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PERFORMANCE EVALUATION OF THE DYNAMIC WALL HOUSE

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DYNAMIC WALL HOUSE

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ABSTRACT

This paper reports the findings of a demonstration project called the University of Toronto Dynamic Wall House. This project demonstrates the concept and operation of a building ventilated by dynamic insulation during several winter months in Central Ontario. Results obtained from the monitoring of temperatures, pressures and moisture levels have shown that this dynamic wall house performed well in a cold and windy environment. Outside air needed for ventilation was induced to infiltrate slowly and uniformly across the surface of the building. The flow of incoming ventilation air was significantly prewarmed resulting in no cold drafts or cold wall surfaces. Wind had little effect on the infiltrating flow. The house also showed a drying of the exterior walls during the monitoring period. Computer simulation of seasonal heating requirements indicate that there would be energy savings for a dynamic wall house when compared to a similar conventional house.

Keywords

Dynamic insulation, infiltration, ventilation, energy conservation.

EXECUTIVE SUMMARY

The Centre for Building Science, University of Toronto, has been carrying out research on dynamic insulation, moisture dynamics in walls and the effect of negative pressure on building performance. Recently this work involved the design and construction of a house which incorporates dynamic wall insulation.

When this house was completed, a performance evaluation was conducted by the Centre for Building Science for Canada Mortgage and Housing Corporation. The project was undertaken to demonstrate the concept and to monitor the performance of the University of Toronto Dynamic Wall House operating in a cold winter environment. Factors examined were the airtightness of the building, the effect of wind on air supply to the house, incoming dynamic air flows and temperatures, wall surface temperatures, moisture levels and drying of the walls while in dynamic operation, and the performance of a naturally aspirated wood burning stove in a negative pressure environment.

The demonstration was carried out by operating the house in the dynamic mode at normal indoor temperatures for several winter months. Various parameters were monitored during this period either remotely by a data acquisition unit or by readings and observation by the project team members.

Results show that the concepts of dynamic insulation can be applied with few drawbacks to housing and that this dynamic wall house can operate in cold weather and strong winds. The project results show that uniform flow and constant infiltration of ventilation air through the exterior Spun Bonded Polyolefin (SBPO) wrap could be maintained

without adversely cooling the interior wall surface temperatures. Also, the incoming air flow through the walls did not create discomfort because it entered at an extremely low rate and the incoming air was warmed up to a temperature which approached room temperature as it moved through the walls.

A computer simulation of seasonal heating requirements using HOTCAN suggests that there would be an energy saving with the house operating in the dynamic mode when compared to conventional operation.

The University of Toronto Dynamic Wall House has demonstrated the application of dynamic insulation in a residential building. Further work must now be undertaken to examine, under carefully controlled laboratory conditions, the individual components and their role in the operation of dynamic insulation. The effects of wind, air infiltration rate, solar radiation, moisture accumulation and drying and air quality, amongst many others, now have to be isolated and examined individually in the laboratory to see what their contribution is to the complex phenomena which is dynamic insulation.

INTRODUCTION

This report is the presentation of the findings from a performance evaluation of an experimental house which was built incorporating dynamic insulation in its walls. This house is known as the University of Toronto Dynamic Wall House and is located approximately 200 km northwest of Toronto, in Bentinck township, Grey county where it is some 12 km north of Hanover. It is in essentially open terrain. A photograph of the house and surroundings is provided in Figure 1.

The purpose of this report is to present monitoring results of the performance of dynamic insulation in the house. Dynamic insulation has been successfully demonstrated in the laboratory and shows great promise as an advanced building technology, however, not having been incorporated in an actual building there has been no proof that it would operate successfully in the extremes of a Canadian winter. The University of Toronto Dynamic Wall House was built incorporating dynamic insulation and presented an opportunity for performance for testing. This paper presents the findings of a two month monitoring of this dynamic wall house.

The Dynamic Wall Approach to Ventilation

It has been recognized for some time that natural ventilation has major shortcomings: 1) ventilation rates are not controlled but depend on outdoor weather conditions, 2) high energy cost are often incurred when warming the ventilation air to acceptable comfort levels and, 3) under some conditions moisture damage can result from the exfiltration of moist interior air through the building envelope.

In technically advanced housing, such as in the R-2000 program, mechanical ventilation and building airtightness requirements are used to overcome these ventilation shortcomings. Mechanical ventilation ensures that there is a controlled ventilation rate in the building with the opportunity of heat recovery by means of a heat recovery ventilator (HRV). Building airtightness requirements reduce the effects of uncontrolled ventilation due to stack effects and wind and therefore, increase this opportunity for heat recovery. Tight building construction also reduces the potential of moisture damage caused by the exfiltration of moist interior air.

