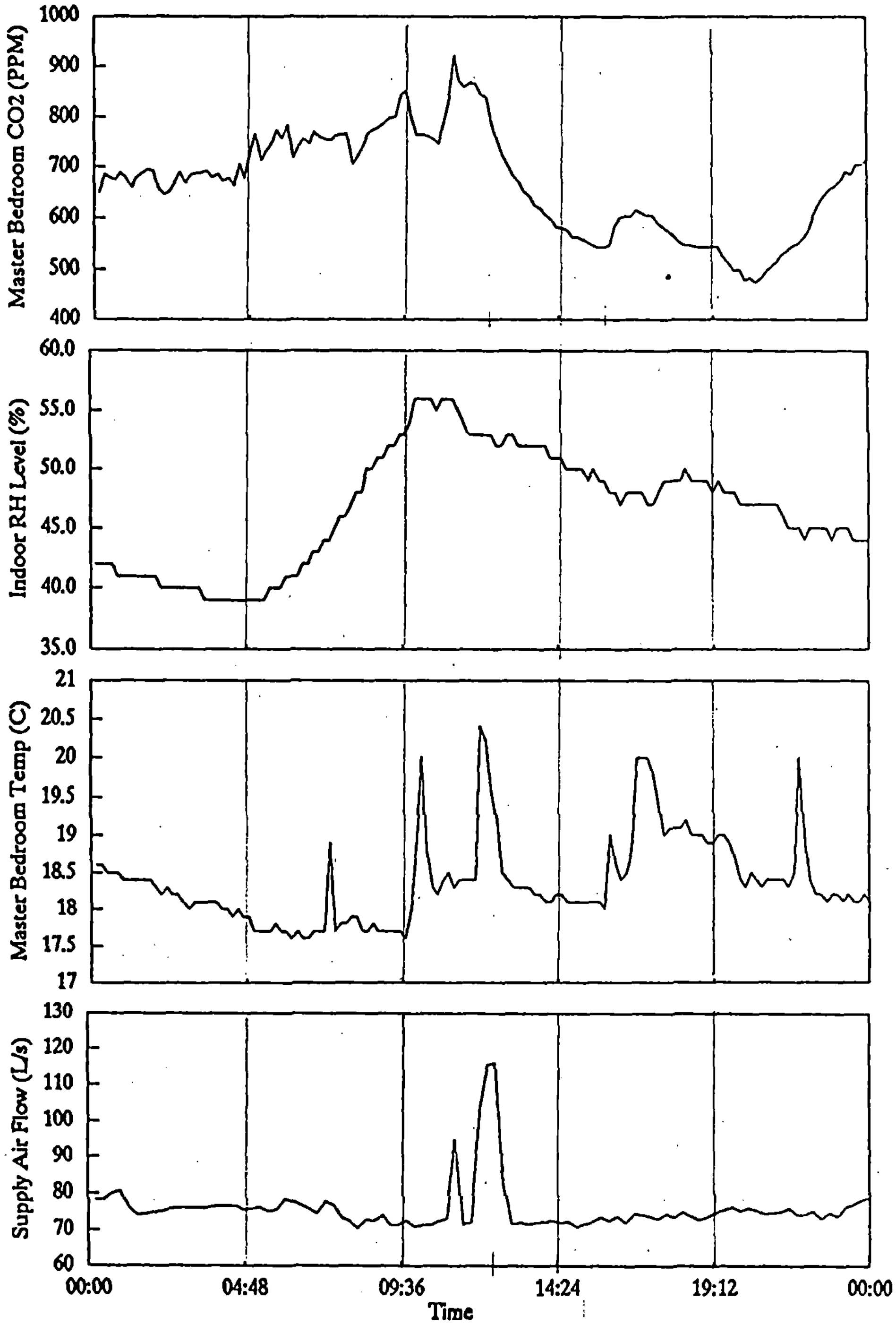


Figure 16: Measured Air Quality Responses to Occupant Activity (October 25,1989)

5.6 Energy Use & Efficiency

5.6.1 Overall Energy Performance of Integrated System

Although a large amount of data was collected during the Clearwater house study, only a cursory analysis of energy use was completed and only a general overview is given in this section. A more meticulous study would reveal the effects of wind, stack pressure, hot water use and variations in ventilation air rates on energy consumption.

• **System Drawbacks:** Three problems existed in the Clearwater house that caused more than expected fuel consumption:

1) the house ELA was higher than intended for an energy efficient home - inducing high a infiltration load;

2) the boiler/IFHWT configuration was incorrect, causing increased cycling of the boiler (refer to Section 2.2.1); and,

3) the piping in the boiler room was not insulated - causing high basement temperatures and possibly increased infiltration due to greater stack pressures.

These problems, if addressed, could result in reduction of fuel consumption of as much as 30% of the average yearly heating costs. Section 5.6.2. provides a more detailed look at the measured consumptions compared a computer energy analysis that was performed prior to monitoring.

5.6.2 Hot 2000 Energy Use Analysis

The Hot 2000 computer energy analysis was performed using the actual measured value for ELA and the results are summarized below, a comparison is made between predicted and measured heat losses and energy consumption. Table 8 summarizes these results.

Table 8: Hot-2000 Estimated & Actual Measured Results for Heating & Ventilation Fuel Costs

	Units	Hot-2000 Prediction	Measured
Ventilation Costs	$/yr	$115	$90
Design Heat Loss @ -7 C	kW	9.38	13.12*
Annual Heat+DHW	GJ/HDD**	0.0314	0.0639
Avg Mech. Air Change Rate	ACH	0.39	0.32

* Includes space heating, mechanical & natural ventilation & DHW (estimated at 7.5 % of total)
** An outdoor temperature weighted index based on average and measured Heating Degree Days for the region.

• **Calculation of Energy Costs**: Energy costs were calculated from measured data. The parameters needed for the calculations were:

- *Total boiler operation time;* from which gas consumption was derived,
- *Average indoor & outdoor temperatures;* used to calculate mechanical ventilation air heating requirements (it was assumed that ventilation air warmer than indoor ambient temperature contributed to space heating and hence, not included,
- *AMM 1 average air flow;* AMM 2 air flow was thought to be an independent consideration.

It is assumed by Hot-2000 that a design day temperature is -7 °C, however, the average for the day was -6.2 °C and there was a temperature swing of 4 °C. The infiltration rate must have been much higher than the Hot-2000 predicted 0.07 ACH (see print out in Appendix 3). According to equation 1 in section 5.4 the average design day house pressure of -4.64 Pa could have resulted in an infiltration rate as high as 0.3 ACH (64 L/s). The discrepancy is significant but not relevant to this study.

• **Hot Water Consumption:** Hot-2000 did not take *DHW* consumption into account because the program version did not recognize the indirect-fired hot water tank in the version of the program that was used. This would add to the overall predicted consumption and partly account for higher heat losses.

DHW consumption (base load) was not directly measured during the house monitoring. A more in depth analysis of the data could reveal the average hot water use for a particular period but this has not yet been done. However, using the Hot-2000 upper range default value for a typical home of *236 L/day* the DHW usage for a day is approximately **0.08 GJ** (costing about $0.40).

For the design day the measured gas use was **1.09 GJ** making hot water use **7.5%** of the daily gas use. After taking DHW usage into account the measured design heat loss is only 30% higher than the Hot-2000 predicted heat loss.

5.6.3 Cost of Ventilation

The measured mechanical ventilation cost, on average over the entire monitoring period was $0.37 /day, which is 13.7% of the total cost of $2.73 /day for heating and hot water at the Clearwater house. The calculated cost does not include natural infiltration air change which, during the coldest periods, can match or exceed the mechanical ventilation cost. The daily mechanical ventilation cost varied from **10.89%** of the total in Feb/Mar 90, to **21.03%** in November when *AMM 1* was set at a high flow of 65-70 L/s . The heating design day cost for ventilation was $0.55 (**10.7%** of the measured whole house heating cost of **$5.09**) based on an air flow from *AMM 1* at an average of 47.2 L/s. A summary of all data collected for the design day, February 17,1990, can be found in Appendix 3. Figure 17 below illustrates the overall gas consumption for each period and compares that to mechanical ventilation consumption.

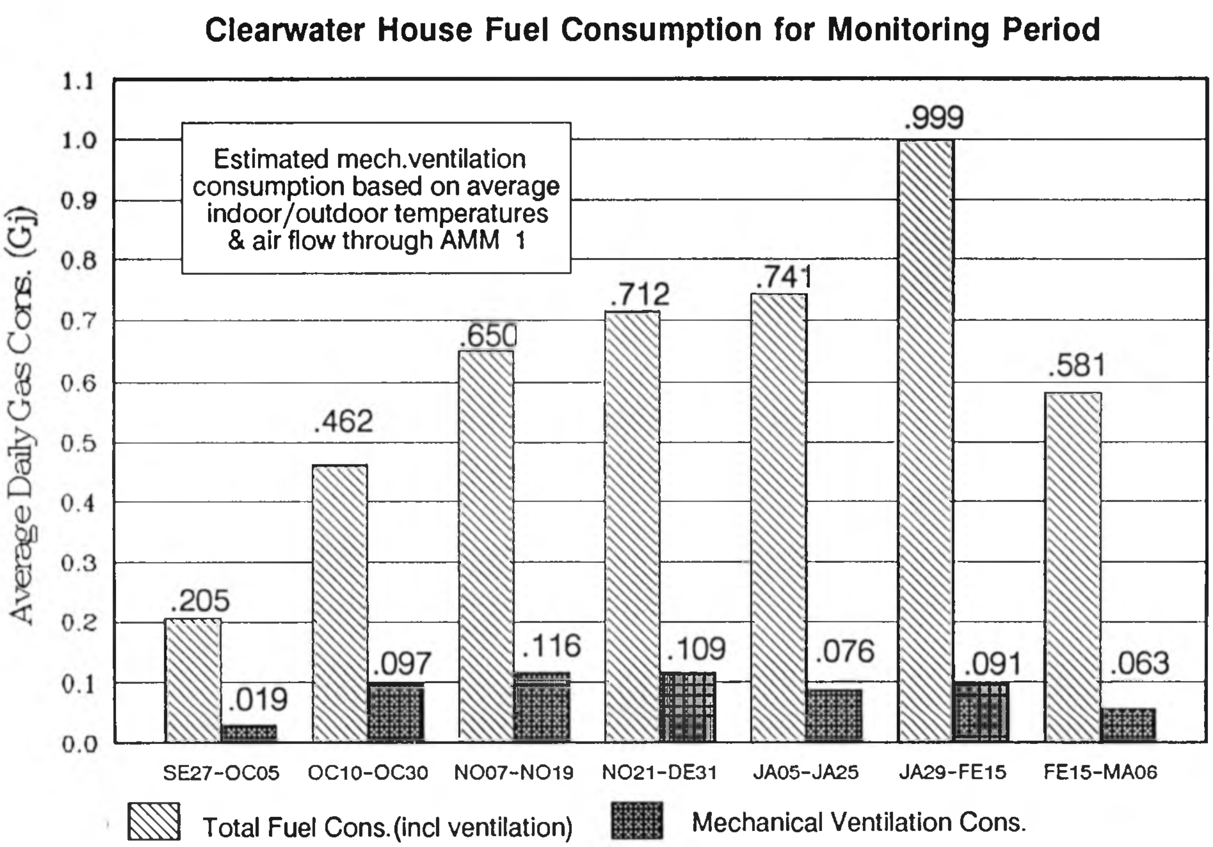


Figure 17: Total Fuel Use (Space, DHW, Infiltration) & Mechanical Ventilation Consumption

6.0 CONCLUSIONS & RECOMMENDATIONS

6.1 General Conclusions: System Performance & Monitoring Results

Our research objective was to design and demonstrate the use of an integrated heating system capable of satisfying requirements for *air quality, ventilation and combustion safety* in new Canadian homes. The Clearwater house project appeared to meet these objectives. Although the system turned out to be more complicated and expensive than expected, the project was successful in all other respects.

Some general conclusions about the performance of the integrated system, based on the results of monitoring the house over 1 1/2 years, are presented below:

1. The overall concept of the AMMs appears to be excellent especially when in conjunction with a hydronically heated house which required tempered ventilation and make-up air for powerful exhaust fans. The AMM provides both thermal comfort and assurance that all exhaust appliances will be operating in a harmonious manner *automatically.*

2. The intended control logic required considerable amount of design time but ultimately was shown to work as a functional system. All the relays, lockouts, timers, and interlocks collectively functioned to manipulate the house environment according they were designed to. The challenge that remains is to design a smaller control box with less complexity, and more durable components.

3. Both the AMM's and the controls proved expensive to install, operate and maintain. Their design could benefit from simplification. The number of different exhaust appliance interactions that are presently controlled by the integrated system central controller could be reduced to only the kitchen fan, clothes dryer & central vacuum. Occupant controls like the dehumidistat and override should remain, but the effectiveness of these devices is questionable. Problems related to calibration and proper use surfaced during this investigation.

   Even the kitchen fan make-up air could be directly interlocked with a make-up fan independent of the main controller. Alternatively a single AMM unit of greater capacity could be installed, instead of two AMMs, that would maintain a base ventilation rate and provide adequate make-up air. The CEV could be shutdown during kitchen fan operation instead of slowed to idle speed. This would cut down the amount of unneeded depressurization and reduce the flow capacity required for a single AMM.

4. The supply air distribution was moderately well balanced by the original installers. Flows were measured at each of the supply and exhaust outlets and found to near enough to F326 room by room requirements. However duct leakage was found to have reduced distribution air to 60% of source air flow. Poor fittings and concealed joints were suspect though some air may have spilled into the basement near the source. There is need for improved duct installation standards, and a need to factor duct leakage when designing distribution to satisfy code requirements.

   Over the long term, monitoring of system air flows showed that high speed operation time of AMM 1 amounted to 5% of the total monitoring period. The influence of the AMM's high flow operation on the long term average flow rate was thus small, dropping the base flow from 55.6 L/s (0.28 ACH) to 52.8 L/s (0.26 ACH). The base flow rate could not be relied upon to be consistent as occupants sometimes adjusted the speed control by accident, or intentionally.

5. The AMM heat exchange loop functioned as well as or better than expected. The thermostatic control valves used (Honeywell V104 F) performed well in regards to air tempering under all given situations up to -10 C and were the most economical of the alternatives at less than $100 (including temperature sensors). The coils provided sufficient heat although a single coil as in AMM 2 was limited to about 30 °C of temperature rise, possibly inadequate for colder climates.

   Tempered air never fell below the occupant comfort level indicated by F326 i.e. 13 °C. On some occasions the after coil air temperature of AMM 2 dropped momentarily to 11.6 °C but the resultant temperature drop at the supply outlet (though not measured) was small due to thermal storage along the length of the duct. This indirectly relieves response time requirements of the control valve.

6. Managing indoor/outdoor pressure differentials was probably the most important task that the system was required to perform. In theory, and for the most part in practice, pressure differentials were kept minimal. In some extreme cases where the system had been overridden by the occupants, momentary pressure "spikes" were recorded exceeding F326 limits by 2 - 3 Pa. Averaged over 10 minutes, however, these drops became less significant. A sensor mounted near the boiler draft hood indicated that no spillage events occurred.

   A shortage of proper status sensors made it difficult to pinpoint occupant activity and properly assess the monitoring results.

Wind & stack pressures combined to create pressure differentials as great as -10 Pa and averaging -7 Pa over 30 minutes (most extreme case). These pressures were measured using an 4 point averaging kit at ground floor level. A pressure measurement based fan control system would be jeopardized by these erratic pressure changes and would be likely to result in erratic operation of supply fans and central exhaust fans.

One crucial factor in assessing the performance of the system the airtightness of the building envelope, The design of the system was based on a predicted airtightness of 1.5 ACH @ 50 Pa. Unfortunately the measured airtightness was 2.3 ACH @ 50 Pa. This made it difficult to fairly judge the pressure control abilities of the systems' most elaborate features. The effects of any ventilation air imbalances due to the use of exhaust appliances were lessened and often immeasurable. Also, indoor air quality was not as effected by occupant generated pollutants as would be the case in a tighter house due to the increased levels of natural infiltration from wind and stack pressure, especially during the colder months.

7. The AIMS NAHB tracer gas air change analysis performed in the Clearwater house during the coldest part of the season concluded an overall air change of 0.338 ACH. This was broken down to 0.171 ACH mechanical (measured from flow station) and 0.167 ACH natural ventilation. This natural infiltration can be roughly calculated since it is a function of the house ELA and the measured stack pressures and projected back for any time during the monitoring period. This may prove useful for future analysis of the database.

8. Relative humidity proved very difficult to measure accurately despite numerous attempts to calibrate the sensor. Though long term RH data is untrustworthy, data from particular days can be corrected. This was done to compare RH with CO_2 and occupancy. Generally, RH rose and fell slowly even when the sensor was placed in the central hallway near the kitchen. CO_2 responded more rapidly, even when located far from the source of activity.

   Carbon dioxide levels in the master bedroom ceiling level climbed to 500 PPM above ambient during periods when base ventilation rate was high (0.35 ACH). The fresh air supply to the room was approximately 8 L/s at the time with the ensuite bathroom exhausting about 25 L/s. This implies that CO_2 concentrations, generated by two people sleeping, are not always manageable.

9. The energy efficiency of the system was affected negatively by the air-leakiness of the building envelope. Fuel consumption during the heating design day was 40% higher than estimated by the Hot2000 energy analysis. This can partly be explained by increased conductive losses due to high temperatures in the basement, a result of uninsulated system piping. Infiltration rates were also higher than expected, due to high stack pressure combined with a relatively high base ventilation rate.