There are three approaches to mechanical ventilation of buildings: 1) balanced pressure approach, 2) positive pressure approach, and 3) negative pressure approach.

In the balanced pressure approach envelope pressures, established by wind and stack, remain unaltered: the volume of ventilation air brought into the house is balanced by the volume of air exhausted. Heat recovery is achieved by transferring heat from warm spent exhaust air to cold incoming fresh air by means of an HRV. Even if the supply and exhaust fans are perfectly balanced, uncontrolled air leakage will occur through the inevitable leakage openings in the building enclosure. A tight envelope, not only during commissioning but throughout the life of the house is therefore essential.

In the positive pressure approach a single fan brings in fresh air from the outside, pressurizing the house in the process.

Positive pressures are used here to exclude contaminants originating from the building enclosure or from the surrounding soil, such as formaldehyde or radon gases. Three major shortcomings of this approach are: (1) heat cannot be recovered from exhaust air, (2) moisture damage to the enclosure may occur and (3) special steps must be taken to heat the incoming cold air.

In the negative pressure approach (of which the Dynamic Wall represents a subset) air is exhausted by means of one or more exhaust fans. All fresh air is brought in through the envelope, either through intentional or unintentional openings. To control the ventilation rate only a single fan needs to be employed. Centrifugal fans, which are relatively insensitive to pressure difference across the fan, provide a simple yet reliable method of controlling ventilation flow rates.

An important difference in the operation of balanced pressure houses compared to positive or negative pressure houses is that in the case of the latter two mass balance dictates that whatever flow is moved by the ventilation fan is automatically matched by air flow through the enclosure. Two parameters determine the flow through the envelope: the equivalent leakage area (ELA) of the envelope and the pressure across the envelope. In tight houses, for example, the ELA is relatively small and house pressure automatically rises to the required level to match the fan controlled ventilation rate.

With the negative pressure approach, as long as the imposed negative pressure is sufficiently large to balance stack and wind-generated positive pressures (i.e. exfiltration causing pressures), heat recovery is possible from all of the exhaust air. Since the imposed negative pressure ensures that only infiltration can occur over the surface of the building, exfiltration is completely eliminated. Therefore, exfiltration-related moisture problems are prevented.

In the balanced-pressure houses some uncontrolled ventilation will always remain so it becomes essential to build and maintain a tight envelope for exfiltration control while the negative pressure approach tolerates a leakier envelope for equal exfiltration control. In other words, performance becomes less sensitive to workmanship and time-dependent loss of airtightness. The first of these requirements has been shown to be achievable in R-2000 houses - but at a substantial premium. The second requirement is only now receiving attention.

In contrast, the negative pressure house offers better short and long-term energy performance at reduced cost. There are important first and operating cost saving potentials:

1. Construction costs are lower since reliance on workmanship to achieve exfiltration control is reduced. The building does not have to be built meticulously airtight which often involves a substantial premium.
2. Simplified internal air distribution systems can be used if it can be shown that fresh air supply to individual rooms through the envelope remains reasonably constant.
3. If heat pump recovered heat from the exhaust air is used to heat domestic water, the house can be pressurized during the summer by reversing fan flow. The heat pump will then continue to provide necessary domestic hot water (DWH). In the process, heat is taken from the incoming ventilation air, thereby providing "free" air conditioning. As the vapour pressure of the now incoming air is reduced, moisture problems in high humidity climatic regions can be reduced. Having the ventilation system double as the air conditioning and DWH system has of course important capital, maintenance and energy cost implications.

With respect to indoor air quality, the coupling of ventilation to domestic hot water provides an assurance that the ventilating equipment is maintained and operated at all times of the year. In contrast, where air conditioners are used without coupled ventilation the poorest indoor air quality occurs during the air conditioning season when the natural ventilation due to stack is weak and wind conditions tend to be calmer.

In the dynamic wall yet another heat recovery opportunity is created by operating the enclosure as a heat exchanger. The concepts of this approach are illustrated in Figures 2 through 4.

Unless fresh air in the negative pressure house is tempered, cold drafts and condensation on wall surfaces will render the approach impractical. One purpose of the dynamic wall is to control air infiltration in such a manner that air supply is controlled both in volume and temperature.

Another important opportunity provided by the dynamic wall is to capture solar heat. The incoming ventilation air is drawn from the immediate surface which can be up to 40°C above ambient air temperature. Solar heat which would be otherwise largely lost due to reradiation of the heat gained now becomes more efficiently utilized.

If there are numerous benefits associated with the negative pressure and dynamic wall approaches, there are also many problems to be resolved and solutions to be verified.

The Dynamic Wall - Background

The concept of dynamic insulation and walls is not new to the authors. The basic theory has been clearly stated by B. Anderlind and B. Johansson: "Dynamic Insulation, A theoretical analysis of thermal insulation through which a gas or fluid flows."

If the dynamic wall concept is relatively simple to express in theory, to produce a practical wall is another matter. Recognizing the unique air flow and moisture diffusion characteristics of spunbonded polyolefin (SBPO), the Centre for Building Science at the University of Toronto embarked on a laboratory evaluation of dynamic insulation. This work was carried out by Mr. M. Lio as a part of his Master of Engineering project work.

In this laboratory work a dynamic wall panel was built comprising of glass fibre insulating sheathing faced with a SBPO air retarder which acts as a weather barrier (Fiberglas "Glasclad" sheathing), wood frame wall with a batt-filled 38x89 mm wood stud wall cavity, polyethylene vapour retarder and drywall air barrier. This wall and modifications of it were evaluated in terms of heat recovery at various flow rates, incoming air temperature, wall surface temperature, sensitivity to flows in the SBPO layer and temperature difference across the wall.

In parallel, the first author of this report designed and built a house employing the dynamic wall concept. This report deals with the evaluation of the performance of the University of Toronto Dynamic Wall House.

THE UNIVERSITY OF TORONTO DYNAMIC WALL HOUSE

Construction was started in August, 1983. The house was built on a 9144 x 6706 mm rubble foundation belonging to an earlier house. To evaluate the airtightness of the SBPO air retarder formed by taping the insulating sheathing sheets to each other, plates, door and window frames, the first floor was deliberately made airtight by means of acoustical sealant between the plywood sheathing and the floor joints. Access to the basement was provided through a gasketed hatch which, for these tests, was screwed to the floor.

Details of the construction are provided in Figure 5. By the summer of 1984 the upstairs ceiling was insulated, provided with a 0.15 mm polyethylene vapour retarder caulked with acoustical sealant and air barrier supported by gypsum board attached by means of screws. The building was tested for airtightness at this stage and found to experience 1.56 air changes per house (ACH) when tested according to Canadian General Standards Board (CGSB) airtightness by fan depressurization method.

By March of 1986 the electrical services and an airtight wood stove had been installed and drywall with taped and filled joints covered the exterior walls. The vapour retarder function was performed by a 0.05 mm stapled (but not caulked) polyethylene sheet. The basement can be considered as well-ventilated crawl space with no insulation between the floor joists.

Parameters Monitored

Data were gathered at the house by manual reading and by automatic recording by means of portable data acquisition units. Parameters monitored automatically were:

1. Outdoor air temperature, one thermocouple, second floor level, N wall, approximately 300 mm from the wall surface.
2. Exterior wall surface temperature (sol-air temperature) at three locations on each of N, E, S and W walls, middle of second floor level. For each wall, two of the thermocouples were in the middle of siding boards exposed to the sun and wind while the third was behind a batten.
3. Attic temperature, one thermocouple.
4. Basement temperature, one thermocouple.
5. Indoor air temperature, a thermocouple for each of first and second floors. Temperatures in each of the three upstairs bedrooms were monitored intermittently.
6. Wet and dry bulb temperatures in the SW bedroom.
7. Incoming dynamic air temperatures, eight thermocouples guarded by radiation and draft shields.
8. Wind speed with a vane type anemometer.
9. Spectral pyranometer mounted on the S wall in a vertical position.

Temperatures monitored in the above nine categories were measured by means of special grade type TT copper-constantan thermocouples. They were, along with the wind speed and solar radiation, sampled automatically on an hourly basis by means of portable Hewlett Packard data acquisition units with results recorded on printer tape. Hourly readings were interspersed with two 2 hour time periods of 5-minute readings.

Manual readings were taken of:

1. Pressure differences (interior/exterior) across the midpoints of the first and second floor walls. Wall cavity pressures were also monitored.
2. Infiltrating air flow rates through all the air inlets.
3. Relative humidity of infiltrating air, one opening on each of the N and S walls, first floor level.
4. Relative humidity and temperature of infiltrating air from first-floor stud cavities which had previously been exposed to induced exfiltration of saturated air at room temperature.
5. Exhaust fan flow rate.
6. Heat flux through the mimic box attached to the upstairs S facing wall.
7. Global solar energy integration for S facing hemisphere.
8. Wall surface temperatures by means of a hand held infrared pyrometer at 15 locations, four heights at each location.
9. Wall surface temperature scans by an infrared camera of all walls.
10. House airtightness characteristics according to CGSB fan depressurization method airtightness test procedures before and after the cutting of ventilation holes into the drywall.
11. Wood moisture content in interior and exterior wall studs by means of a Delmhorst moisture meter.
12. Moisture content in wood samples which were at equilibrium with exterior moisture (after storage in an unheated shed) introduced into two wall cavities. Moisture content monitored by gravimetric methods.
13. Venting performance of the airtight stove.