   Mechanical ventilation cost $0.37/day, or 13.5% of the total house fuel cost of $2.73/day, averaged over the entire 5 months monitoring period. This cost does not directly include electrical costs for powering ventilation equipment. A Hot2000 analysis attributed 30% of total heat loss to ventilation based on 0.39 ACH mechanical & 0.07 ACH natural. The measured mechanical average base rate was 0.28 ACH with an estimated average natural ACH of 0.15. DHW consumption was not measured directly but, based on empirical averages, is estimated at 7.5% of the total or $0.20/day

6.2 Recommendations For Future Design Of AMM & Controller

The design for a production model of the AMM is now being considered by Allied Engineering and Raymond Tam Scientific. The design objectives for this new model are summarized below:

More Output Options
- At least two sizes of heat exchangers and fans would be available for large and small houses;

Convenient Modular Design
- The fan can be kept separate from the heat exchanger so that components can be mixed & matched;

More Efficient Heat Load Sizing
- The heat exchange area can be minimized, or in the case of a single coil system, the number of passes could be increased so that more heat per unit of area could be extracted;

Better Accessability
- The access to the inside of the appliance would be improved. At present the AMMs fan could not be serviced without partially dismantling the outer casing;

Lower Operating Costs
- An economizer cycle for summertime use would reduce unnecessary tempering. This may be just a switch which

isolates the AMMs piping loop and de-energises the circulation pump. It would probably need to be occupant controlled;

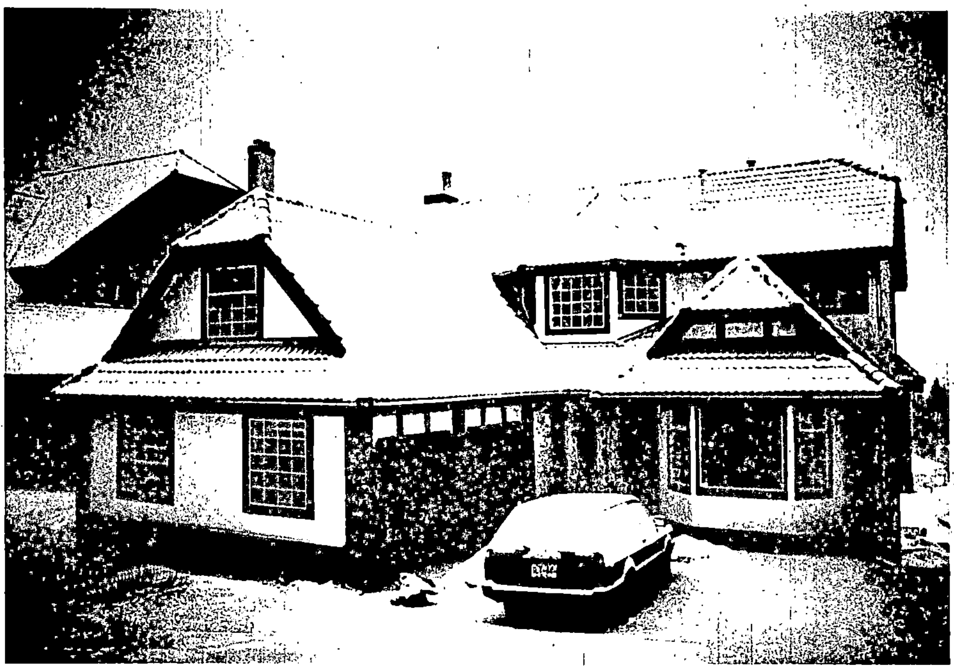
Easier Wiring for Trades
- The controller needs a prefab companion panel for mounting next to the electrical service. This would simplify installation and serviceability of the control centre;

Less Conservative Approach to Pressure Control
- The kitchen make-up air fan might be eliminated. The CEV can parallel AMM operation from 0 - 50 % of maximum capacity. As the AMM switches to high when any exhaust appliance is energized, the CEV would shut down;

Lower Component Costs
- The CEV & AMM would be operated by a single speed control combined with supply-fail lights for proving flow;

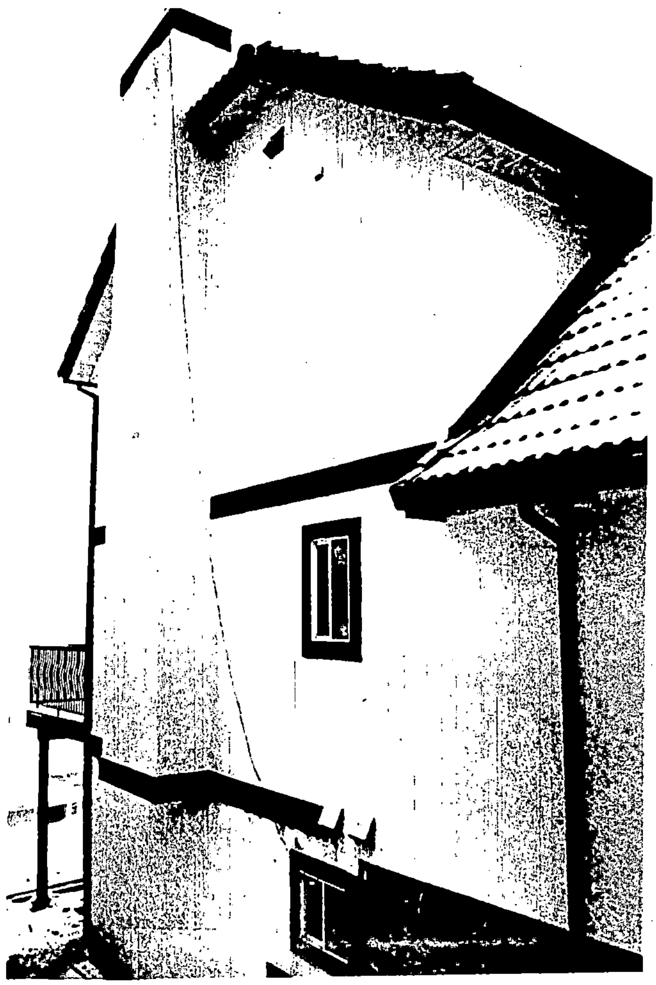
APPENDIX 1

PHOTOGRAPHIC REVIEW OF INTEGRATED APPLIANCE PROJECT

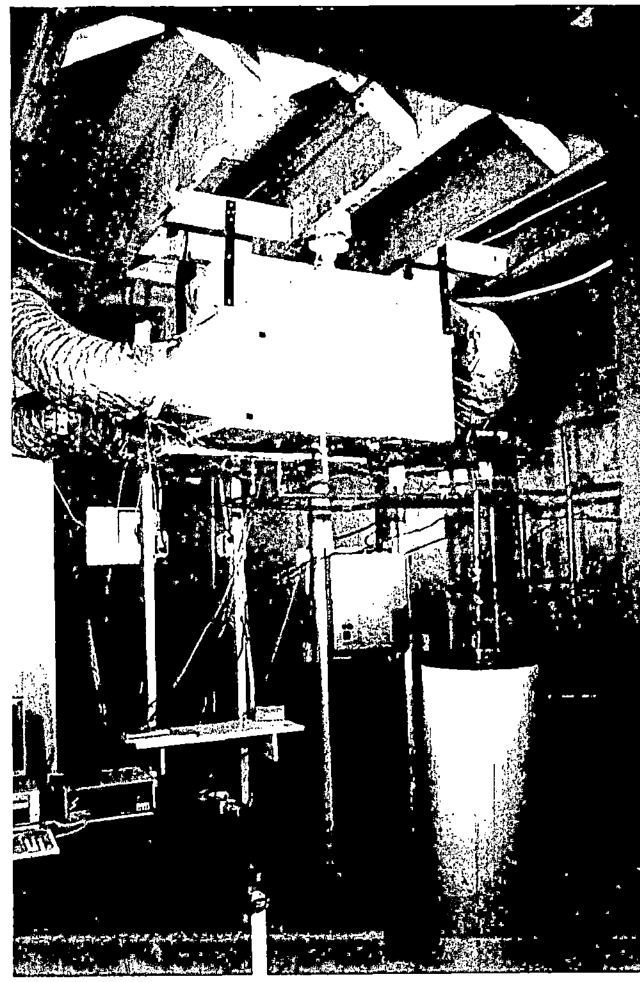


1) Front View of Clearwater House

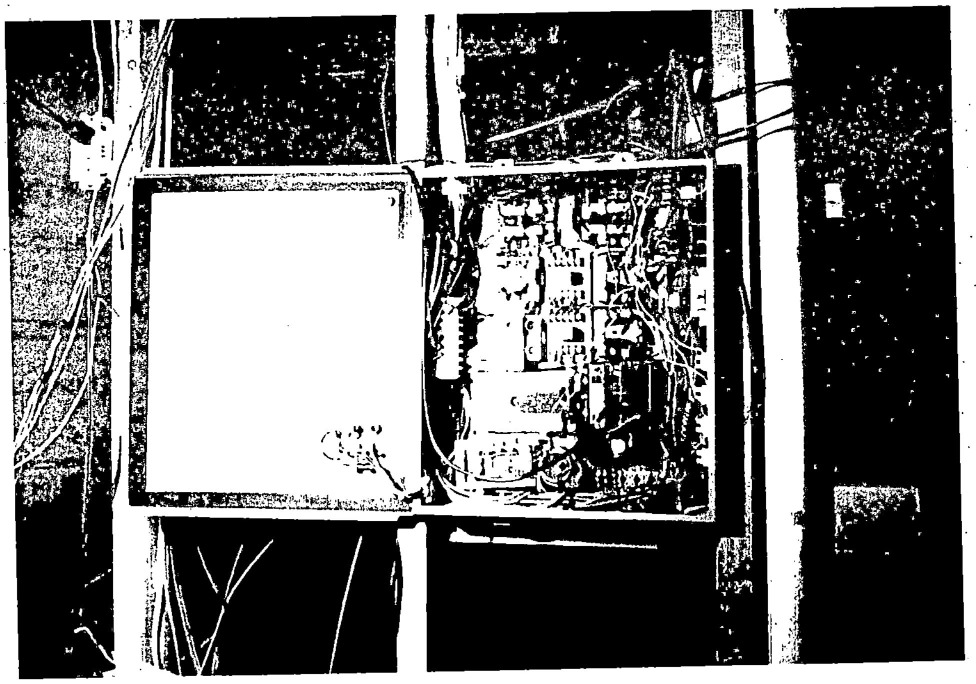
2) View of Supply/Exhaust Hoods on Northwest Elevation



3) AMMs 1 & 2 Mounted in Boiler Room

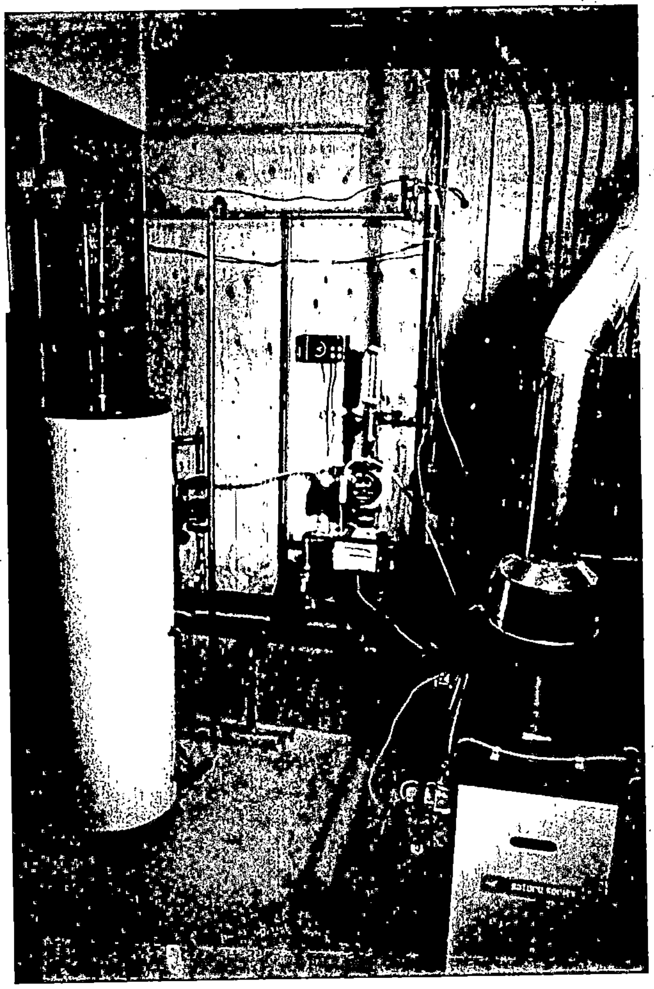


4) Central Exhaust Ventilator (CEV) in Attic

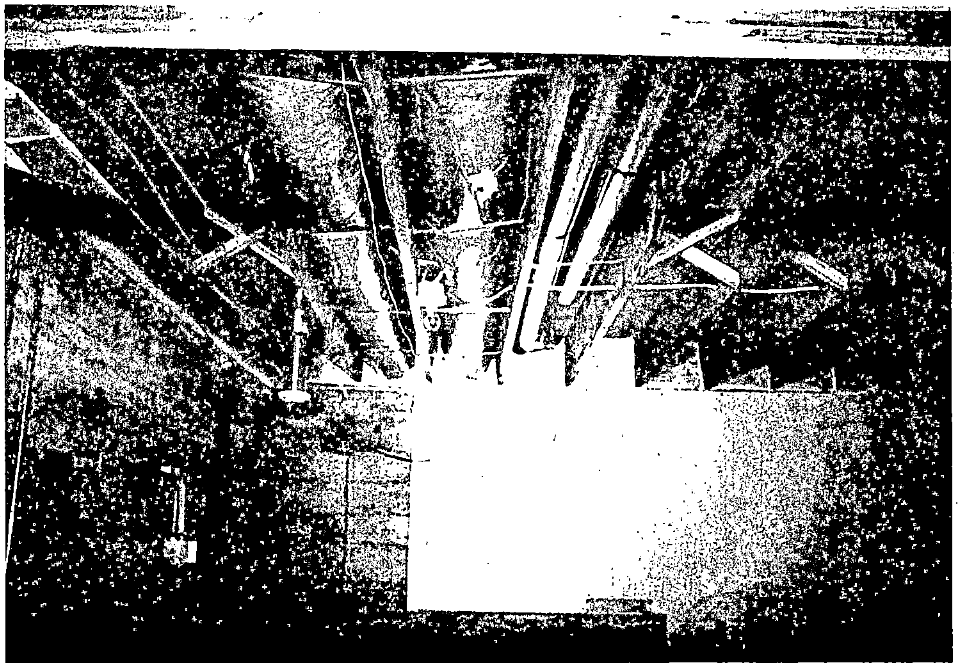


5) Central Control Box in Boiler Room

6) Boiler Room Layout



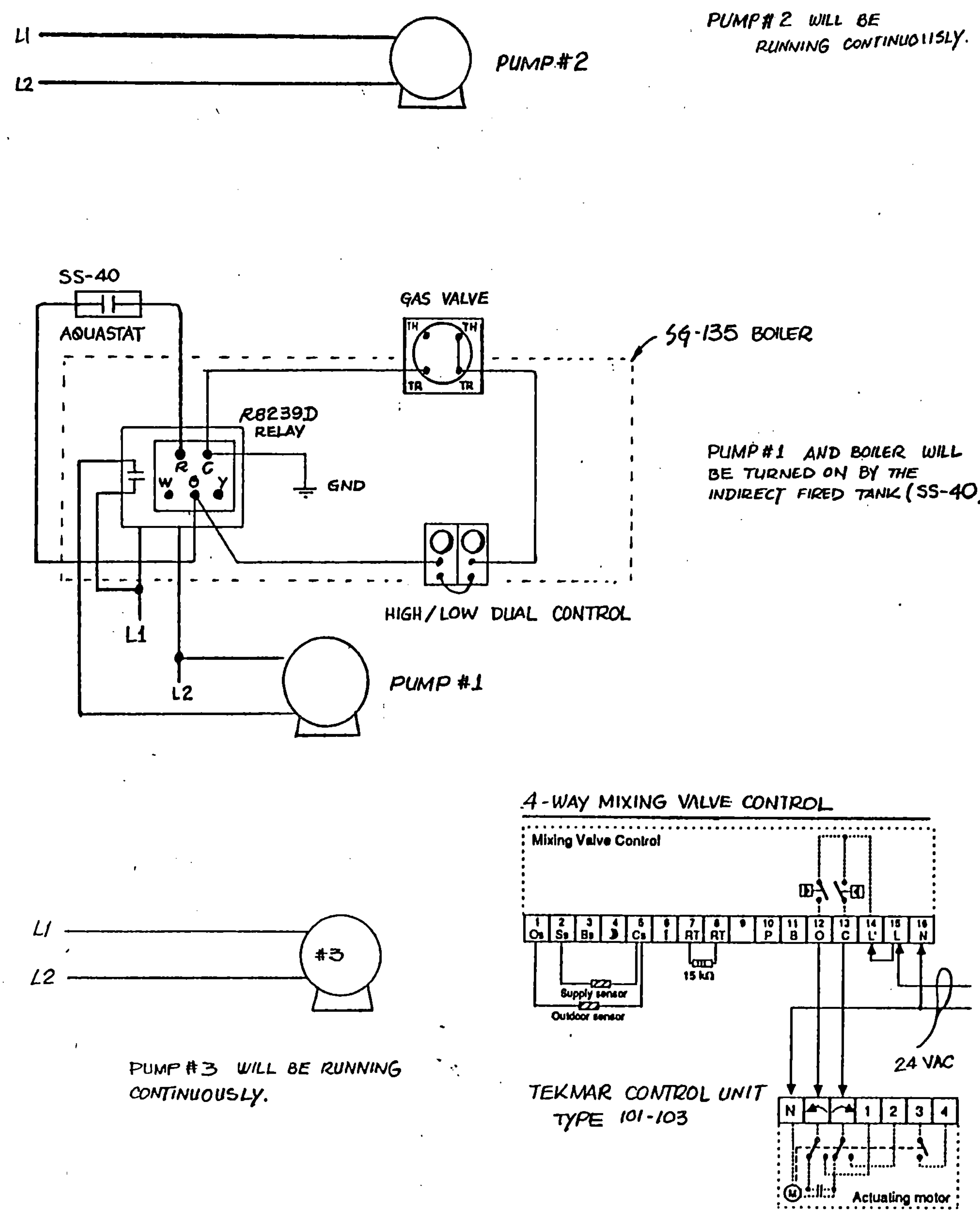
7) External Wall-mounted Controls in Central Hallway



8) Insulated Supply-air Ducting in Basement Ceiling

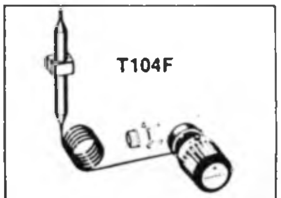
APPENDIX 2

ENGINEERING SPECIFICATIONS & PERFORMANCE DATA



REV. & COMM.		
	Dwg. No. FC-W-010-01	ALLIED ENGINEERING COMPANY DIV. OF E-Z-RECT MANUFACTURING LTD.
	Scale NTS	
	Date 20 APRIL 89	For SHELTAIR R&D PROJECT
	Drawn By WCC	Title WIRING DIAGRAM -
	Check By	

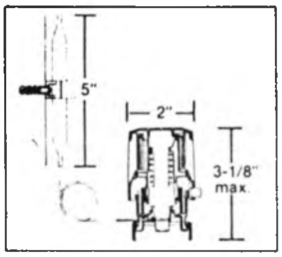
Thermostatic Control



*T104A & F controls are limited to the * mark. The limit may be adjusted to other settings.

Description

The T104F control is used with a V110 valve body to control radiators, convectors or baseboard heating units. The control is self powered and requires no electrical connections. T104F thermostats are made up of a setpoint dial and actuator, connected by capillary tube to a sensor. The setpoint dial and actuator are mounted on the valve body, and the sensor is mounted separately. The setpoint dial has reference marks (1-5) and when turned clockwise to the stop (*frostmark) maintains a temperature of 9° C (48° F). NOTE: To turn to the "0" mark an internal stop must be removed. The red button represents a setpoint limit of approximately 20° C (68° F). Higher settings can be made by holding in the button while turning.



The T104F actuator/setpoint is attached to the valve body by a threaded ring, and may be positioned at any angle. The remote sensor is installed beneath the heating coils in the cold air return, or on a nearby wall where air flow is not restricted. (See typical installations for details.)

Specifications

The T104F control is constructed of industrial grade plastics with low thermal conductivity. The fastening ring is of plated brass, with some internal parts of other metals. The thermostatic sensor is protected against excess temperatures to 52° C (125° F). Capillary length: 2m (6'8"). Temperature range: 9-28° C (48-83° F).

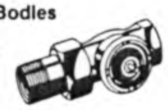
Reference Guide

	0	•	1	2	3	4	5
°C	off	9	16	18	20	22	24
°F	off	48	61	64	68	72	75

This guide shows setpoint temperatures under ideal conditions. Because factors affecting temperature at the sensor vary for each installation, it may be necessary to adjust the setpoint higher or lower to achieve the desired space temperature.

Valve Bodies

V110D



V110E

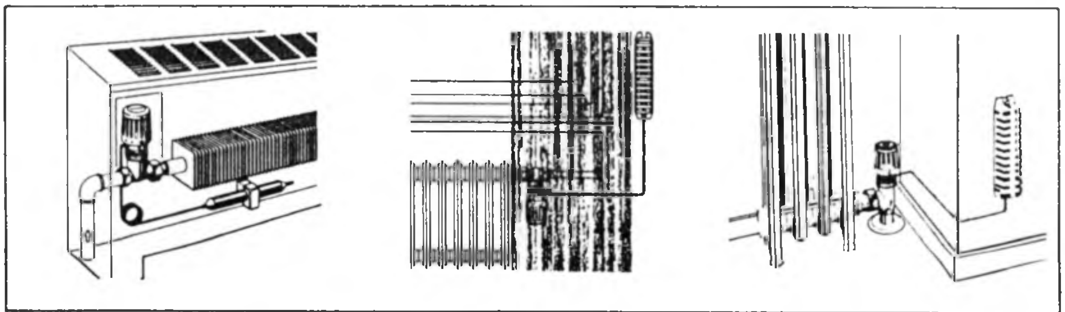
V110F

Installation

Note 1. When installing T104F controls, ensure that the bosses on the control base fit into the grooves in the valve body. Hand tighten the knurled ring firmly. Improper mounting of the control can cause overheating.

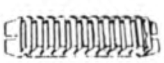
Note 2. T104F controls can be installed inside enclosures, providing the sensor is located a minimum of 3" beneath the heating coils, in the cold air return. Excess capillary tubing should be coiled beneath and away from the heating coils. Care should be taken not to break, kink or sharply bend the capillary tubing.

Typical Installations



Accessories

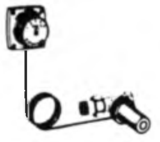
Bulbguard G111B103 — for protection of sensor when mounted on wall.



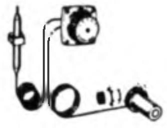
Other controls available

T104A — with internal sensor
T104B — with remote sensor/setpoint
T104C — with remote sensor and remote setpoint
T104V — with internal sensor, tamper resistant setpoint

T104A



T104B



T104C

T104V

Form No. 95C-10475
Residential & Building Controls Group

Honeywell Braukmann

T104A and T104F (also T100A, T100F) non-electric thermostatic controls are supplied with an adjustable range limiting pin (additional pins available). The pin is factory set to limit the low range of the control to the * mark. (see fig. 1) The pin can be moved to a different limit, lock point, or removed. A second pin may be inserted when both high and low limits are desired.

TO SET LIMIT different from that set at the factory, use the following procedures:

1. Determine the temperature range limit desired, or locking temperature, and the corresponding number on the adjustment knob (fig. 1).
2. Lift end cap from adjustment knob (fig. 2).
3. Remove adjustment knob from actuator as follows:
   A. Turn knob to align desired high limit number (or desired lock point) on knob, with white line on actuator base.
   B. Pull knob off head or insert screwdriver in one of 3 slots in base (fig. 3) and pry up against knob.

TO LIMIT RANGE

4. Push pin up and slide to correct slot which provides desired temperature limit (fig. 4). (Insert additional pin at drop-in point and slide to correct slot for 2nd limit.)
   Example: If desired temperature range is 16°C to 24°C (61°F to 75°F), place one pin in slot 1 and one pin in slot 5.
   Example: If desired temperature range is OFF to 20°C (OFF to 68°F), place one pin in slot 3 and *remove* other pin to allow knob to be set a 0 (OFF position).
5. To replace adjustment knob, realign high limit number from step 3A with white line on base and push knob towards base, making sure all three arm clips snap in place at top of adjustment knob.
6. Replace end cap.

TO LOCK CONTROL AT SINGLE TEMPERATURE

See steps 1-3 above.

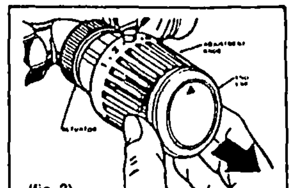
4a. Insert pin in slot 2.

5a. To replace adjustment knob, align red button (not number from step 3A) with white line on base and push knob towards base, making sure all three arm clips snap in place at top of adjustment knob.

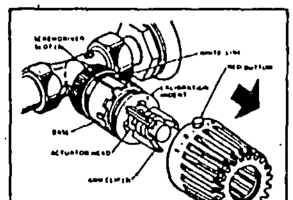
6a. Replace end cap.

TO RECALIBRATE CONTROL

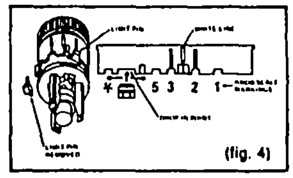
1. Remove end cap and actuator knob as in steps 2 and 3B above.
2. Turn actuator head clockwise until it stops (fig. 3). Turn actuator head counterclockwise one turn (approx.) until calibration indent on head aligns with white line on base.
   NOTE: *Distance between activator head and static portion of the control should now measure approx. 9mm (.35").*
3. To replace adjustment knob, align red button with white line on base and push knob towards base, making sure all three arm clips snap in place at top of adjustment knob.
4. Replace end cap.



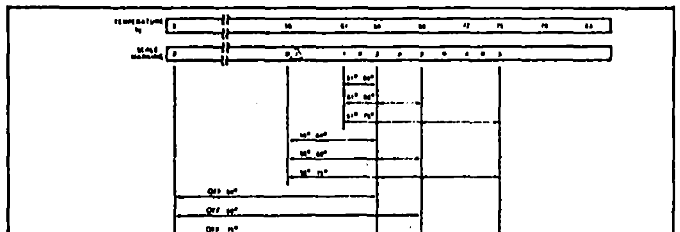
(fig. 2)



(fig. 3)



(fig. 4)



(fig. 1)

*' MARK REPRESENTS 9°C (48°F).

Trouble Shooting List

SYMPTOM	POSSIBLE REASON	SOLUTION
Not all sections of radiator heating up	1. Many radiators are over-sized and all sections are not required to heat up to maintain the set room temperature.	1. System is 'A' OK.
Underheating	2. Sensor in the wrong location. 3. T104A or T104V control mounted in vertical position. 4. Capillary tube excess is coiled above or too near heat source. 5. Flow through valve is in the wrong direction. 6. Inadequate system temperature or pressure. 7. Steam traps defective. 8. Air lock in hot water system. 9. Scale or debris blocking flow. 10. Heating cabinet dampers are closed.	2. Change sensor location, or change control type. See installation instructions. 3. These control types must be mounted horizontally. 4. Coil below or away from heat source. 5. Check arrow on valve body. It should be in the direction of flow. Change valve direction, or flow direction. 6. Check operating and limiting controls on boiler Check circulating pump and isolating valves. 7. Repair or replace traps. 8. Open valve fully to allow air to pass. Install vents. 9. Flush system. Do not use oil base additives. 10. Open or remove dampers
Overheating	11. Sensor in the wrong location. 12. Control not properly installed. 13. Capillary tube broken, kinked, or bent sharply. 14. Dirt or scale under seat, preventing tight shutoff. 15. Flow through valve is in the wrong direction, damaging the valve seat. 16. Steam traps defective. 17. Excessive differential pressure is forcing valve open. (Hot water systems)	11. Change sensor location, or change control type 12. Set bosses in grooves (A & F models) and tighten knurled ring to valve body 13. Replace control. 14. Remove control from valve body, allowing valve to open fully and flush away scale and debris. Reinstall control and turn fully clockwise. If valve does not fully close, remove control and inspect valve seat area using cartridge changer tool or service socket tool. 15. Check arrow on valve body. It should be in the direction of flow. Change valve direction, or flow direction. Remove valve cartridge and inspect for damage to seat disc. 16. Repair or replace traps. 17. Install differential pressure regulator to maintain less than 117 kPa (17 psi) defferential between supply and return pipes (D146A).
Chattering or knocking	18. Flow through valve is in wrong direction. 19. Vacuum in system. 20. Excessive differential pressure. 21. Binding of piping.	18. Check arrow on valve body It should be in the direction of flow. Change valve direction, or flow direction. 19. Steam — check traps and vents. Hot water — check expansion tank operation and location. 20. Install differential pressure regulator to maintain less than 117 kPa (17 psi) differential between supply and return pipes (D146A). 21. Ensure adequate space for piping.

For further information, contact:

Area Representative — OR

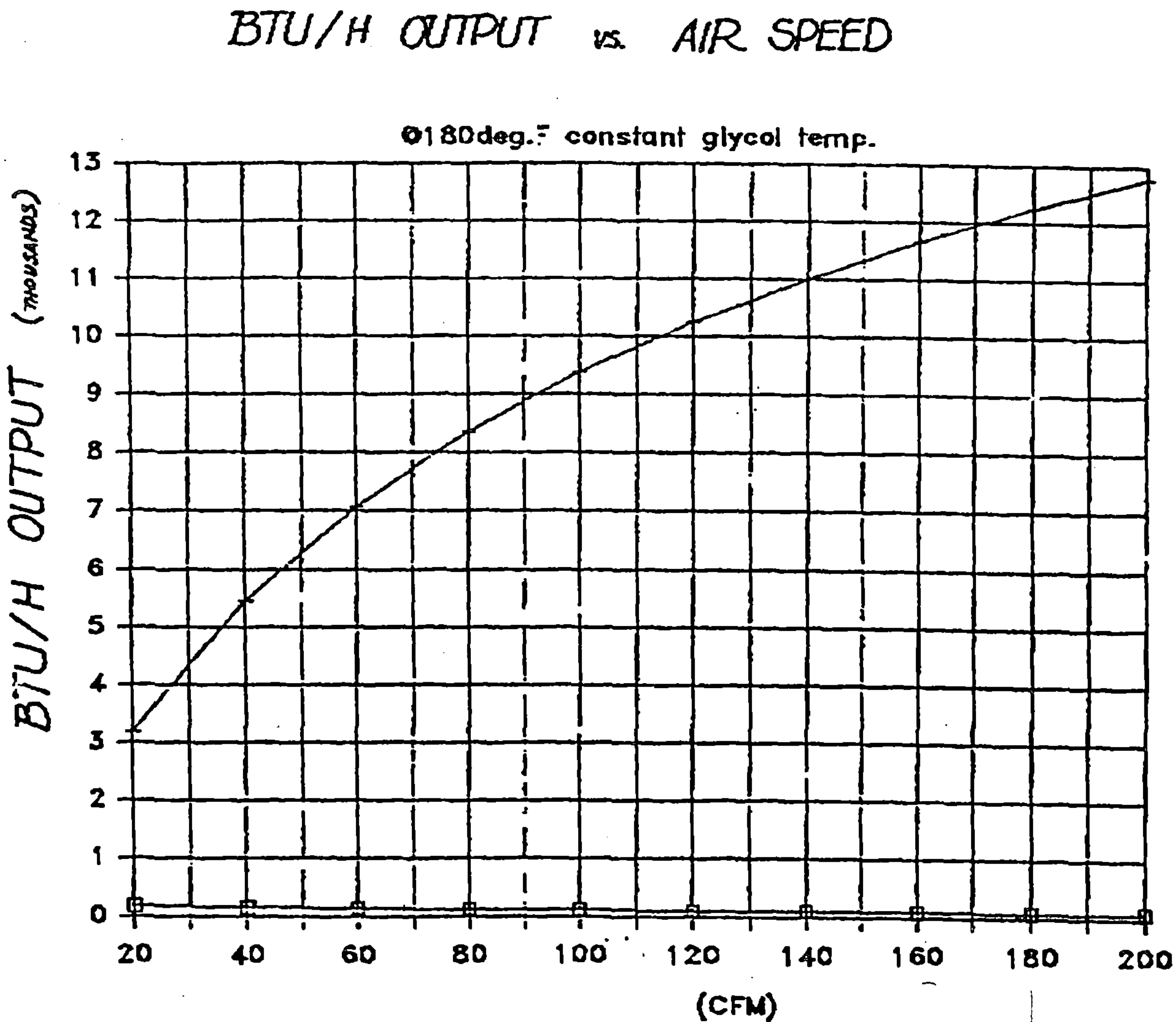
Honeywell Braukmann
740 Ellesmere Road
Scarborough, Ontario
M1P 2V9

Table A1:

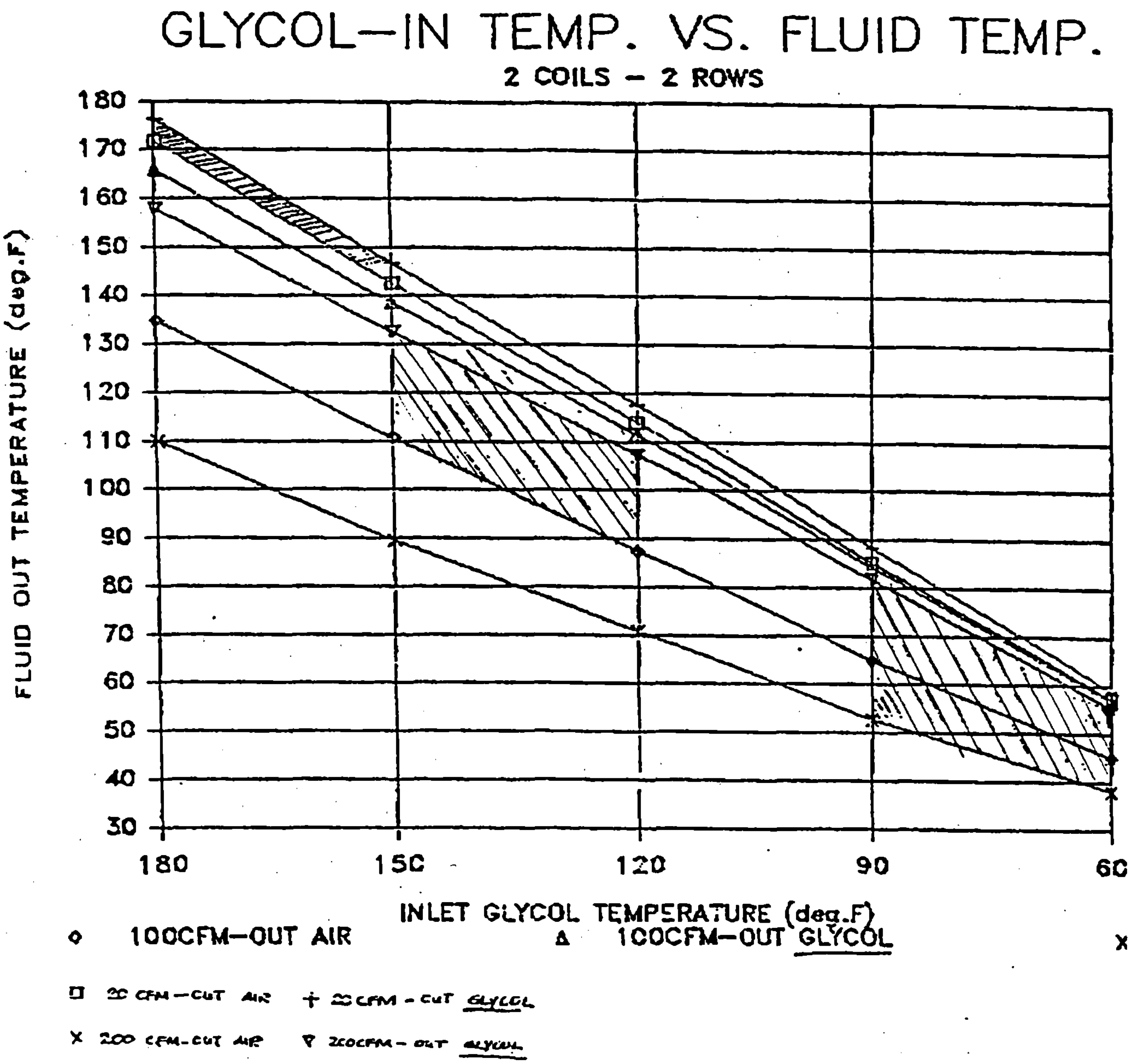
Design Heat Output of AMM 1 & AMM2 Heat Exchangers
@ 25 C Outlet Air Temperature

Before Coil Temperature	High speed	Medium speed AMM1 (2 Coils)	Low Speed	High speed AMM2 (1 Coils)
(C)	(115 L/s)	(70 L/s)	(40 L/s)	(105 L/s)
	(kW)	(kW)	(kW)	(kW) *
-30	7.62	4.64	2.65	-
-25	6.93	4.22	2.41	-
-20	6.24	3.80	2.17	-
-15	5.54	3.37	1.93	-
-10	4.85	2.95	1.69	-
-5	4.16	2.53	1.45	3.80
0	3.46	2.11	1.21	3.16
5	2.77	1.69	0.96	2.53
10	2.08	1.27	0.72	1.90

* Based on design specifications AMM2 with only 1 circuit, can produce a maximum of 3.7 k @ 80 C heating fluid temperature. The highest available temperature rise is 30 C.

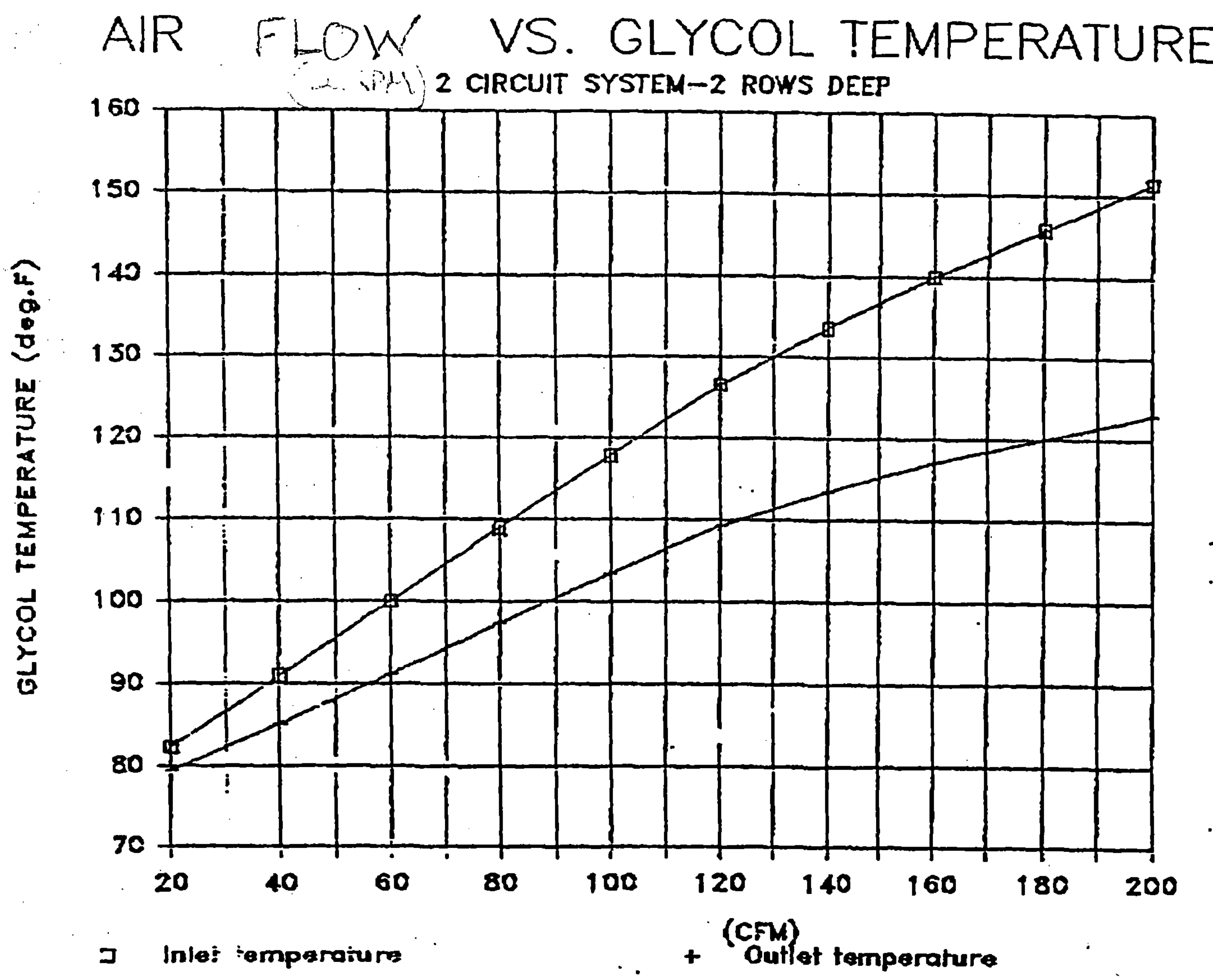


Graph A1: Heat Output of Single Coil Heat Exchanger @ Constant Glycol Temperature (80 C)