RESULTS

Airtightness

The dynamic wall house tested is a two-storey, south facing detached building. It has an exposed wall area of 138.2 m^2, floor area of 61.7 m^2, 18.5 m^2 of glazing and 4.7 m^2 of doors. The volume of the building is 316.4 m3.

The dynamic house was carefully built to be relatively free of large air leakage sources so that air would infiltrate slowly and uniformly over the entire main wall area. At several points during construction the building airtightness was measured using the Canadian General Standards Board (CGSB) fan depressurization method.

The first airtightness test was performed when the exterior insulating sheathing was taped and made airtight to the windows and doors. The second floor ceiling was made airtight with caulked polyethylene air barrier/vapour retarder and the first floor/basement was sealed airtight with acoustical sealant between the plywood floor joints. The exterior walls were not yet insulated with batt insulation nor were they drywalled at this point. This first test was then a measure of airtightness achieved by the SBPO outer skin of the building and showed 1.56 ACH at 50 Pascals.

When the polyethylene vapour retarder (the polyethylene was loosely stapled and not caulked thus it did not act as the air barrier) and drywall were installed the house was tested again and found to have an air change rate of 1.33 ACH and an equivalent leakage area (ELA) of 0.014 m^2.

For dynamic operation, fifty-four 25 mm holes (one per stud cavity) were drilled through the drywall and polyethylene vapour retarder on the second floor. These holes were located in the baseboard region of the wall, about 100 mm above the floor. Twenty-five similar holes were drilled through the first floor drywall/polyethylene. The house was again retested for airtightness and it was found that the ELA had increased to 0.017 m^2 and the air change rate to 1.51 ACH.

The drilling of seventy-nine 25 mm holes in the drywall (an area of 0.039 m^2) resulted in an increase in the ELA of only 0.002 m^2. This demonstrates that the airtightness of the building was provided mainly by the taped SBPO and not by the drywall/polyethylene.

This house relies on the SBPO for airtightness and is therefore not a sealed polyethylene "plastic bag" house nor an airtight drywall house.

A further airtightness test was performed with the air intake of the airtight stove taped closed and resulted in the reduction of the ELA by 0.002 m^2 and the air change per hour by 0.11 ACH.

Dynamic Operations

The flow rate selected for operating the dynamic house was the same as specified in the R-2000 Ventilation Requirements and ASHRAE Standard 62-81 for minimum ventilation requirements for residential buildings; namely, 5 L/s per habitable room continuously and an additional 25 L/s that can be supplied as required. This requirement translated to 40 L/s continuously (the house has 8 habitable rooms; 3 bedrooms, 2 bathrooms, dining room, living room and kitchen) and 65 L/s on demand. Forty litres per second corresponds to 0.46 ACH.

Depressurization was achieved by means of one centrifugal fan which was located on the first floor. One fan was sufficient to depressurize the whole house. It was fastened to the gasketed and screwed down basement hatch and it vented into the basement. The basement, in this case, was unheated, sealed from air leakage to the house and very well ventilated. It acted and was treated as a deep unheated crawl space.

Fan speed and therefore air flow was controlled by means of a rotary dimmer switch. Flow through the fan was monitored by measuring the pressure drop in a 100 mm tube which was attached to the inlet of the fan. This inlet tube was calibrated against a sharp edged orifice.

The depressurization achieved in the house at a flow of 40 L/s was approximately 11 Pa.

The performance of the depressurizing fan was monitored under various conditions. The fan output was found to be insensitive to pressure variations across it such as those caused by the opening of doors and windows.

However, the fan speed did vary with line voltage fluctuations. This fluctuation caused corresponding flow variations of a noted maximum of 5 L/s. Line load variations were caused when items such as electric heaters or the water pump were operating. No steps could be undertaken to correct this fluctuation.

Wind

Wind was measured hourly with a Bendix Aerovane Transmitter, a vane (propeller) type anemometer which produced a direct current voltage signal proportional to wind speed. This signal was recorded automatically by the data acquisition unit.

As illustrated in Figure 6, the wind speeds when plotted hourly have quite a range of variation. It is, however, clear that during most of the monitoring period there was a medium to brisk wind blowing, that is between 10 and 30 km/h.

Wind direction was not recorded remotely but was noted by the team members during the period. To augment the wind direction data weather records for the monitoring period were obtained from the two closest weather centres, namely Mount Forest to the southeast and Wiarton to the north.