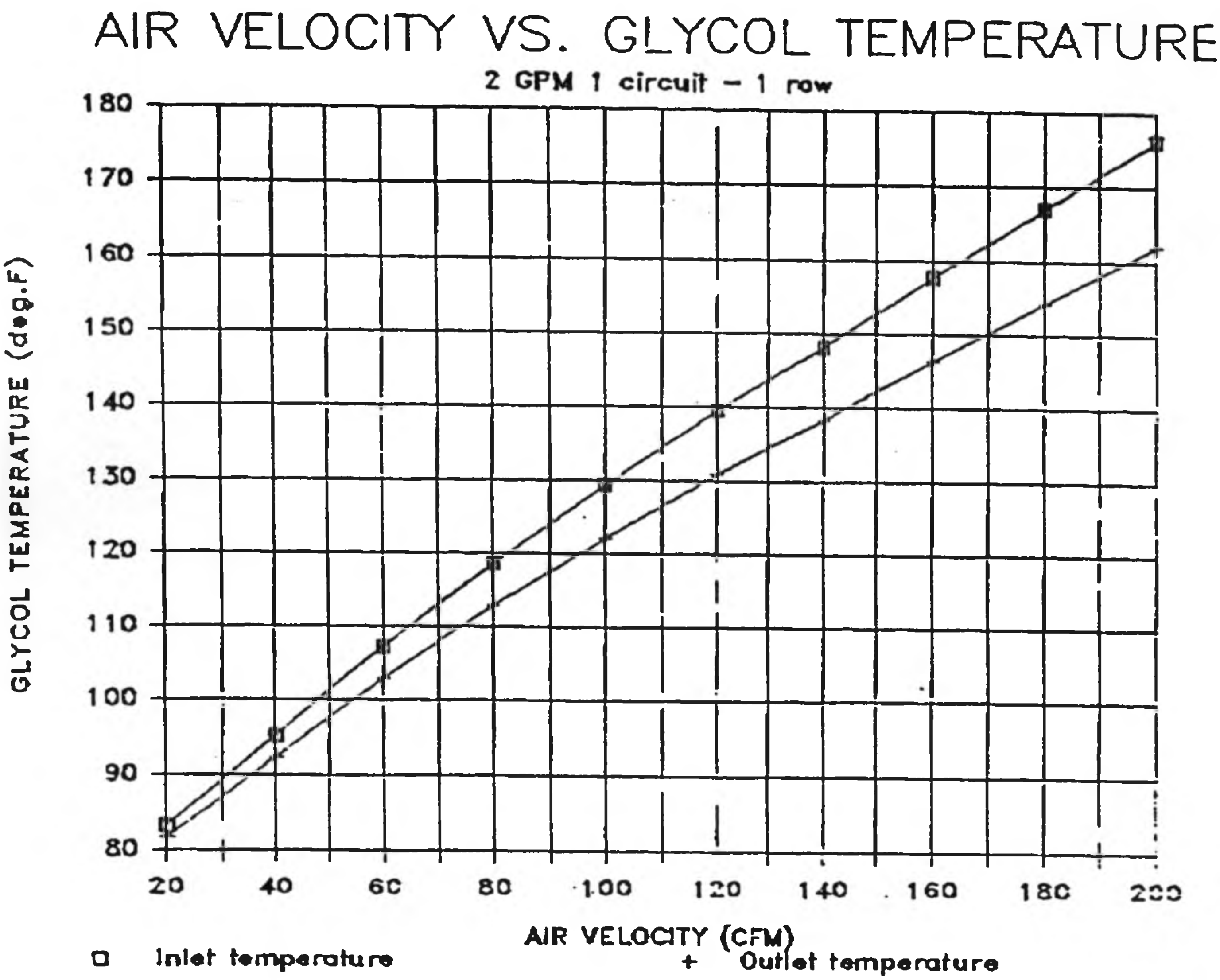


Graph A2: Air & Glycol Exit Temp. vs Inlet Glycol Temperature for AMM 1 (2 coil system)

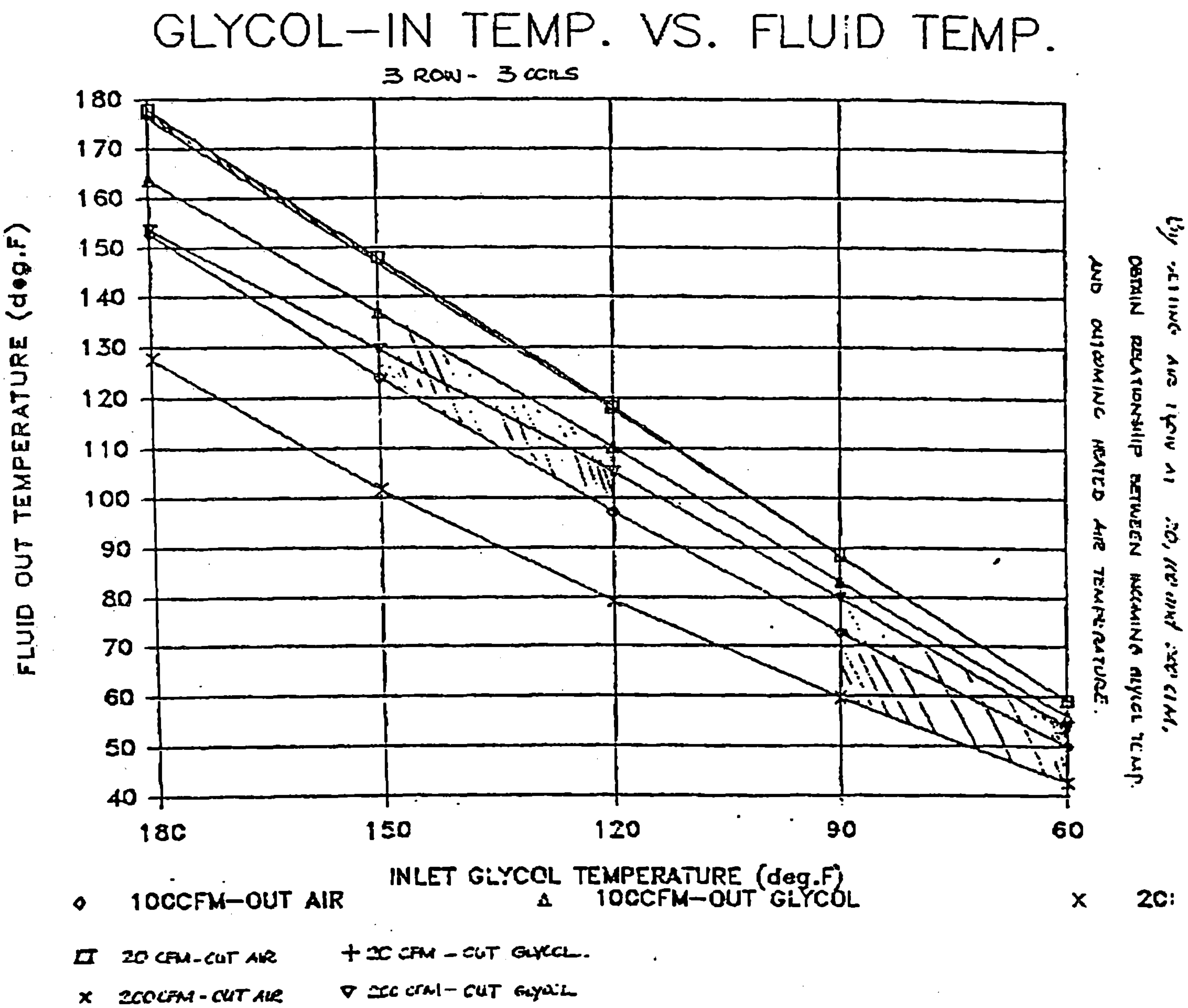
The graph shows exit air and glycol temperatures on the y-axis and inlet glycol temperature on the x-axis. Three sets of curves are shown in this graph: each set contains one air exit temperature and one glycol outlet temperature curve. The shaded areas represent simply an attempt to distinguish these three sets of data. For instance, the curve consisting of square markers and the curve consisting of plus '+' markers represent a set of curves showing the relationship among exit air and outlet glycol temperatures as a function of the inlet glycol temperature.



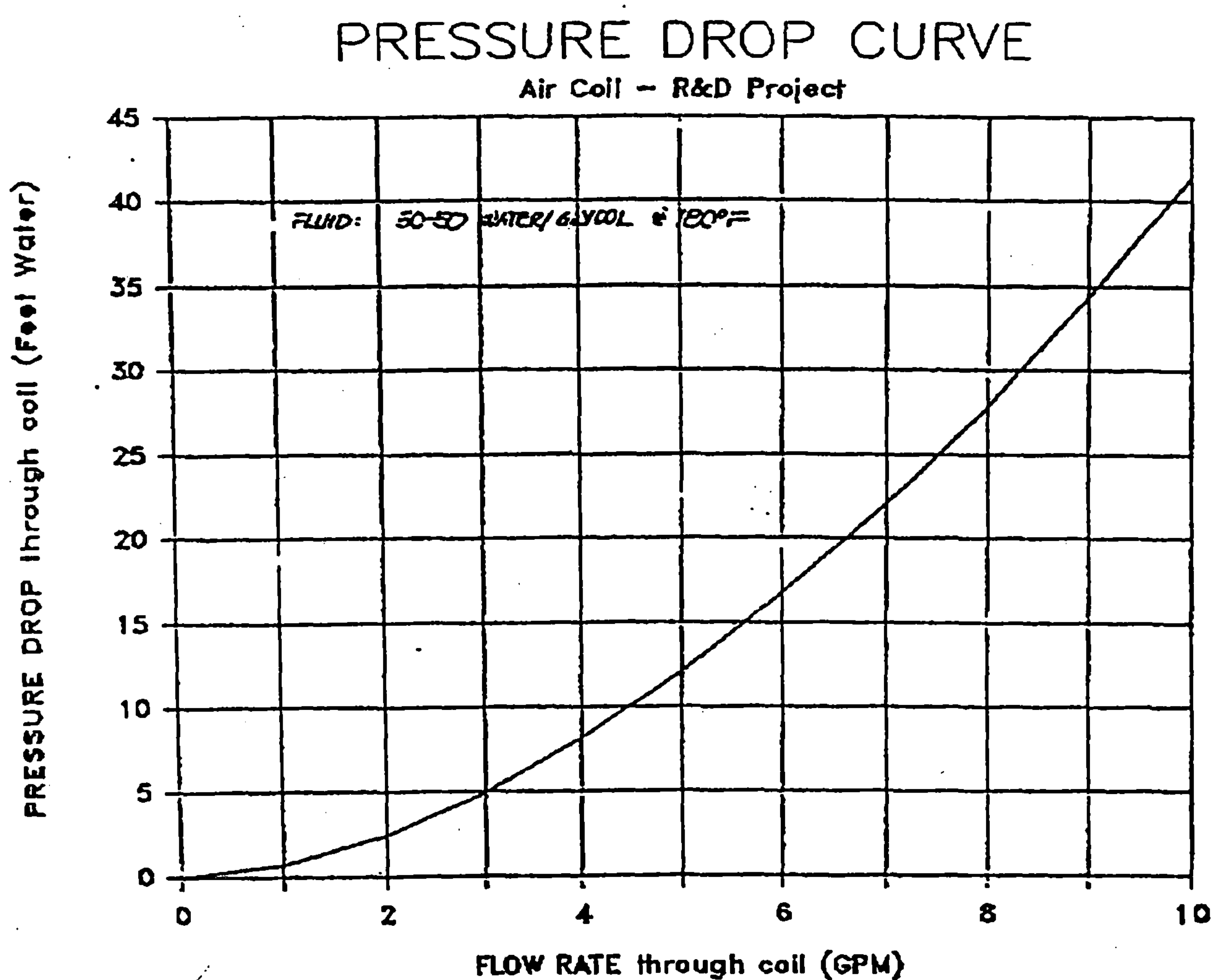
Graph A3: Air Flow vs Glycol Inlet & Exit Temperatures for AMM 1 with Glycol Flow of 2 USgpm (2 coil system)



Graph A4: Air Flow vs Glycol Inlet & Exit Temperatures for AMM 2 with Glycol Flow of 2 USgpm (1 coil system)



Graph A5: Air & Glycol Exit Temp. vs Inlet Glycol Temperature
Same as graph A2 but for hypothetical 3 coil system



Graph A6: Pressure Drop Curve; Resistance to glycol flow through a single coil heat exchanger

APPENDIX 3

PRESSURE CONTROL TRUTH TABLES AND CONTROL LOGIC WIRING

Table 4a: House Depressurization Potential Without Use of AMM1 & AMM2(using manufacturer specified air flows)									
Condition(No Ventilation ON)	dP F326	dP Hse	Imbalance	CEV	Dndrft	Dry	Vac	FP1	FP2
	(Pa)	(Pa)	(L/s)	L/s-->					
Downdraft in Use	-29.5	-7.2	-150	0	-150	0	0	0	0
Dryer Only	-11.0	-2.8	-75	0	0	-75	0	0	0
Vacuum Only	-4.5	-1.2	-40	0	0	0	-40	0	0
FP1	-11.0	-2.8	-75	0	0	0	0	-75	0
FP2	-6.2	-1.6	-50	0	0	0	0	0	-50
Dndrft+Dryer	-52.7	-12.6	-225	0	-150	-75	0	0	0
Dndrft+Vacuum	-41.4	-10.0	-190	0	-150	0	-40	0	0
Dndrft+FP1	-52.7	-12.6	-225	0	-150	0	0	-75	0
Dndrft+FP2	-44.6	-10.7	-200	0	-150	0	0	0	-50
Dndrft+Dryer+Vac	-66.6	-15.8	-265	0	-150	-75	-40	0	0
Dndrft+Dryer+FP1	-79.5	-18.7	-300	0	-150	-75	0	-75	0
Dndrft+Dryer+FP2	-70.2	-16.6	-275	0	-150	-75	0	0	-50
Dndrft+Dryer+Vac+FP1	-95.1	-22.2	-340	0	-150	-75	-40	-75	0
Dndrft+Dryer+Vac+FP2	-85.3	-20.0	-315	0	-150	-75	-40	0	-50
Dndrft+Dryer+Vac+FP1+FP2	-115.7	-26.8	-390	0	-150	-75	-40	-75	-50
Dndrft+Dryer+FP1+FP2	-99.1	-23.1	-350	0	-150	-75	0	-75	-50
Dndrft+Vac+FP1	-66.6	-15.8	-265	0	-150	0	-40	-75	0
Dndrft+Vac+FP2	-57.8	-13.8	-240	0	-150	0	-40	0	-50
Dndrft+Vac+FP1+FP2	-85.3	-20.0	-315	0	-150	0	-40	-75	-50
Dndrft+FP1+FP2	-70.2	-16.6	-275	0	-150	0	0	-75	-50
Dryer+Vac	-20.2	-5.0	-115	0	0	-75	-40	0	0
Dryer+FP1	-29.5	-7.2	-150	0	0	-75	0	-75	0
Dryer+FP2	-22.8	-5.6	-125	0	0	-75	0	0	-50
Dryer+Vac+FP1	-41.4	-10.0	-190	0	0	-75	-40	-75	0
Dryer+Vac+FP2	-33.9	-8.2	-165	0	0	-75	-40	0	-50
Dryer+Vac+FP1+FP2	-57.8	-13.8	-240	0	0	-75	-40	-75	-50
Dryer+FP1+FP2	-44.6	-10.7	-200	0	0	-75	0	-75	-50
Vac+FP1	-20.2	-5.0	-115	0	0	0	-40	-75	0
Vac+FP2	-14.2	-3.6	-90	0	0	0	-40	0	-50
Vac+FP1+FP2	-33.9	-8.2	-165	0	0	0	-40	-75	-50
FP1+FP2	-22.8	-5.6	-125	0	0	0	0	-75	-50
Notes:									
dP F326 - Depressurization predicted based on F326 airtightness values									
dP Hse - Depressurization predicted based on measured airtightness values									

Table 4a: House Depressurization Potential Without Use of AMM1 & AMM2(using manufacturer specified air flows)(CONT'D)									
Condition(Normal Operation)	dP F326	dP Hse	Imbalance	CEV	Dndrft	Dry	Vac	FP1	FP2
	(Pa)	(Pa)	(L/s)	L/s-->					
Normal Operation	-9.9	-2.5	-70	-70	0	0	0	0	0
Normal Operation+Dndrft	-51.1	-12.2	-220	-70	-150	0	0	0	0
Normal Operation+Dryer	-28.1	-6.9	-145	-70	0	-75	0	0	0
Normal Operation+Vacuum	-19.0	-4.7	-110	-70	0	0	-40	0	0
Normal Operation+FP1	-28.1	-6.9	-145	-70	0	0	0	-75	0
Normal Operation+FP2	-21.5	-5.3	-120	-70	0	0	0	0	-50
Normal Operation+Dndrft+Dryer	-77.6	-18.3	-295	-70	-150	-75	0	0	0
Normal Operation+Dndrft+Vacuum	-64.8	-15.4	-260	-70	-150	0	-40	0	0
Normal Operation+Dndrft+FP1	-77.6	-18.3	-295	-70	-150	0	0	-75	0
Normal Operation+Dndrft+FP2	-68.4	-16.2	-270	-70	-150	0	0	0	-50
Normal Operation+Dndrft+Dryer+Vac	-93.1	-21.8	-335	-70	-150	-75	-40	0	0
Normal Operation+Dndrft+Dryer+Vac+FP1	-124.3	-28.7	-410	-70	-150	-75	-40	-75	0
Normal Operation+Dndrft+Dryer+Vac+FP2	-113.6	-26.3	-385	-70	-150	-75	-40	0	-50
Normal Operation+Dndrft+Dryer+Vac+FP1+FP2	-146.5	-33.6	-460	-70	-150	-75	-40	-75	-50
Normal Operation+Dndrft+Dryer+FP1	-107.3	-24.9	-370	-70	-150	-75	0	-75	0
Normal Operation+Dndrft+Dryer+FP2	-97.1	-22.7	-345	-70	-150	-75	0	0	-50
Normal Operation+Dndrft+Dryer+FP1+FP2	-97.1	-22.7	-345	-70	-150	-75	0	0	-50
Normal Operation+Dndrft+Vac+FP1	-93.1	-21.8	-335	-70	-150	0	-40	-75	0
Normal Operation+Dndrft+Vac+FP2	-68.4	-16.2	-270	-70	-150	0	0	0	-50
Normal Operation+Dndrft+Vac+FP1+FP2	-113.6	-26.3	-385	-70	-150	0	-40	-75	-50
Normal Operation+Dndrft+FP1+FP2	-97.1	-22.7	-345	-70	-150	0	0	-75	-50
Normal Operation+Dryer+Vac	-56.1	-13.4	-235	-70	0	-75	-40	0	-50
Normal Operation+Dryer+FP1	-68.4	-16.2	-270	-70	0	-75	0	-75	-50
Normal Operation+Dryer+FP2	-43.0	-10.3	-195	-70	0	-75	0	0	-50
Normal Operation+Dryer+FP1+FP2	-68.4	-16.2	-270	-70	0	-75	0	-75	-50
Normal Operation+Dryer+Vac+FP1	-64.8	-15.4	-260	-70	0	-75	-40	-75	0
Normal Operation+Dryer+Vac+FP2	-56.1	-13.4	-235	-70	0	-75	-40	0	-50
Normal Operation+Dryer+Vac+FP1+FP2	-83.3	-19.6	-310	-70	0	-75	-40	-75	-50
Normal Operation+Vac+FP1	-56.1	-13.4	-235	-70	0	0	-40	-75	-50
Normal Operation+Vac+FP2	-32.4	-7.9	-160	-70	0	0	-40	0	-50
Normal Operation+Vac+FP1+FP2	-56.1	-13.4	-235	-70	0	0	-40	-75	-50
Normal Operation+FP1+FP2	-43.0	-10.3	-195	-70	0	0	0	-75	-50
Notes:									
dP F326 - Depressurization predicted based on F326 airtightness values									