After the equipment was installed and the house prepared for testing there were two 4-day periods of intensive monitoring. Coincidentally, the wind directions during these periods were different. This allowed for actual observation of the influence of different wind directions on the performance of the dynamic house.

Figures 7 and 8 give a relative ranking of the incoming air temperatures on the four sides of the building during the same hours of the day but with south to southeast winds in Figure 7 and north to northwest winds in Figure 8. As seen in these graphs the direction the wind is blowing from is the side of house with the lowest incoming temperatures but the changes in the incoming temperatures are not large. This suggests that wind does not have a significant effect on dynamic wall performance; that is, incoming ventilation air volume and temperature.

A check of the wind induced pressure distribution around the house was made by the use of "simultaneous" pressure readings of the four sides of the house referenced to indoors. As shown in Figure 9, there is a clear pattern of pressure being higher on the side of the building from which the wind is blowing. These simultaneous readings were taken with a strong wind blowing from the southeast. The wind did produce a momentary but weak negative pressure on the west side of the building. The momentary not negative pressure on the leeward side of the house was not sustained even in a strong wind, suggesting that this particular dynamic house is not subjected to uncontrolled exfiltration even in open windy conditions.

Pressure and Flow

Pressures were measured across the envelope of the house at mid wall level on all sides of the building and on both floors. Pressure differences between the house interior and the stud cavity were also measured in eight stud cavities, four on each floor. These pressures are presented in Table 1.

From Table 1 it can be seen that the average pressure drop across the drywall (the pressure difference between the interior of the house and the stud cavity) was 0.4 Pa at 40 L/s and 1.9 Pa at 63 L/S. At the same time the average pressure across the entire exterior wall (house interior pressure to outside pressure) was 9.1 Pa and 12.7 Pa for 40 L/s and 63 L/s respectively. These measures show that by far the largest part of the pressure drop occurs across the taped SBPO and not the drywall indicating that the SBPO and not the drywall is acting as the main air retarder. Since the SBPO is uniform in air permeability around the entire exterior surface of building, it can be interpreted that the entire surface of the SBPO is infiltrating more or less uniformly and participates in the dynamic wall effect. Lack of cold surface areas on the drywall attributable to uneven air flow supports this conjecture.

The pressure measured across the drywall was compared to the total pressure across the exterior wall. Referred to as the cavity to wall pressure ratio, it is an indication of tightness of the respective drywall surface. Differences between second and first floor cavity to wall pressure ratios were approximately 0.8 to 0.95 respectively. The second floor drywall was caulked and was essentially airtight and resulted in a higher pressure across the drywall than in the first floor. This implies that there is some air flow entering the first floor level through cracks and openings around the first floor drywall other than just through the 25 mm holes drilled into drywall to gather and direct the dynamic flow.

The influence of the different directions of the wind can be seen in Table 1. During the first monitoring period the wind was south to southeast while in the second period it was north to northwest and this is reflected in the higher pressures in the respective windward sides. From Table 1 it is evident that envelope pressures are influenced by wind direction and speed.

Table 1 also presents differences in upstairs and downstairs pressures of 2 to 2.5 Pa. These differences between the floors agree very well with calculated stack effects.

Exterior wall pressures do not vary a great deal among the walls of any one floor. This suggests a relatively even supply of air to all sides of the house.

The last column in Table 1 presents the overall average of the pressure drop across the envelope. At 40 L/s the average depressurization of the house was 9.1 Pa while at 63 L/s the depressurization was 12.7 Pa.

The measures indicate at approximately what levels of depressurization this dynamic house would have to operate if it were to meet the required air exchange rates of the R-2000 Program.

Flows were measured at all 25 mm holes drilled through the drywall and polyethylene by means of a calibrated flow cone and hot wire anemometer. Results of the average recorded flows are presented in Table 2. Here it can be seen that during the first period when winds were from the east to southeast, the flows were highest from these holes. During the second period with winds from the northwest to west, the west holes had the largest flows.

Table 2 shows that even with the different wind direction, the overall infiltrating flows through the holes were low and did not vary significantly. This indicates that there was adequate supply of ventilating air from all exterior walls to the house - an effective ventilation system for supplying and distributing ventilating air to all rooms of the building.

Also from Table 2 it can be seen that the flow through all the 25 mm holes totalled approximately 20 L/s measured while the depressurizing fan exhausted 40 L/s. When the fan exhausted 63 L/s, an air flow of 25 L/s was measured through the drilled holes.

These measured flows do not account for all the dynamic infiltration, only that which actually flows through the holes in the drywall. Lower pressures measured across the drywall of the first floor (which was less tight than the second floor) suggest air flow into the house through cracks and holes other than the drilled 25 mm holes.

Therefore, it can be concluded that at 40 L/s at least 20 L/s or 50% of the exhausted air had infiltrated through the stud cavities, and at 63 L/s that at least 40% infiltrated through the stud cavities. Since there is no way air can enter the stud cavity other than by slow infiltration through the SBPO it can be interpreted that at least this amount of air participates in the dynamic insulation phenomena.

Temperature

As mentioned previously, temperatures were recorded automatically at one-hour intervals interpersed with two 2-hour periods of readings at five-minute intervals. It was found that the resolution of one-hour intervals was sufficient for analysis as the response of temperatures in the wall was relatively slow. Figure 10 is an example of a two-hour period with readings at 5-minute intervals. All graphs in this report are based on hourly monitoring results.

Figure 6 to 8 and 10 to 20 represent two approximately four-day periods. Hour 0 represents midnight of the first day and all subsequent readings are based on their same staring time.

For ease of reference, the first monitoring period, hours 0 to 140, is referred to as the 40 L/s period and the second period, hours 270 to 370, is referred to as the 63 L/s period. This designation is derived simply from the dynamic air flow which corresponds to the two periods.

As can be seen in Figure 6 the outdoor temperature (T_O) was relatively low, averaging about zero degrees Celsius over the two periods but with large fluctuations. The indoor temperature was maintained at approximately 20 degrees Celsius with solar gains raising room temperature above the thermostat set point even on overcast days. Figure 7 presents the average solar radiation striking the south wall. As indicated, there were a few hazy, cloudy days during the first monitoring period with mainly strong sun during the second period.

Figure 11 and 12 show the significant siding temperature rise above ambient air temperature. This is especially evident in Figure 13 where, at about hour 60, the south wall sol-air temperature is some 40°C above ambient. A factor which helped create such a large temperature rise was reflected radiation from snow cover which was present during the first period.

Figure 12 shows clear patterns of temperatures on each side of the house peaking at different times. The first and smallest peak is on the east wall, the south wall temperature has the highest and longest rise and the west wall experiences a shorter but still significant rise later in the day. Even on the north side there is a noticeable sol-air temperature rise. These sol-air temperatures are significant in determining infiltrating air temperatures.

Figures 13 through 20 show the variation of incoming air temperatures (dynamic air) compared to outside ambient temperature (T_o) and the indoor second floor temperature (T_i) for all four walls and under two dynamic infiltration levels. In all cases the significant effect of the solar radiation can be seen in the rise of temperature of the dynamic air during the sunny times of the day.

Also evident is the effect the different levels of air flow have on the incoming air temperatures. During the monitoring at 40 L/s the incoming temperatures were close to ambient room temperature even exceeding it briefly on extremely sunny days on the south and west walls (Figures 13 and 19).

The general tempering of the infiltrating air can be defined as the proportion of the total inside/outside temperature difference. This calculation is presented in Table 6, and is about 82% at the flow of 40 L/s, that is, the incoming air has been preheated by about 80% of the absolute indoor/ outdoor temperature difference. At 63 L/s the tempering is only about 63% as the air is drawn at a greater velocity and does not have an opportunity to warm up to the same levels.

The actual increase in the temperature of the incoming air varies with the indoor/outdoor temperature difference. The rise in temperature experienced by the incoming air is presented in Figure 21 and, as is evident, varies considerably. During the 40 L/s monitoring period the average rise appears to be about 15°C while during the 63 L/s period it varies much more but appears to be at least 10°C.

The mean incoming air temperature at 40 L/s appears to be about 17°C while at 63 L/s it is closer to 14°C which would create a cold draft were it not for the low velocities and quantities of air through the individual holes.

The results presented in Figure 13 to 20 clearly show that the incoming air has been heated to a temperature above ambient exterior temperatures and actually enters the house close to indoor temperature suggesting that there should be no cold spots on the walls caused by the infiltrating air. This was confirmed by two scans of all the exterior walls by an infrared thermographic camera. The thermography revealed no unusual cold spots on the walls even with outdoor temperatures of -20°C and a flow of 63 L/s.

These results were reinforced by repeated readings of drywall temperatures with a hand held infrared pyrometer. Wall temperature results from these scans are presented in Table 7.

Overall it can be seen that in the University of Toronto Dynamic Wall House ventilation air is preheated to a significant degree of the indoor/outdoor temperature difference. Also, no cold spots result from this flow and therefore little risk of increased wall surface condensation exists. Discomfort due to drafts is not a concern because of the very high level of preheating and the very low incoming velocities and quantities.