Table 4a: House Depressurization Potential Without Use of AMM1 & AMM2(using manufacturer specified air flows)(CONT'D)									
Condition(RH>Setpoint)	dP F326	dP Hse	Imbalance	CEV	Dndrft	Dry	Vac	FP1	FP2
	(Pa)	(Pa)	(L/s)	L/s-->					
RH>Setpoint	-21.5	-5.3	-120	-120	0	0	0	0	0
RH>Setpoint+Dndrft	-68.4	-16.2	-270	-120	-150	0	0	0	0
RH>Setpoint+Dryer	-43.0	-10.3	-195	-120	0	-75	0	0	0
RH>Setpoint+Vacuum	-32.4	-7.9	-160	-120	0	0	-40	0	0
RH>Setpoint+FP1	-43.0	-10.3	-195	-120	0	0	0	-75	0
RH>Setpoint+FP2	-35.3	-8.6	-170	-120	0	0	0	0	-50
RH>Setpoint+Dndrft+Dryer	-97.1	-22.7	-345	-120	-150	-75	0	0	0
RH>Setpoint+Dndrft+Vacuum	-83.3	-19.6	-310	-120	-150	0	-40	0	0
RH>Setpoint+Dndrft+FP1	-97.1	-22.7	-345	-120	-150	0	0	-75	0
RH>Setpoint+Dndrft+FP2	-87.2	-20.4	-320	-120	-150	0	0	0	-50
RH>Setpoint+Dndrft+Dryer+Vac	-113.6	-26.3	-385	-120	-150	-75	-40	0	0
RH>Setpoint+Dndrft+Dryer+Vac+FP1	-146.5	-33.6	-460	-120	-150	-75	-40	-75	0
RH>Setpoint+Dndrft+Dryer+Vac+FP2	-135.2	-31.1	-435	-120	-150	-75	-40	0	-50
RH>Setpoint+Dndrft+Dryer+Vac+FP1+FP2	-169.7	-38.8	-510	-120	-150	-75	-40	-75	-50
RH>Setpoint+Dndrft+Dryer+FP1	-128.6	-29.7	-420	-120	-150	-75	0	-75	0
RH>Setpoint+Dndrft+Dryer+FP2	-117.8	-27.3	-395	-120	-150	-75	0	0	-50
RH>Setpoint+Dndrft+Dryer+FP1+FP2	-117.8	-27.3	-395	-120	-150	-75	0	0	-50
RH>Setpoint+Dndrft+Vac+FP1	-113.6	-26.3	-385	-120	-150	0	-40	-75	0
RH>Setpoint+Dndrft+Vac+FP2	-87.2	-20.4	-320	-120	-150	0	0	0	-50
RH>Setpoint+Dndrft+Vac+FP1+FP2	-135.2	-31.1	-435	-120	-150	0	-40	-75	-50
RH>Setpoint+Dndrft+FP1+FP2	-117.8	-27.3	-395	-120	-150	0	0	-75	-50
RH>Setpoint+Dryer+Vac	-73.9	-17.4	-285	-120	0	-75	-40	0	-50
RH>Setpoint+Dryer+FP1	-87.2	-20.4	-320	-120	0	-75	0	-75	-50
RH>Setpoint+Dryer+FP2	-59.6	-14.2	-245	-120	0	-75	0	0	-50
RH>Setpoint+Dryer+FP1+FP2	-87.2	-20.4	-320	-120	0	-75	0	-75	-50
RH>Setpoint+Dryer+Vac+FP1	-83.3	-19.6	-310	-120	0	-75	-40	-75	0
RH>Setpoint+Dryer+Vac+FP2	-73.9	-17.4	-285	-120	0	-75	-40	0	-50
RH>Setpoint+Dryer+Vac+FP1+FP2	-103.2	-24.0	-360	-120	0	-75	-40	-75	-50
RH>Setpoint+Vac+FP1	-73.9	-17.4	-285	-120	0	0	-40	-75	-50
RH>Setpoint+Vac+FP2	-47.8	-11.5	-210	-120	0	0	-40	0	-50
RH>Setpoint+Vac+FP1+FP2	-73.9	-17.4	-285	-120	0	0	-40	-75	-50
RH>Setpoint+FP1+FP2	-59.6	-14.2	-245	-120	0	0	0	-75	-50

Notes:

dP F326 - Depressurization predicted based on F326 airtightness values

dP Hse - Depressurization predicted based on measured airtightness values

Table 4b: House Depressurization Potential With Use of AMM1 & AMM2 and interlock system(using manufacturer specified air flows)

Condition(Normal Operation)	dP F326	dP Hse	Imbalance	OVERRIDE	AMM1	AMM2	CEV	Dndrft	Dry	Vac	FP1	FP2
	(Pa)	(Pa)	(L/s)	USED	L/s-->							
Normal Operation	0.0	0.0	0		70	0	-70	0	0	0	0	0
Normal Operation+Dndrft	8.0	2.0	60		120	120	-30	-150	X	X	0	0
Normal Operation+Dryer	1.1	0.3	15		120	0	-30	X	-75	X	0	0
Normal Operation+Vacuum	6.2	1.6	50		120	0	-30	X	X	-40	0	0
Normal Operation+FP1	1.1	0.3	15		120	0	-30	0	0	0	-75	0
Normal Operation+FP2	4.5	1.2	40		120	0	-30	0	0	0	0	-50
Normal Operation+Dndrft+Dryer	-1.1	-0.3	-15	Y	120	120	-30	-150	-75	X	0	0
Normal Operation+Dndrft+Vacuum	1.7	0.5	20	Y	120	120	-30	-150	X	-40	0	0
Normal Operation+Dndrft+FP1	-1.1	-0.3	-15		120	120	-30	-150	X	X	-75	0
Normal Operation+Dndrft+FP2	0.6	0.2	10		120	120	-30	-150	X	X	0	-50
Normal Operation+Dndrft+Dryer+Vac	-7.0	-1.8	-55	Y	120	120	-30	-150	-75	-40	0	0
Normal Operation+Dndrft+Dryer+Vac+FP1	-24.1	-5.9	-130	Y	120	120	-30	-150	-75	-40	-75	0
Normal Operation+Dndrft+Dryer+Vac+FP2	-17.8	-4.4	-105	Y	120	120	-30	-150	-75	-40	0	-50
Normal Operation+Dndrft+Dryer+Vac+FP1+FP2	-38.3	-9.3	-180	Y	120	120	-30	-150	-75	-40	-75	-50
Normal Operation+Dndrft+Dryer+FP1	-14.2	-3.6	-90	Y	120	120	-30	-150	-75	X	-75	0
Normal Operation+Dndrft+Dryer+FP2	-8.9	-2.3	-65	Y	120	120	-30	-150	-75	X	0	-50
Normal Operation+Dndrft+Dryer+FP1+FP2	-26.8	-6.6	-140	Y	120	120	-30	-150	-75	X	-75	-50
Normal Operation+Dndrft+Vac+FP1	-7.0	-1.8	-55	Y	120	120	-30	-150	X	-40	-75	0
Normal Operation+Dndrft+Vac+FP2	-3.0	-0.8	-30	Y	120	120	-30	-150	X	-40	0	-50
Normal Operation+Dndrft+Vac+FP1+FP2	-17.8	-4.4	-105	Y	120	120	-30	-150	X	-40	-75	-50
Normal Operation+Dndrft+FP1+FP2	-8.9	-2.3	-65		120	120	-30	-150	X	X	-75	-50
Normal Operation+Dryer+Vac	-2.3	-0.6	-25	Y	120	0	-30	X	-75	-40	0	0
Normal Operation+Dryer+FP1	-8.0	-2.0	-60		120	0	-30	X	-75	X	-75	0
Normal Operation+Dryer+FP2	-3.7	-1.0	-35		120	0	-30	X	-75	X	0	-50
Normal Operation+Dryer+FP1+FP2	-19.0	-4.7	-110		120	0	-30	X	-75	X	-75	-50
Normal Operation+Dryer+Vac+FP1	-16.6	-4.1	-100	Y	120	0	-30	X	-75	-40	-75	0
Normal Operation+Dryer+Vac+FP2	-11.0	-2.8	-75	Y	120	0	-30	X	-75	-40	0	-50
Normal Operation+Dryer+Vac+FP1+FP2	-29.5	-7.2	-150	Y	120	0	-30	X	-75	-40	-75	-50
Normal Operation+Vac+FP1	-2.3	-0.6	-25		120	0	-30	X	X	-40	-75	0
Normal Operation+Vac+FP2	0.0	0.0	0		120	0	-30	X	X	-40	0	-50
Normal Operation+Vac+FP1+FP2	-11.0	-2.8	-75		120	0	-30	X	X	-40	-75	-50
Normal Operation+FP1+FP2	-3.7	-1.0	-35		120	0	-30	0	0	0	-75	-50

Notes:

dP F326 - Depressurization predicted based on F326 airtightness values

dP Hse - Depressurization predicted based on measured airtightness values

X - Appliance locked out by Controller

OVERRIDE USED - Y = Occupant used manual overide switch

Table 4b: House Depressurization Potential With Use of AMM1 & AMM2 and interlock system(using manufacturer specified air flows)(CONT'D)												
Condition(RH>Setpoint)	dP F326	dP Hse	Imbalance	OVERRIDE	AMM1	AMM2	CEV	Dndrft	Dry	Vac	FP1	FP2
	(Pa)	(Pa)	(L/s)	USED	L/s-->							
RH>Setpoint	0.0	0.0	0		120	0	-120	0	0	0	0	0
RH>Setpoint+Dndrft	8.0	2.0	60		120	120	-30	-150	X	X	0	0
RH>Setpoint+Dryer	1.1	0.3	15		120	0	-30	X	-75	X	0	0
RH>Setpoint+Vacuum	6.2	1.6	50		120	0	-30	X	X	-40	0	0
RH>Setpoint+FP1	1.1	0.3	15		120	0	-30	0	0	0	-75	0
RH>Setpoint+FP2	4.5	1.2	40		120	0	-30	0	0	0	0	-50
RH>Setpoint+Dndrft+Dryer	-1.1	-0.3	-15	Y	120	120	-30	-150	-75	X	0	0
RH>Setpoint+Dndrft+Vacuum	1.7	0.5	20	Y	120	120	-30	-150	X	-40	0	0
RH>Setpoint+Dndrft+FP1	-1.1	-0.3	-15		120	120	-30	-150	X	X	-75	0
RH>Setpoint+Dndrft+FP2	0.6	0.2	10		120	120	-30	-150	X	X	0	-50
RH>Setpoint+Dndrft+Dryer+Vac	-7.0	-1.8	-55	Y	120	120	-30	-150	-75	-40	0	0
RH>Setpoint+Dndrft+Dryer+Vac+FP1	-24.1	-5.9	-130	Y	120	120	-30	-150	-75	-40	-75	0
RH>Setpoint+Dndrft+Dryer+Vac+FP2	-17.8	-4.4	-105	Y	120	120	-30	-150	-75	-40	0	-50
RH>Setpoint+Dndrft+Dryer+Vac+FP1+FP2	-38.3	-9.3	-180	Y	120	120	-30	-150	-75	-40	-75	-50
RH>Setpoint+Dndrft+Dryer+FP1	-14.2	-3.6	-90	Y	120	120	-30	-150	-75	X	-75	0
RH>Setpoint+Dndrft+Dryer+FP2	-8.9	-2.3	-65	Y	120	120	-30	-150	-75	X	0	-50
RH>Setpoint+Dndrft+Dryer+FP1+FP2	-26.8	-6.6	-140	Y	120	120	-30	-150	-75	X	-75	-50
RH>Setpoint+Dndrft+Vac+FP1	-7.0	-1.8	-55	Y	120	120	-30	-150	X	-40	-75	0
RH>Setpoint+Dndrft+Vac+FP2	-3.0	-0.8	-30	Y	120	120	-30	-150	X	-40	0	-50
RH>Setpoint+Dndrft+Vac+FP1+FP2	-17.8	-4.4	-105	Y	120	120	-30	-150	X	-40	-75	-50
RH>Setpoint+Dndrft+FP1+FP2	-8.9	-2.3	-65		120	120	-30	-150	X	X	-75	-50
RH>Setpoint+Dryer+Vac	-2.3	-0.6	-25	Y	120	0	-30	X	-75	-40	0	0
RH>Setpoint+Dryer+FP1	-8.0	-2.0	-60		120	0	-30	X	-75	X	-75	0
RH>Setpoint+Dryer+FP2	-3.7	-1.0	-35		120	0	-30	X	-75	X	0	-50
RH>Setpoint+Dryer+FP1+FP2	-19.0	-4.7	-110		120	0	-30	X	-75	X	-75	-50
RH>Setpoint+Dryer+Vac+FP1	-16.6	-4.1	-100	Y	120	0	-30	X	-75	-40	-75	0
RH>Setpoint+Dryer+Vac+FP2	-11.0	-2.8	-75	Y	120	0	-30	X	-75	-40	0	-50
RH>Setpoint+Dryer+Vac+FP1+FP2	-29.5	-7.2	-150	Y	120	0	-30	X	-75	-40	-75	-50
RH>Setpoint+Vac+FP1	-2.3	-0.6	-25		120	0	-30	X	X	-40	-75	0
RH>Setpoint+Vac+FP2	0.0	0.0	0		120	0	-30	X	X	-40	0	-50
RH>Setpoint+Vac+FP1+FP2	-11.0	-2.8	-75		120	0	-30	X	X	-40	-75	-50
RH>Setpoint+FP1+FP2	-3.7	-1.0	-35		120	0	-30	0	0	0	-75	-50

Notes:

dP F326 - Depressurization predicted based on F326 airtightness values

dP Hse - Depressurization predicted based on measured airtightness values

X - Appliance locked out by Controller

OVERRIDE USED - Y = Occupants used manual override switch

Table 4c: House Depressurization Potential With Use of AMM1 & AMM2 and interlock system(using measured air flows)

Condition(Normal Operation)	dP F326	dP Hse	Imbalance	OVERRIDE	AMM1	AMM2	CEV	Dndrft	Dry	Vac	FP1	FP2
	(Pa)	(Pa)	(L/s)	USED	L/s-->							
Normal Operation	0.0	0.0	0		70	0	-70	0	0	0	0	0
Normal Operation+Dndrft	11.6	2.9	78		115	105	-30	-112	X	X	0	0
Normal Operation+Dryer	0.6	0.2	10		115	0	-30	X	-75	X	0	0
Normal Operation+Vacuum	5.3	1.4	45		115	0	-30	X	X	-40	0	0
Normal Operation+FP1	0.6	0.2	10		115	0	-30	0	0	0	-75	0
Normal Operation+FP2	3.7	1.0	35		115	0	-30	0	0	0	0	-50
Normal Operation+Dndrft+Dryer	0.1	0.0	3	Y	115	105	-30	-112	-75	X	0	0
Normal Operation+Dndrft+Vacuum	4.2	1.1	38	Y	115	105	-30	-112	X	-40	0	0
Normal Operation+Dndrft+FP1	0.1	0.0	3		115	105	-30	-112	X	X	-75	0
Normal Operation+Dndrft+FP2	2.7	0.7	28		115	105	-30	-112	X	X	0	-50
Normal Operation+Dndrft+Dryer+Vac	-4.0	-1.1	-37	Y	115	105	-30	-112	-75	-40	0	0
Normal Operation+Dndrft+Dryer+Vac+FP1	-19.5	-4.8	-112	Y	115	105	-30	-112	-75	-40	-75	0
Normal Operation+Dndrft+Dryer+Vac+FP2	-13.6	-3.4	-87	Y	115	105	-30	-112	-75	-40	0	-50
Normal Operation+Dndrft+Dryer+Vac+FP1+FP2	-33.0	-8.0	-162	Y	115	105	-30	-112	-75	-40	-75	-50
Normal Operation+Dndrft+Dryer+FP1	-10.4	-2.6	-72	Y	115	105	-30	-112	-75	X	-75	0
Normal Operation+Dndrft+Dryer+FP2	-5.6	-1.5	-47	Y	115	105	-30	-112	-75	X	0	-50
Normal Operation+Dndrft+Dryer+FP1+FP2	-22.0	-5.4	-122	Y	115	105	-30	-112	-75	X	-75	-50
Normal Operation+Dndrft+Vac+FP1	-4.0	-1.1	-37	Y	115	105	-30	-112	X	-40	-75	0
Normal Operation+Dndrft+Vac+FP2	-0.8	-0.2	-12	Y	115	105	-30	-112	X	-40	0	-50
Normal Operation+Dndrft+Vac+FP1+FP2	-13.6	-3.4	-87	Y	115	105	-30	-112	X	-40	-75	-50
					115	105						
Normal Operation+Dndrft+FP1+FP2	-5.6	-1.5	-47		115	105	-30	-112	X	X	-75	-50
Normal Operation+Dryer+Vac	-3.0	-0.8	-30	Y	115	0	-30	X	-75	-40	0	0
Normal Operation+Dryer+FP1	-8.9	-2.3	-65		115	0	-30	X	-75	X	-75	0
Normal Operation+Dryer+FP2	-4.5	-1.2	-40		115	0	-30	X	-75	X	0	-50
Normal Operation+Dryer+FP1+FP2	-20.2	-5.0	-115		115	0	-30	X	-75	X	-75	-50
Normal Operation+Dryer+Vac+FP1	-17.8	-4.4	-105	Y	115	0	-30	X	-75	-40	-75	0
Normal Operation+Dryer+Vac+FP2	-12.0	-3.0	-80	Y	115	0	-30	X	-75	-40	0	-50
Normal Operation+Dryer+Vac+FP1+FP2	-31.0	-7.5	-155	Y	115	0	-30	X	-75	-40	-75	-50
Normal Operation+Vac+FP1	-3.0	-0.8	-30		115	0	-30	X	X	-40	-75	0
Normal Operation+Vac+FP2	-0.2	-0.1	-5		115	0	-30	X	X	-40	0	-50
Normal Operation+Vac+FP1+FP2	-12.0	-3.0	-80		115	0	-30	X	X	-40	-75	-50
Normal Operation+FP1+FP2	-4.5	-1.2	-40		115	0	-30	0	0	0	-75	-50

Notes:

dP F326 - Depressurization predicted based on F326 airtightness values

dP Hse - Depressurization predicted based on measured airtightness values

X - Appliance locked out by controller

OVERRIDED USED - Y = Occupant used manual override switch

Table 4c: House Depressurization Potential With Use of AMM1 & AMM2 and interlock system(using measured air flows)(CONT'D)