Moisture

Three moisture related studies were performed at the house: wood drying experiment, stud moisture content monitoring and induced moisture experiment. The findings are summarized below.

I. Wood Drying Experiment

In this test a 250 mm wide x 900 mm high panel of drywall was removed from the upper portion of an exterior wall cavity on the ground floor of each of the north and south walls. A piece of lumber, which had been stored outdoors in an unheated shed, was weighed, moisture content measured and inserted into each cavity. The cavities were then resealed and a 25 mm hole was drilled through the drywall to permit the cavity to infiltrate in the dynamic mode for a period of two months (March 12 to May 14).

After the two month period, during which the house was infiltrating in the dynamic mode, the two pieces of wood were removed from the respective exterior wall cavities. They were then weighed again and had their moisture contents measured. Results are presented in Table 3.

As shown in Table 3 the weight loss of the sample pieces of lumber was about 5% and the reduction in moisture content was 2.5 to 3.5%. This shows that the dynamic house had a significant drying of the exterior walls although the relative proportions of this drying due to the house being heated and the dynamic air flow through the wall cannot be determined by this test.

II. Stud Moisture Content Monitoring

The moisture content of two south wall and two north wall studs was measured at the beginning of the experiment with a Delmhorst Wood Moisture Meter. After two months of heating and dynamic operation, the moisture content was again measured. Results are presented in Table 4.

As the readings show, there was a reduction in the moisture content of the studs at all locations where readings were taken. This shows that there is drying taking place in the heated and dynamically operated building. As noted above, it cannot be determined what portion of the drying of the wood was a result of the dynamic air flow and what portion was attributable to normal drying of the exterior walls.

The moisture content of two interior studs was also measured at the end of the drying period. The interior studs were found to have a moisture content of between 9.0 and 9.2%.

III. Induced Moisture Experiment

In this experiment moisture was introduced from the inside of the house into two ground floor wall cavities (one on the north and one on the south side) by means of two small pumps blowing in moist air through the 25 mm air hole in the bottom of the cavity. For a seven day period these two cavities were exfiltrating due to the pressurization from the pumps.

After the seven day period the pumps were disconnected and vapour pressures were monitored as the cavities were now allowed to infiltrate in the dynamic wall mode. At the same time incoming vapour pressures were also measured in a north and south wall cavity which had been continuously infiltrating and acted as references. Results are presented in Table 5.

Results in Table 5 show that the vapour pressure of the incoming air, whether from the test or reference cavity, was always higher than the outdoor vapour pressure. This indicates that drying of the walls was taking place in both the sections which had moisture pumped in as well as the continuously infiltrating reference sections.

Upon disconnection of the pumps the south wall shows an immediate and continuous greater vapour pressure in the test cavity when compared to the reference cavity.

When the pumping of moist air into the north cavity was stopped, the test cavity appears to initially infiltrate at a lower vapour pressure than the reference cavity. This continued through the night (the pumps were disconnected at 19:50 at which time the outside temperature was -18°C) and into the late stages of the following morning.

During the later stages of the following morning and during the following days the incoming vapour pressure of the test cavity increased to and remained at a higher level than the reference cavity. It is hypothesized that some of the moisture that was pumped into the wall was stored as ice in the wall and was released the next morning as the outdoor temperature increased, thus accounting for the period of lower moisture levels during the first night.

Both the north and south test cavities then continued to infiltrate at higher vapour pressures indicating that the test cavities were "wetter" than the reference cavities.

Although all cavities were shown to be drying conclusion cannot be drawn with respect to the driving forces which influence this drying.

Heat Flux

Heat flow from the room into the second floor south wall of the house was measured with a calibrated "mimic box" heat flow metering apparatus. Resulting heat loss values are presented in Figure 22 and 23. The results show clear cyclical patterns corresponding to day/night and outdoor/indoor temperatures.

It was expected that the dynamic operation of the wall would result in somewhat higher conductive heat loss from the room into the wall, but due to heat recapture by the infiltrating air, the net conductive heat loss from the wall to the outside would be lower than from a similar wall which was not infiltrating dynamically.

Actual heat flow readings obtained were too "noisy" to be used to establish whether the heat loss increased through the wall or not. The results are at about the same levels expected as in non-infiltrating walls. This can only suggest that conductive heat loss from the room increased only marginally.

Heating Performance

The main purpose of dynamic insulation is to provide a continuous uniformly distributed supply of prewarmed ventilation air to a building, thereby reducing space heating costs. Instead of having to heat ventilation air from ambient outdoor temperatures to room temperature before distribution in the house, dynamic house ventilation air would require little if any heating. In addition, as mentioned in the introduction, heat recovery can be added to the exhaust side of the depressurization fan, although this step is strictly optional.