Condition(RH>Setpoint)	dP F326	dP Hse	Imbalance	OVERRIDE	AMM1	AMM2	CEV	Dndrft	Dry	Vac	FP1	FP2
	(Pa)	(Pa)	(L/s)	USED	L/s-->							
RH>Setpoint	-1.4	-0.4	18		115	0	-97	0	0	0	0	0
RH>Setpoint+Dndrft	11.6	2.9	78		115	105	-30	-112	X	X	0	0
RH>Setpoint+Dryer	0.6	0.2	10		115	0	-30	X	-75	X	0	0
RH>Setpoint+Vacuum	5.3	1.4	45		115	0	-30	X	X	-40	0	0
RH>Setpoint+FP1	0.6	0.2	10		115	0	-30	0	0	0	-75	0
RH>Setpoint+FP2	3.7	1.0	35		115	0	-30	0	0	0	0	-50
					115							
RH>Setpoint+Dndrft+Dryer	0.1	0.0	3	Y	115	105	-30	-112	-75	X	0	0
RH>Setpoint+Dndrft+Vacuum	4.2	1.1	38	Y	115	105	-30	-112	X	-40	0	0
RH>Setpoint+Dndrft+FP1	0.1	0.0	3		115	105	-30	-112	X	X	-75	0
RH>Setpoint+Dndrft+FP2	2.7	0.7	28		115	105	-30	-112	X	X	0	-50
RH>Setpoint+Dndrft+Dryer+Vac	-4.0	-1.1	-37	Y	115	105	-30	-112	-75	-40	0	0
RH>Setpoint+Dndrft+Dryer+Vac+FP1	-19.5	-4.8	-112	Y	115	105	-30	-112	-75	-40	-75	0
RH>Setpoint+Dndrft+Dryer+Vac+FP2	-13.6	-3.4	-87	Y	115	105	-30	-112	-75	-40	0	-50
RH>Setpoint+Dndrft+Dryer+Vac+FP1+FP2	-33.0	-8.0	-162	Y	115	105	-30	-112	-75	-40	-75	-50
RH>Setpoint+Dndrft+Dryer+FP1	-10.4	-2.6	-72	Y	115	105	-30	-112	-75	X	-75	0
RH>Setpoint+Dndrft+Dryer+FP2	-5.6	-1.5	-47	Y	115	105	-30	-112	-75	X	0	-50
RH>Setpoint+Dndrft+Dryer+FP1+FP2	-22.0	-5.4	-122	Y	115	105	-30	-112	-75	X	-75	-50
RH>Setpoint+Dndrft+Vac+FP1	-4.0	-1.1	-37	Y	115	105	-30	-112	X	-40	-75	0
RH>Setpoint+Dndrft+Vac+FP2	-0.8	-0.2	-12	Y	115	105	-30	-112	X	-40	0	-50
RH>Setpoint+Dndrft+Vac+FP1+FP2	-13.6	-3.4	-87	Y	115	105	-30	-112	X	-40	-75	-50
RH>Setpoint+Dndrft+FP1+FP2	-5.6	-1.5	-47		115	105	-30	-112	X	X	-75	-50
RH>Setpoint+Dryer+Vac	-3.0	-0.8	-30	Y	115	0	-30	X	-75	-40	0	0
RH>Setpoint+Dryer+FP1	-8.9	-2.3	-65		115	0	-30	X	-75	X	-75	0
RH>Setpoint+Dryer+FP2	-4.5	-1.2	-40		115	0	-30	X	-75	X	0	-50
RH>Setpoint+Dryer+FP1+FP2	-20.2	-5.0	-115		115	0	-30	X	-75	X	-75	-50
RH>Setpoint+Dryer+Vac+FP1	-17.8	-4.4	-105	Y	115	0	-30	X	-75	-40	-75	0
RH>Setpoint+Dryer+Vac+FP2	-12.0	-3.0	-80	Y	115	0	-30	X	-75	-40	0	-50
RH>Setpoint+Dryer+Vac+FP1+FP2	-31.0	-7.5	-155	Y	115	0	-30	X	-75	-40	-75	-50
RH>Setpoint+Vac+FP1	-3.0	-0.8	-30		115	0	-30	X	X	-40	-75	0
RH>Setpoint+Vac+FP2	-0.2	-0.1	-5		115	0	-30	X	X	-40	0	-50
RH>Setpoint+Vac+FP1+FP2	-12.0	-3.0	-80		115	0	-30	X	X	-40	-75	-50
RH>Setpoint+FP1+FP2	-4.5	-1.2	-40		115	0	-30	0	0	0	-75	-50

Notes:

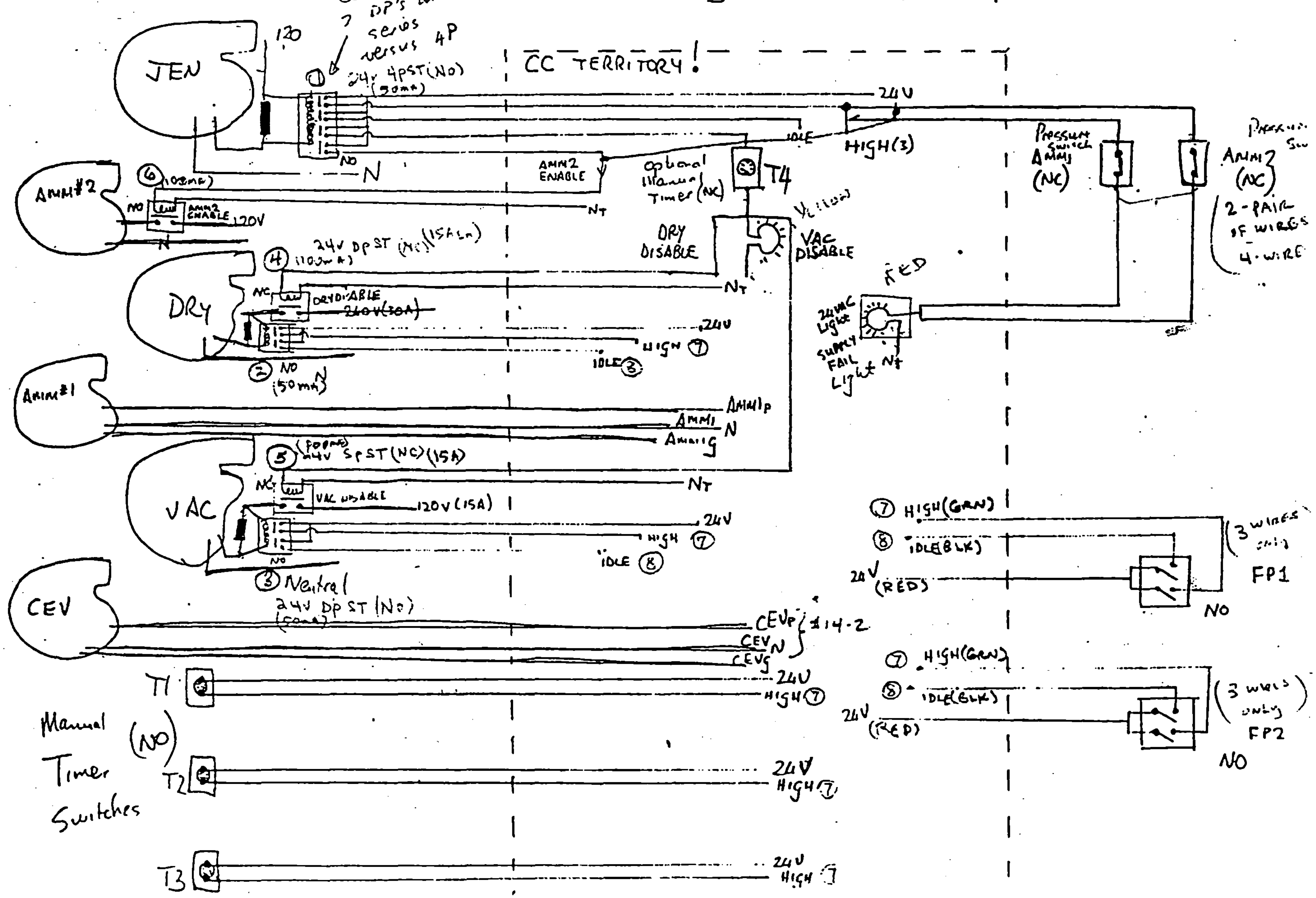
dP F326 - Depressurization predicted based on F326 airtightness values

dP Hse - Depressurization predicted based on measured airtightness values

X - Appliance locked out by Controller

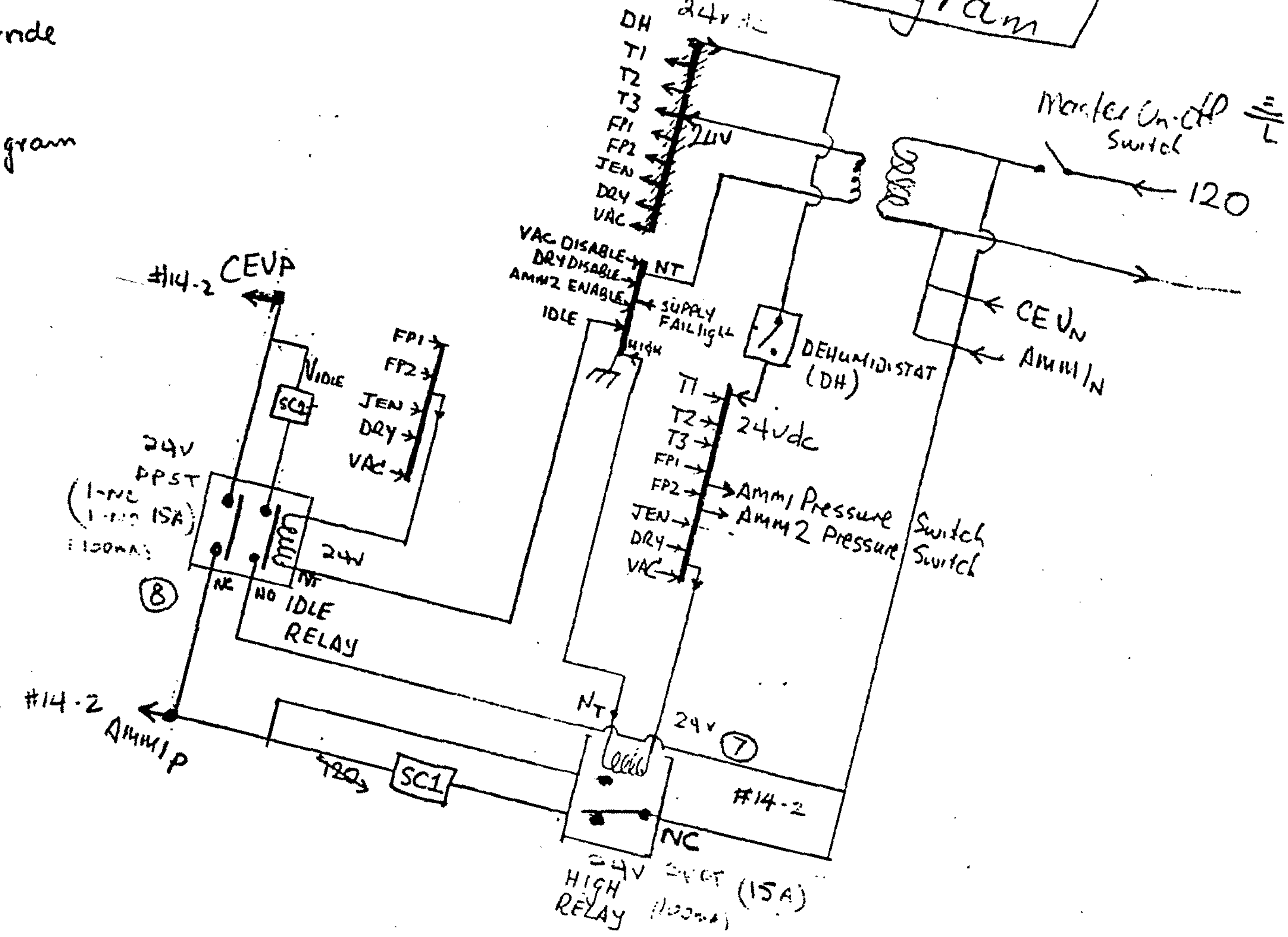
OVERRIDE USED - Y = Occupant used manual override switch

External wiring & relay requirements



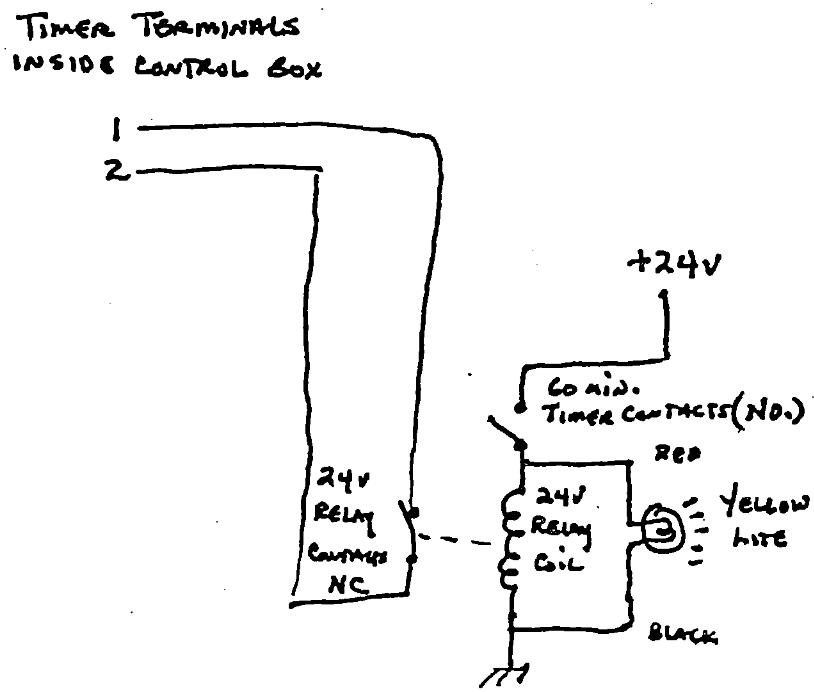
Also see
SUPPLY FAIL Light
and VAC/DRY DISABLE
Manual Timer Override
Circuits ... shown
on External Wiring & relay diagram

CC Functional Circuit Diagram



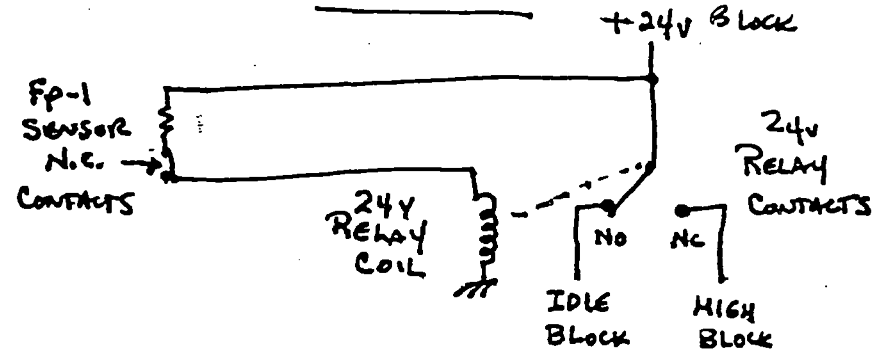
SC1 and SC2 are speed controls
Only SC1 is homeowner adjustable
SC2 is installer adjustable

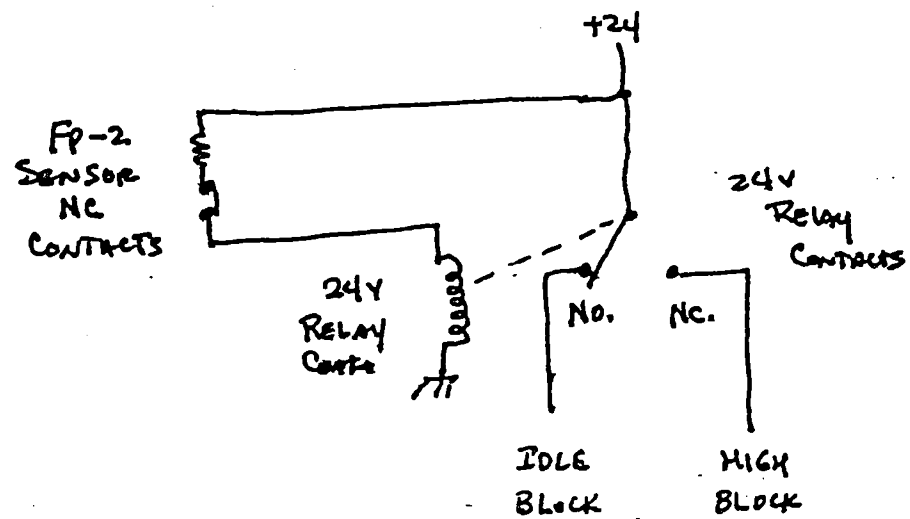
60 MINUTE MANUAL TIMER WIRING



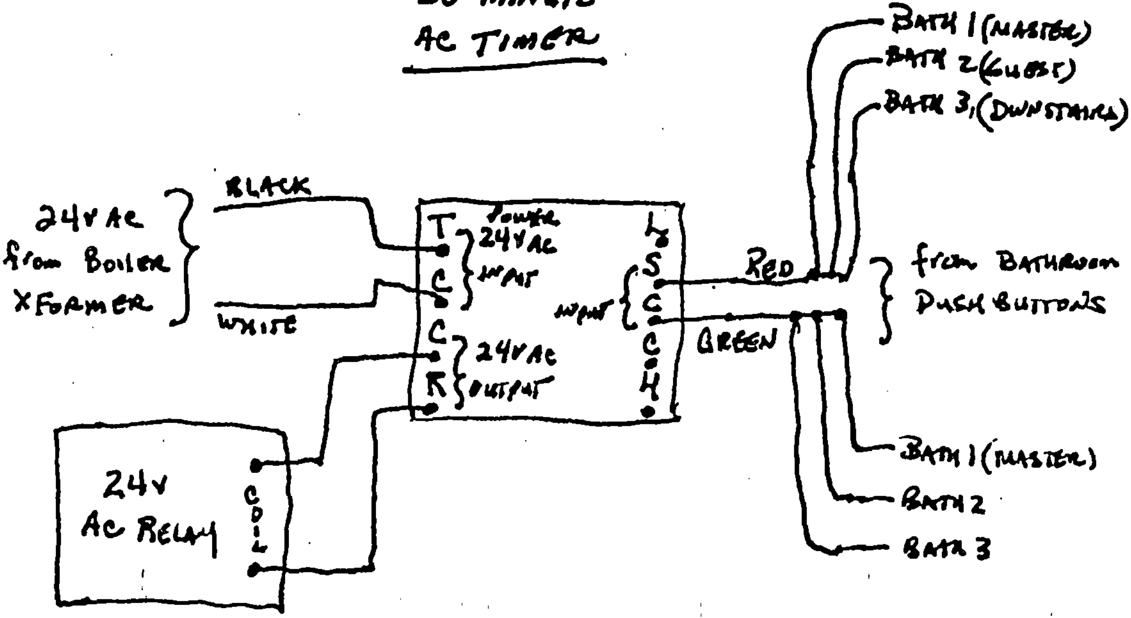
DRYER & VAC DISABLE OVERRIDE

FIREPLACE SENSOR WIRING:

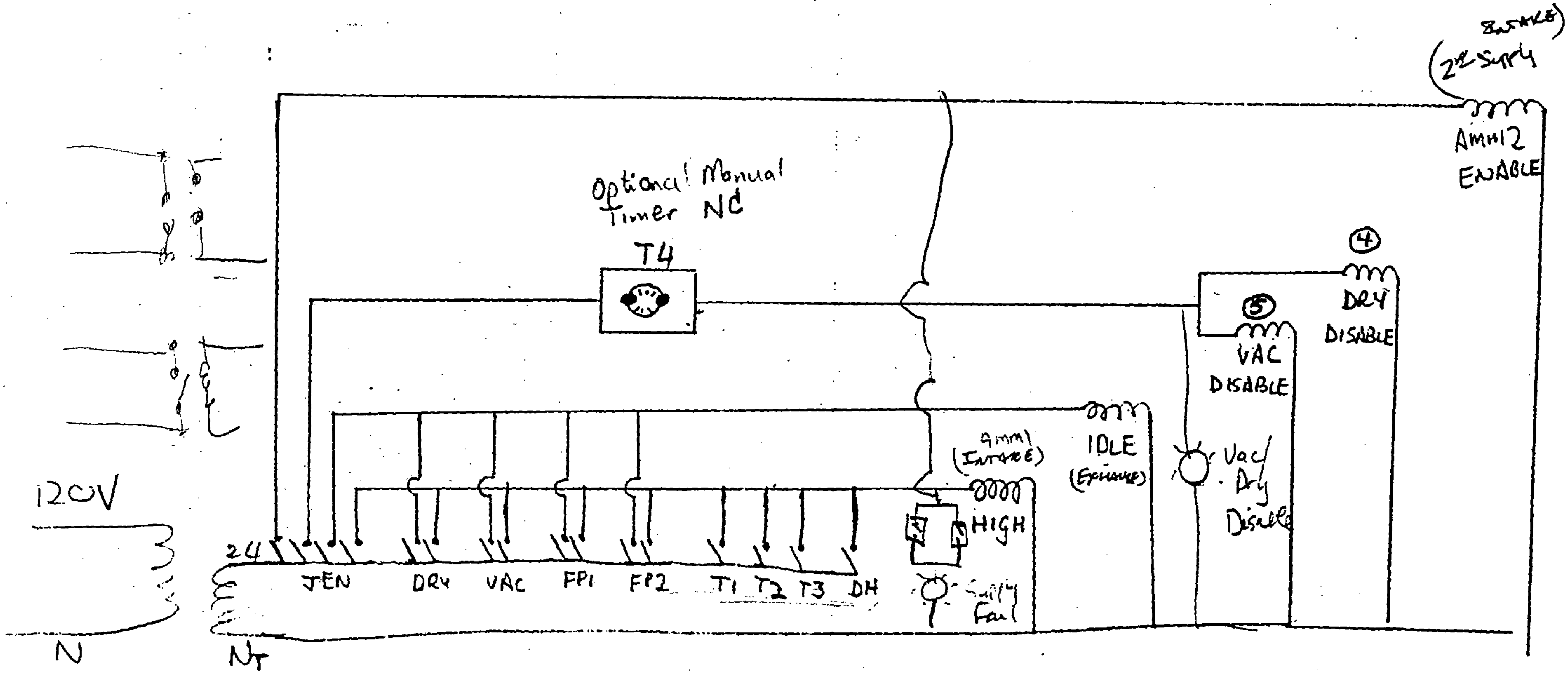




20 MINUTE AC TIMER

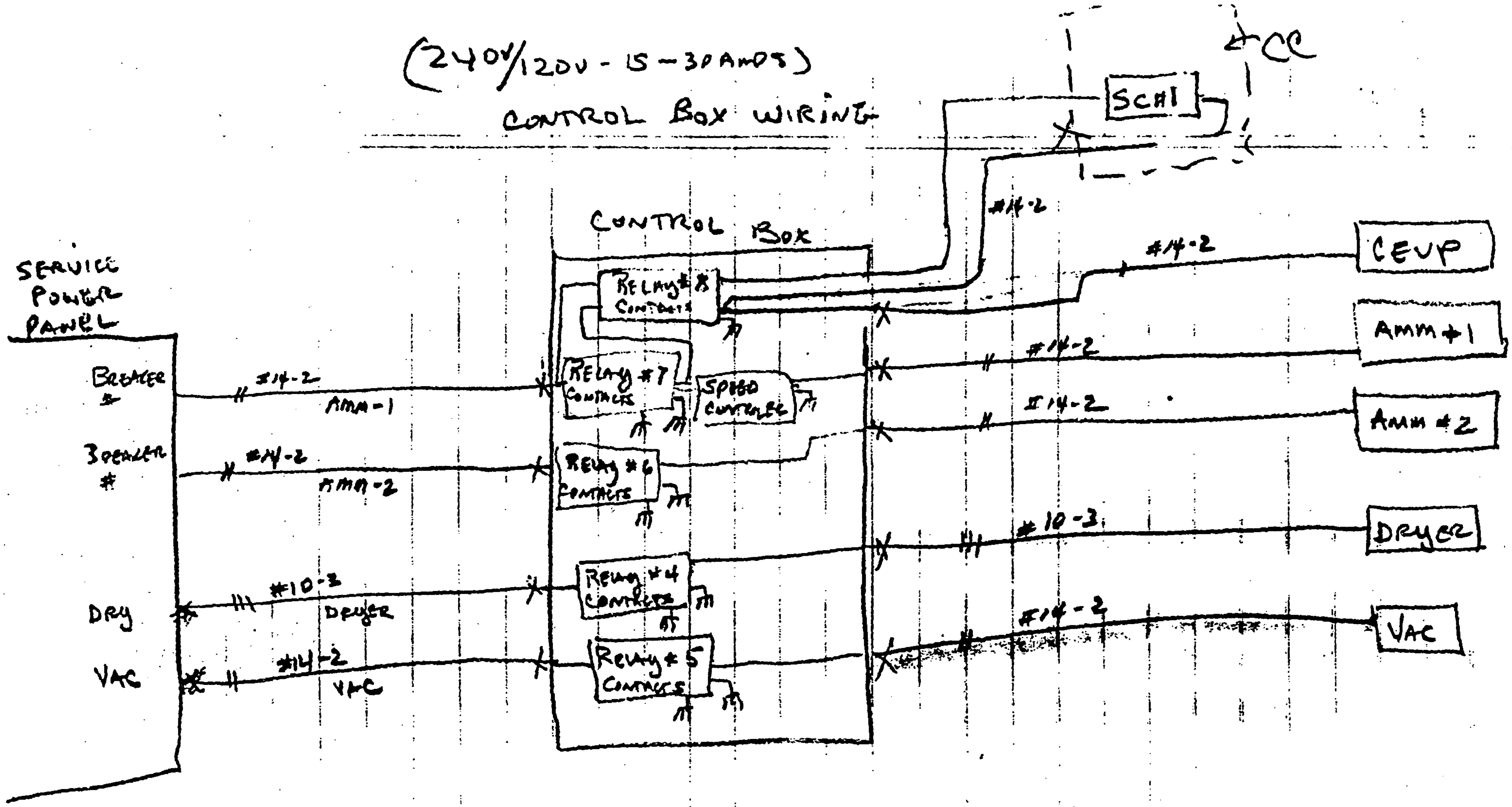


ontrol Relay(s) Energizing Coil Circuit



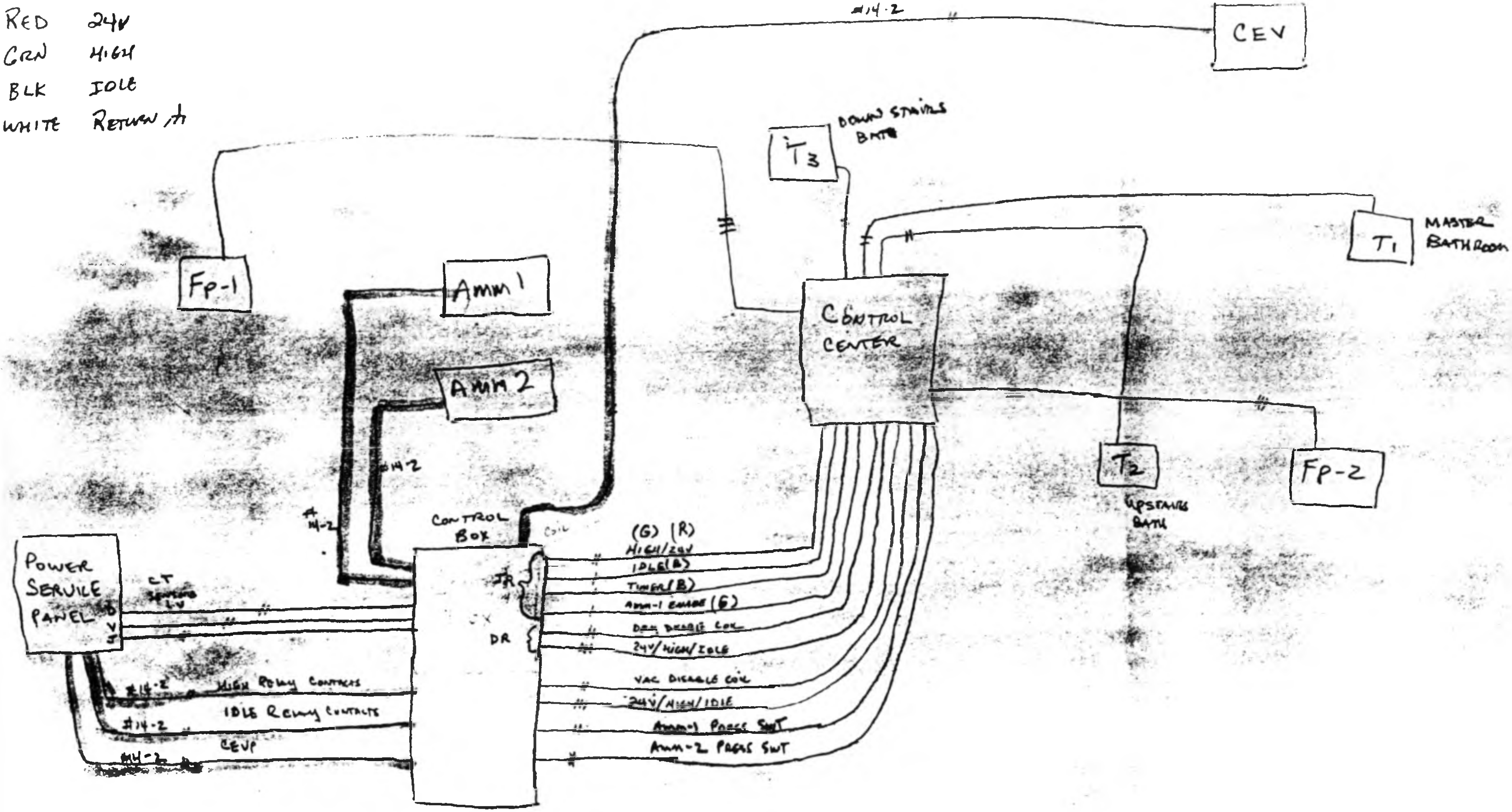
(240V/120V - 15 - 30 AMPS)

CONTROL BOX WIRING



WIRING DIAGRAM (Bunke House)

RED	24V
GRN	HIGH
BLK	IDLE
WHITE	Return



APPENDIX 4

DATA SUMMARIES

SUMMARY FOR ENTIRE MONITORING PERIOD (Sept/27/89 - Mar/06/90)

Element	Units	Average	Std Dev	Minimum	Maximum	Sum
Wind avg	(kmh)	6.39	1.761	0	49	23177
wind max	(kmh)	3.65	2.722	1	94	
Wind Direction	(deg)	124.17	15.171	0	353	463259
Family rm suppl	(C)	23.12	0.321	14.70	34.40	
AMM2 after coil	(C)	5.48	0.269	18.5	29.4	
AMM2 min after	(C)	3.61	2.690	20.2	25.9	
Master BR Temp	(C)	20.04	0.418	12.7	30.4	
Master Br CO2	(PPM)	615.65	16.000	0	1384	
Boiler Hood Tem	(C)	5.94	0.266	18.8	30.1	
End run Temp	(C)	22.88	0.260	16.1	31.3	
Outdoor Temp	(C)	5.58	0.569	-9.4	21.7	
AMM1 before coi	(C)	6.93	0.550	-6.6	21.9	
AMM1 after coil	(C)	23.20	0.530	10.3	41.4	
Indoor RH	(%)	39.46	2.879	0	99	
Min Env	(Pa)	-2.64	0.273	-10	1.6	
Avg Env	(Pa)	-3.21	0.355	-9.9	4.4	
Supply	(L/S)	61.65	4.275	0	125	5.69E+05
Max Flow	(hours)	0.05	0.033	0	0.557829	185.76727
Max Hood	(C)	6.02	0.279	19.3	32.6	
Boiler on	(hours)	0.08	0.008	0	0.38	471.78
Boiler on	(%)	0.13	0.023	0	0.76	208.36
Dryer on	(hours)	0.00	0.013	0	0.86	29.06
Dehum on	(hours)	0.01	0.008	0	0.25	58.6

Number of Full days	94.000	Days	
Total # of Days	125.000	Days	
Number of good hours	2541.167	Hours	
Heating Degree Days	1302.643	HDD's	
Heating Cons.(Total)	67.193	GJ	
Heating Cons.(Avg Daily)	0.635	GJ Adj.	$2.73 /day (@ $4.30/GJ)
Boiler % on Time	18.57%	%	
Ventilation Cons.(Total)	9.221	GJ Adj.	
Vent. Cons.(Avg Daily)	0.087	GJ Adj.	$0.37 /day
Vent % of Total	13.72%		

Summary for Period from Sep/27/90 to Oct/5/90

Element	Units	Average	Std Dev	Minimum	Maximum	Sum
Wind avg	(kmh)	6.86	1.448	1	27	
wind max	(kmh)					
Wind Direction	(deg)	102.83	10.186	19	237	
Family rm suppl	(C)	18.49	0.538	14.80	23.90	
AMM2 after coil	(C)					
AMM2 min after	(C)					
Master BR Temp	(C)	22.81	0.603	19.4	30.4	
Master Br CO2	(PPM)	701.00	38.681	363	1161	
Boiler Hood Tem	(C)					
End run Temp	(C)	20.09	0.388	17.1	25.2	
Outdoor Temp	(C)	13.03	0.897	7.6	21.7	
AMM1 before coi	(C)	13.49	0.867	8.2	21.9	
AMM1 after coil	(C)	15.57	0.780	10.8	23.2	
Indoor RH	(%)	48.58	1.337	30	64	
Min Env	(Pa)	0.23	0.160	-1	1.2	
Avg Env	(Pa)	0.23	0.161	-1	1.2	
Supply	(L/S)	88.27	5.967	63.3	122.6	5.40E+04
Max Flow	(hours)					
Max Hood	(C)					
Boiler on	(hours)	0.01	0.006	0	0.12	9.29
Boiler on	(%)					
Dryer on	(hours)	0.01	0.025	0	0.25	5.67
Dehum on	(hours)	0.00	0.002	0	0.05	0.06

Number of Full days	5.000 Days	
Total # of Days	9.000 Days	
Number of good hours	154.750 Hours	
Heating Degree Days	34.136 HDD's	
Heating Cons.(Total)	1.323 GJ	
Heating Cons.(Avg Daily)	0.205 GJ Adj.	$0.88 /day
Boiler % on Time	6.00% %	
Ventilation Cons.(Total)	0.125 GJ Adj.	
Vent. Cons.(Avg Daily)	0.019 GJ Adj.	$0.08 /day
Vent % of Total	9.46%	

Summary for Period from Oct/10/89 to Oct/30/89

Element	Units	Average	Std Dev	Minimum	Maximum	Sum
Wind avg	(kmh)	9.07	2.828	1	49	13490
wind max	(kmh)					
Wind Direction	(deg)	111.57	11.759	0	262	174631
Family rm suppl	(C)	22.43	0.902	15.50	34.40	
AMM2 after coil	(C)					
AMM2 min after	(C)					
Master BR Temp	(C)	19.81	0.333	16.6	25.2	
Master Br CO2	(PPM)	711.38	55.266	415	1384	
Boiler Hood Tem	(C)					
End run Temp	(C)	22.76	0.611	17.1	31.3	
Outdoor Temp	(C)	9.41	0.648	3	15.3	
AMM1 before coi	(C)	10.06	0.621	4.2	15.7	
AMM1 after coil	(C)	21.93	1.486	10.3	41.4	
Indoor RH	(%)	51.77	10.846	0	99	
Min Env	(Pa)	-1.71	0.241	-4.7	1.4	
Avg Env	(Pa)	-2.46	0.460	-9.9	4.4	
Supply	(L/S)	89.84	6.647	65	125	1.40E+05
Max Flow	(hours)	0.08	0.043	0	0.25	126.66
Max Hood	(C)					
Boiler on	(hours)	0.03	0.009	0	0.17	52.09
Boiler on	(%)	0.13	0.035	0	0.68	208.36
Dryer on	(hours)	0.01	0.029	0	0.25	16.67
Dehum on	(hours)	0.03	0.045	0	0.25	58.23

Number of Full days	14.000	Days	
Total # of Days	20.000	Days	
Number of good hours	385.250	Hours	
Heating Degree Days	134.510	HDD's	
Heating Cons.(Total)	7.419	GJ	
Heating Cons.(Avg Daily)	0.462	GJ Adj.	$1.99 /day
Boiler % on Time	13.52%	%	
Ventilation Cons.(Total)	1.560	GJ Adj.	
Vent. Cons,(Avg Daily)	0.097	GJ Adj.	$0.42 /day
Vent % of Total	21.03%		

Summary for Period from Nov/7/89 to Nov/19/89

Element	Units	Average	Std Dev	Minimum	Maximum	Sum
Wind avg	(kmh)	8.88	1.841	1	42	
wind max	(kmh)					
Wind Direction	(deg)	139.46	12.325	20	323	
Family rm suppl	(C)	24.18	0.037	23.70	24.60	
AMM2 after coil	(C)					
AMM2 min after	(C)					
Master BR Temp	(C)	18.90	0.354	16.1	22.6	
Master Br CO2	(PPM)	454.58	18.052	318	802	
Boiler Hood Tem	(C)					
End run Temp	(C)	24.20	0.083	23.4	25	
Outdoor Temp	(C)	6.78	0.380	0.9	12.7	
AMM1 before coi	(C)	7.62	0.360	2.1	13.3	
AMM1 after coil	(C)	24.09	0.038	23.3	24.8	
Indoor RH	(%)	48.61	5.788	0	72	
Min Env	(Pa)	-2.44	0.141	-4.2	-0.7	
Avg Env	(Pa)	-3.45	0.529	-9.9	0	
Supply	(L/S)	77.52	3.290	67.1	117.3	9.63E+04
Max Flow	(hours)	0.01	0.026	0	0.25	17.7
Max Hood	(C)					
Boiler on	(hours)	0.05	0.004	0	0.15	59.14
Boiler on	(%)	0.19	0.017	0	0.6	
Dryer on	(hours)	0.00	0.000	0	0	N/A
Dehum on	(hours)	0.00	0.000	0	0	

Number of Full days	12.000	Days	
Total # of Days	13.000	Days	
Number of good hours	311.000	Hours	
Heating Degree Days	145.198	HDD's	
Heating Cons.(Total)	8.423	GJ	
Heating Cons.(Avg Daily)	0.650	GJ Adj.	$2.80 /day
Boiler % on Time	19.02%	%	
Ventilation Cons.(Total)	1.502	GJ Adj.	
Vent. Cons.(Avg Daily)	0.116	GJ Adj.	$0.50 /day
Vent % of Total	17.84%		

Summary for Period from Nov/21/89 to Dec/31/89

Element	Units	Average	Std Dev	Minimum	Maximum	Sum
Wind avg	(kmh)	5.34	1.806	0	35	6991
wind max	(kmh)					
Wind Direction	(deg)	142.33	18.454	27	353	174318
Family rm suppl	(C)	24.08	0.514	14.70	25.00	
AMM2 after coil	(C)					
AMM2 min after	(C)					
Master BR Temp	(C)	20.50	0.511	12.7	25.5	
Master Br CO2	(PPM)	N/A	N/A	N/A	N/A	
Boiler Hood Tem	(C)					
End run Temp	(C)	24.14	0.457	16.1	25.9	
Outdoor Temp	(C)	5.40	0.333	0.2	12.1	
AMM1 before coi	(C)	6.49	0.316	1.3	12.7	
AMM1 after coil	(C)	23.96	0.213	22.9	28.4	
Indoor RH	(%)	46.71	0.617	37	55	
Min Env	(Pa)	-2.36	0.313	-4.8	1.6	
Avg Env	(Pa)	-3.31	0.422	-9.9	1.1	
Supply	(L/S)	67.74	3.460	34.2	114	4.39E+04
Max Flow	(hours)	0.01	0.038	0	0.5	9.85
Max Hood	(C)					
Boiler on	(hours)	0.10	0.016	0	0.38	127.46
Boiler on	(%)	0.20	0.033	0	0.76	
Dryer on	(hours)	0.00	0.000	0	0	0
Dehum on	(hours)	0.00	0.008	0	0.2	0.31

Number of Full days	22.000	Days	
Total # of Days	32.000	Days	
Number of good hours	611.500	Hours	
Heating Degree Days	315.013	HDD's	
Heating Cons.(Total)	18.153	GJ	
Heating Cons.(Avg Daily)	0.712	GJ Adj.	$3.06 /day
Boiler % on Time	20.84%	%	
Ventilation Cons.(Total)	2.768	GJ Adj.	
Vent. Cons.(Avg Daily)	0.109	GJ Adj.	$0.47 /day
Vent % of Total	15.25%		

Summary for Period from Jan/5/90 to Jan/25/90

Element	Units	Average	Std Dev	Minimum	Maximum	Sum
Wind avg	(kmh)	2.98	1.198	0	11	2696
wind max	(kmh)					
Wind Direction	(deg)	117.23	15.564	22	341	114310
Family rm suppl	(C)	23.30	0.044	22.70	24.00	0
AMM2 after coil	(C)					
AMM2 min after	(C)					
Master BR Temp	(C)	20.52	0.503	16.4	27.2	0
Master Br CO2	(PPM)	N/A	N/A	N/A	N/A	0
Boiler Hood Tem	(C)					
End run Temp	(C)	23.08	0.067	22.4	24	0
Outdoor Temp	(C)	3.61	0.357	-1.1	8.6	0
AMM1 before coi	(C)	5.56	0.330	1.2	10.3	0
AMM1 after coil	(C)	23.82	0.077	22.5	25.1	0
Indoor RH	(%)	N/A	N/A	N/A	N/A	N/A
Min Env 2	(Pa)	-3.37	0.394	-8.2	-1.5	-3293.3
Avg Env	(Pa)	-4.68	0.427	-9.9	-2.6	-4590.6
Supply	(L/S)	43.54	5.032	0	106.5925	4.24E+04
Max Flow	(hours)	0.17	0.075	0	0.557829	15.98727
Max Hood	(C)					
Boiler on	(hours)	0.11	0.004	0.02	0.28	105.61
Boiler on	(%)	0.22	0.009	0.04	0.56	
Dryer on	(hours)	0.00	0.000	0	0	0
Dehum on	(hours)	0.00	0.000	0	0	0

Number of Full days	20.000	Days	
Total # of Days	21.000	Days	
Number of good hours	487.000	Hours	
Heating Degree Days	290.515	HDD's	
Heating Cons.(Total)	15.042	GJ	
Heating Cons.(Avg Daily)	0.741	GJ Adj.	$3.19 /day
Boiler % on Time	21.69%	%	
Ventilation Cons.(Total)	1.542	GJ Adj.	
Vent. Cons.(Avg Daily)	0.076	GJ Adj.	$0.33 /day
Vent % of Total	10.25%		

Summary for Period from Jan/29/90 to Feb/15/90

Element	Units	Average	Std Dev	Minimum	Maximum	Sum
Wind avg	(kmh)	10.48	2.002	0	49	
wind max	(kmh)	22.68	3.436	2	94	
Wind Direction	(deg)	125.06	20.786	0	319	
Family rm suppl	(C)	23.61	0.049	23.00	24.80	
AMM2 after coil	(C)	23.77	0.337	19.9	27	
AMM2 min after	(C)					
Master BR Temp	(C)	19.85	0.235	17.3	22.5	
Master Br CO2	(PPM)	N/A	N/A	N/A	N/A	
Boiler Hood Tem	(C)	28.00	0.153	26.1	29.9	
End run Temp	(C)	23.23	0.074	22.7	24.6	
Outdoor Temp	(C)	-1.21	0.379	-6.1	2.8	
AMM1 before coi	(C)	1.04	0.313	-3.3	4.8	
AMM1 after coil	(C)	23.57	0.118	22.4	27.2	
Indoor RH	(%)	41.13	0.680	34	51	
Min Env	(Pa)	-5.32	0.465	-10	-3.5	
Avg Env	(Pa)	-4.41	0.244	-7.3	-2.4	-3763.4
Supply	(L/S)	42.27	1.973	21.96	92.47	3.68E+04
Max Flow	(hours)	0.00	0.008	0	0.17	1.35
Max Hood	(C)	28.52	0.158	26.3	32.6	24837.1
Boiler on	(hours)	0.14	0.009	0.02	0.29	42.26
Boiler on	(%)					
Dryer on	(hours)	0.00	0.003	0	0.05	0.11
Dehum on	(hours)	0.00	0.000	0	0	0

Number of Full days	3.000 Days	
Total # of Days	10.000 Days	
Number of good hours	144.667 Hours	
Heating Degree Days	115.771 HDD's	
Heating Cons.(Total)	6.019 GJ	
Heating Cons.(Avg Daily)	0.999 GJ Adj.	$4.29 /day
Boiler % on Time	29.21% %	
Ventilation Cons.(Total)	0.546 GJ Adj.	
Vent. Cons.(Avg Daily)	0.091 GJ Adj.	$0.39 /day
Vent % of Total	9.06%	

Summary for Period from Feb/15/90 to Mar/06/90

Element	Units	Average	Std Dev	Minimum	Maximum	Sum
Wind avg	(kmh)	6.00	1.202	1	30	
wind max	(kmh)	13.40	2.009	1	75	
Wind Direction	(deg)	114.20	17.122	13	346	
Family rm suppl	(C)	22.90	0.161	20.20	27.40	
AMM2 after coil	(C)	23.48	0.200	18.5	29.4	
AMM2 min after	(C)	20.51	2.690	20.2	25.9	
Master BR Temp	(C)	18.99	0.389	15.4	25.7	
Master Br CO2	(PPM)	N/A	N/A	N/A	N/A	
Boiler Hood Tem	(C)	24.73	0.380	18.8	30.1	
End run Temp	(C)	20.96	0.137	19	23.6	
Outdoor Temp	(C)	3.45	0.993	-9.4	13.4	
AMM1 before coi	(C)	5.48	1.046	-6.6	14.5	
AMM1 after coil	(C)	24.49	0.999	21.2	37.4	
Indoor RH	(%)	51.85	0.885	33	67	
Min Env	(Pa)	-3.30	0.197	-10	0.8	
Avg Env	(Pa)	-2.75	0.243	-6.7	1.9	
Supply	(L/S)	34.77	3.556	21.77	109.67	1.56E+05
Max Flow	(hours)	0.00	0.010	0	0.35	14.22
Max Hood	(C)	25.01	0.400	19.3	31.5	
Boiler on	(hours)	0.08	0.009	0.03	0.34	75.93
Boiler on	(%)					
Dryer on	(hours)	0.01	0.037	0	0.86	6.61
Dehum on	(hours)	0.00	0.000	0	0	0

Number of Full days	18.000 Days	
Total # of Days	20.000 Days	
Number of good hours	447.000 Hours	
Heating Degree Days	267.500 HDD's	
Heating Cons.(Total)	10.814 GJ	
Heating Cons.(Avg Daily)	0.581 GJ Adj.	$2.50 /day
Boiler % on Time	16.99% %	
Ventilation Cons.(Total)	1.177 GJ Adj.	
Vent. Cons.(Avg Daily)	0.063 GJ Adj.	$0.27 /day
Vent % of Total	10.89%	

DESIGN DAY; FEB, 17, 1990

Daily	Units	Average	Std Dev	Minimum	Maximum	Sum
Wind avg	(kmh)	6.90	3.45	1	14	
wind max	(kmh)	14.08	6.36	1	30	
Wind Direction	(deg)	134.38	17.34	66	166	
Family rm supply	(C)	23.34	0.21	22.8	24.1	
AMM2 after coil	(C)	23.56	0.62	20.9	25	
AMM2 min after co	(C)	18.40	0.92	11.6	20.2	
Master BR Temp	(C)	18.82	1.57	15.4	24.9	
Boiler Hood Temp	(C)	28.18	0.86	26.3	30.1	
End run Temp	(C)	22.31	0.26	21.8	23	
Outdoor Temp	(C)	-6.22	2.00	-9.4	0	
AMM1 before coil	(C)	-3.81	1.72	-6.6	-1.2	
AMM1 after coil	(C)	23.53	0.51	22.3	28.4	
Indoor RH	(%)	51.07	2.11	47	57	
Avg Env	(Pa)	-4.64	0.83	-6.7	-2.7	-1091.5
Min Env	(Pa)	-5.10	0.85	-7	-3.8	
Boiler on	(hours)	0.16	0.06	0.05	0.28	7.66
Boiler on	(%)	31.92%	11.21%	10.00%	56.00%	
Dryer on	(hours)	0.02	0.08	0	0.48	0.83
Dehum on	(hours)	0.00	0.00	0	0	0
Supply Max Flow	(L/S)	47.24	9.03	23.53	92.33	11101.72
Max Hood	(C)	28.85	0.98	26.5	30.9	6780.2

Number of Full days	1 Days	
Number of Partial Days	0 Days	
Number of good hours	23.2 Hours	
Heating Degree Days	23.4 HDD's(<18C)	
Heating Cons. (Total)	1.09 GJ	
Heating Cons. (Avg Daily)	1.130 GJ	$5.09 /day @ $4.50/GJ
Boiler % on Time	33.06%	
Ventilation Cons. (Total)	0.117 GJ	
Vent Cons. (Avg Daily)	0.121 GJ/day	$0.55 /day @ $4.50/GJ
Vent % of Total	10.74%	

Table A2: Electrical & Gas Meter Readings for Clearwater House 89/90

Date	Time	Gas Meter (m^3)	Electrical (kWh)
9/27/89	16:00	3767.3	2610.4
9/30/90	16:00	3786.9	2686.3
10/14/89	17:30	3905.7	3041.4
10/21/89	12:45	3998.2	3237.2
11/07/89	22:00	4293.4	3726.2
12/14/89	18:20	4812.6	5035.5
1/04/90	20:30	5496.7	5572.6
1/29/90	20:45	6021.3	6366.5
2/15/90	18:00	6436.1	6872.1
3/06/90	17:00	6739.5	7347.0
10/06/90	13:00	8568.0	11822.4
10/24/90	20:00	8769.0	12186.5

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*                                      *
*              HOT-2000                *
*            Version 5.04              *
*  Energy, Mines and Resources Canada  *
*         September 01, 1987           *
*                                      *
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DATE (mm/dd/yy): 05/10/90
CLIENT NAME : GARRY BUNKEY
ADDRESS : 582 CLEARWATER WAY

HOUSE DATA FILENAME: bunke
WEATHER DATA IS FOR: Vancouver (British Columbia)

*** TEMPERATURE AND BUILDING MASS ***

HEATING TEMPERATURES	MAIN FLOOR	= 21.1 C
	BASEMENT	= 20 C
	TEMP. SWING FROM 21.1 C	= 3.3 C

SOIL TYPE: Normal Conductivity: dry sand, loam, clay, low water table

HOUSE THERMAL MASS LEVEL: (1) Wood frame construction, 12.5 mm gyproc walls and ceiling, wooden floor

*** FOUNDATION CONSTRUCTION CHARACTERISTICS ***

FOUNDATION CONSTRUCTION	ATTACHMENT SIDES	INSULATION PLACEMENT
FULL BASEMENT	NONE	INTERIOR

*** WINDOW/GLAZING CHARACTERISTICS ***

ORIENTATION	AVERAGE # GLAZINGS	AVERAGE TRANSMISSION COEFFICIENT	AVERAGE WINDOW HEIGHT m	AVERAGE OVERHANG WIDTH m	AVERAGE HEADER HEIGHT m
South	2.00	.82	1.52	.61	.20
North	2.00	.82			
East	2.00	.82			
West	2.00	.82			

*** BUILDING PARAMETERS ***

COMPONENT		AREA m2	RSI	HEAT LOSS MJ	% ANNUAL HEAT LOSS
ABOVE GRADE COMPONENTS					
Ceiling					
		110.86	7.04		
	TOTAL:	110.86	7.04	7136	4.46
Main walls					
		224.73	3.52		
	TOTAL:	224.73	3.52	27480	17.18
Doors					
		6.92	1.23		
	TOTAL:	6.92	1.23	2546	1.59
Exposed floor					
		2.93	3.52		
	TOTAL:	2.93	3.52	330	.21
FULL DEPTH BASEMENT					
Upper basement walls					
		54.23	2.11		
	TOTAL:	54.23	2.11	8220	5.14
Floor perimeter					
		39.02	1.76		
	TOTAL:	39.02	1.76	4293	2.68
Floor center					
		53.25	1.76		
	TOTAL:	53.25	1.76	6704	4.19

WINDOWS/GLAZING		GLAZING AREA (m2)	RSI GLAZING (SHUTTER)	HEAT LOSS MJ	% ANNUAL HEAT LOSS
South windows					
		2.23	.38		
	TOTAL:	2.23	.38	2658	1.66
North windows					
		1.11	.38		
	TOTAL:	1.11	.38	1329	.83
East windows					
		28.66	.38		
	TOTAL:	28.66	.38	34166	21.37
West windows					
		14.26	.38		
	TOTAL:	14.26	.38	17000	10.63

AIR LEAKAGE AND VENTILATION	VOLUME	AIR CHANGE	HEAT LOSS MJ	% ANNUAL HEAT LOSS
	734.10 m3	.46 ACH	37198	30.51

*** AIR LEAKAGE AND VENTILATION ***

BUILDING ENVELOPE SURFACE AREA = 538.2 m2
AIR LEAKAGE TEST RESULTS AT 50 Pa.(0.2 in. H2O) = 2.37 ACH
EQUIVALENT LEAKAGE AREA = 652 cm2
BUILDING ENVELOPE IS SHELTERED FROM THE WIND.

AVERAGE VENTILATION RATE (Balanced) = .39 ACH (80 L/s)

VENTILATION SYSTEM IS : Mechanical ventilator and/or fans

MANUFACTURER: ALLIED ENGINEERING COMPANY
MODEL NUMBER: Air Management Module #1

TOTAL ELECTRICAL POWER REQUIRED = 250 Watts

GROSS AIR LEAKAGE AND VENTILATION ENERGY LOAD = 41061 MJ
SEASONAL HEAT RECOVERY VENTILATOR EFFICIENCY = 0 %
ESTIMATED VENTILATION ELECTRICAL LOAD: HEATING HOURS = 7726 MJ
ESTIMATED VENTILATION ELECTRICAL LOAD: NON-HEATING HOURS = 158 MJ
NET AIR LEAKAGE AND VENTILATION ENERGY LOAD = 41061 MJ

*** SPACE HEATING SYSTEM ***

PRIMARY SPACE HEATING FUEL IS : NATURAL GAS
SPACE HEATING EQUIPMENT : Conventional furnace/boiler with continuous pilo

SPACE HEATING EQUIPMENT MANUFACTURER : ALLIED ENGINEERING COMPANY
SPACE HEATING EQUIPMENT MODEL : SUPER-HOT
SPACE HEATING EQUIPMENT OUTPUT CAPACITY = 39.6 kW
MANUFACTURER'S STEADY STATE EFFICIENCY = 80 %
DERIVED SEASONAL EFFICIENCY = 65 %

*** ANNUAL SPACE HEATING SUMMARY ***

DESIGN HEAT LOSS AT -7 C	= 9.38 kW
GROSS SPACE HEATING LOAD	=121906 MJ
SENSIBLE DAILY HEAT GAIN FROM OCCUPANTS	= 2.00 kWh/day
USABLE INTERNAL GAINS	= 19973 MJ
USABLE INTERNAL GAINS FRACTION	= 16 %
USABLE SOLAR GAINS	= 35809 MJ
USABLE SOLAR GAINS FRACTION	= 29 %
AUXILIARY ENERGY REQUIRED	= 66124 MJ
VENTILATION EQUIPMENT ELECTRICAL CONTRIBUTION	= 3863 MJ
FURNACE/BOILER ANNUAL ENERGY CONSUMPTION	= 95787 MJ

*** DOMESTIC WATER HEATING SYSTEM ***

PRIMARY WATER HEATING FUEL :
WATER HEATING EQUIPMENT : No DHW system installed

WATER HEATING EQUIPMENT MANUFACTURER	:
WATER HEATING EQUIPMENT MODEL	:
WATER HEATING EQUIPMENT TANK CAPACITY	= 0 Litres
SEASONAL EFFICIENCY	= 0 %

*** ANNUAL DOMESTIC WATER HEATING SUMMARY ***

DAILY HOT WATER CONSUMPTION	= 236 Litres/day
ESTIMATED DOMESTIC WATER HEATING LOAD	= 0 MJ
PRIMARY DOMESTIC WATER HEATING ENERGY CONSUMPTION	= 0 MJ

*** LIGHTING AND APPLIANCES SUMMARY ***

DAILY ELECTRICAL LOAD	= 16 kWh/day
ESTIMATED ANNUAL ENERGY CONSUMPTION	= 5840 kWh

*** R-2000 HOME PROGRAM ENERGY CONSUMPTION SUMMARY REPORT ***

ESTIMATED ANNUAL SPACE HEATING ENERGY CONSUMPTION	= 95787 MJ	= 26607 kWh
VENTILATOR ELECTRICAL CONSUMPTION: HEATING HOURS	= 7726 MJ	= 2146 kWh
ESTIMATED ANNUAL DHW HEATING ENERGY CONSUMPTION	= 0 MJ	= 0 kWh
ESTIMATED ANNUAL SPACE + DHW ENERGY CONSUMPTION	=103513 MJ	= 28753 kWh
ANNUAL R-2000 SPACE + DHW ENERGY CONSUMPTION TARGET	= 61393 MJ	= 17054 kWh
ESTIMATED ANNUAL BASE ELECTRICAL ENERGY CONSUMPTION	= 21024 MJ	= 5840 kWh
VENTILATOR ELECTRICAL CONSUMPTION: NON HEATING HOURS	= 158 MJ	= 44 kWh

*** ESTIMATED ANNUAL FUEL CONSUMPTION SUMMARY ***

FUEL		SPACE HEATING	+ DHW HEATING	+ APPLIANCES	=	TOTAL
NATURAL GAS	(m3)	2570	0	0	=	2570 m3
ELECTRICITY	(kWh)	2146	0	5884	=	8030 kWh

1 m3 natural gas = 37.23 MJ or 10.34 kWh

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Energy units: MJ = Megajoules (3.6 MJ = 1 kWh)

The calculated heat losses and energy consumptions are only estimates, based upon the data entered and assumptions within the program. Actual energy consumption and heat losses will be influenced by construction practices, localized weather, equipment characteristics and the lifestyle of the occupants.

NAHB—RESEARCH FOUNDATION
AIMS

05-10-1990

PROJECT: NONE
HOUSE: BUNKE

START: 14:30 (02-15-1990)
STOP: 16:45 (03-06-1990)

FILE: ESCMS
ANALYZED: 05-04-1990

** RATES **

OVERALL INFILTRATION RATE = 248.2 ± 86.8(m^3/h)
OVERALL AIR EXCHANGE RATE = 0.338 ± 0.120(1/h)

ZONE	ZONE LOCATION	SOURCE RATE @25C (nL/m)	QTY	@T (nL/h)	EXFILTRATION RATE (m^3/h)	SD	INFILTRATION RATE (m^3/h)	SD	ACH (/h)	SD
1	WHOLE HSE	24.1	4	4762	248.2	86.8	248.2	86.8	0.338	0.120

** ANALYSIS **

ZONE	VOL m^3	SOURCE TYPE	AVG. TRACER CONC. (pL/L) ± SD PMCH
1	734	PMCH	19.18 ± 6.43

ZONE	CATS#	CONCENTRATION(pL/L) PMCH	PDCB	PDCH	PMCP
1	26	20.140	0.000	0.000	0.000
1	597	14.015	0.000	0.000	0.000
1	1768	27.904	0.000	0.000	0.000
1	529	14.668	0.000	0.000	0.000

C.F.:	PDCB	PMCP	PMCH	PDCH	COEFFICIENTS FILE
	0.00	0.00	1.00	0.00	3TSCLLL7

** NOTES **

The standard deviation in the source strength has been set at 10 %.
The standard deviation in the volume measurement has been set at 5 %.
STANDARD DEVIATION OF PMCH IN ZONE 1 IS GREATER THAN 25 %