In an attempt at simulating what the savings may be for a dynamic house (such as the one tested) four runs of the HOTCAN energy analysis program were performed. Data used were the actual building envelope areas and the degree days for Hanover, Ontario (4339 degree days).

The basic reference run was the house as actually built but with an assumed floor insulation of R-4.9. As mentioned previously, the basement is treated as a deep unheated crawl space. There was no heat recovery assumed on the ventilation air in <u>any</u> of the runs, except where this feature is used to simulate dynamic air prewarming (i.e. neither the conventional nor the dynamic house are credited with any heat recovery from the exhaust of the mechanical ventilation system). The mechanical ventilation is assumed to provide 0.46 ACH for all runs.

Because HOTCAN cannot calculate reduced insulation values by "air washing" the effect of the reduced R-value (and increased conductive heat loss through the wall) was simulated by reducing the R-value of the wall insulation to 90% of the actual installed value. The 90% effective R-value is supported by previous laboratory results.

To simulate the heating credit obtained from the prewarming of the dynamic ventilation air the heat recovery option of HOTCAN was used. Since the results obtained at the dynamic wall house suggest a prewarming of at least one half of the ventilation air to 80% of the net indoor/outdoor temperature difference this dynamic heat recovery effect was simulated in HOTCAN by entering an HRV efficiency of 0.8 on half the ventilation air.

The first run, used as a reference, is the "conventional" house, full insulation value, no dynamic insulation credit. The second run is the same house but with only 90% of the R-value of the wall insulation. This run simulates the effect of an increase in conductive heat loss through the walls of about 11% but is still a "conventional" house.

Run three simulates the reference house with full R-value (no increased conductive heat loss) and a credit for dynamic insulation prewarming of the ventilation air. This would occur if a conventional house could be operated dynamically without additional conductive heat loss.

Run four simulates the dynamic wall house with a reduction in wall insulation (ie. 11% increase in conductive heat loss) and a credit for ventilation air prewarmed by the dynamic insulation. This run is the simulation of the dynamic wall house.

Results of these runs are presented in Table 8. As seen in Table 8 a reduction in the effective R-value would, by itself, increase space heating costs by about 5% (run two). The reduction in heating requirements by preheating of the ventilation air by dynamic action alone is about 18% (run three). The combination of the reduced effective R-value (to 90%) and a heat recovery efficiency of 80% on half the incoming air would result in a net space heating requirement of 86% of the non-dynamic house (run four).

The sum effect of a reduction in the effective R-value and heat recovery on the ventilation air would be net saving of 1311 kWh per heating season. This translates to some 1311 x 0.08¢/kWh = $105/year.

Although only a rough first attempt at calculating benefits to be accrued by dynamic insulation the HOTCAN runs do show that there would be a net benefit of operating this house in the dynamic mode.

It should also be noted that there are added heat recovery opportunities created by the dynamic house that were not included in these modified HOTCAN runs. These are available at the single point exhaust stream of the depressurizing fan. This exhaust of warm air can be tapped by a heat pump to provide space heating or domestic hot water. The system can be reversed in the summer months to cool the house while continuing to provide domestic hot water year round. The conventional house also has recovery opportunities (HRV for mechanical ventilation) which were not included in these runs.

Airtight Stove

The performance of the airtight stove under negative pressure was evaluated by starting a fire in the stove, adding a significant amount charcoal to the firebox, then allowing it to die down. Monitored during this time were the temperature in the chimney flue and the carbon monoxide and oxygen levels about 100 mm outside of the stove's fresh air intake. Recording was done automatically by a data acquisition unit.

Results of this experiment are presented in Figure 24. Here it can be see that a significant spillage of carbon monoxide into the house began at the 200-minute time period even though the temperature in the stove flue (at about 50°C) was still well above room temperature.

This simple demonstration shows that, in a negative pressure house, any naturally aspirated combustion appliance has to be equipped with a separate supply of combustion and dilution air and that the system should be isolated away from the negative pressure of the house.

CONCLUSION

This project has demonstrated that the University of Toronto Dynamic Wall House design and implementation of dynamic insulation can operate during the winter months in Central Ontario, under a negative pressure and supply a relatively constant and uniform supply of prewarmed ventilation air from all sides of the building without producing cold drafts or cold wall surfaces. The flow was sufficient to meet the R-2000 ventilation air requirements.

Moisture related tests performed in the dynamic wall house showed a drying of the exterior walls. Whether or not and to what extent the dynamic operation of the building contributed to the drying of the walls could not be determined in this project.

The measurement of heat flux through the dynamic wall was inconclusive as to what extent, if any, the conductive heat loss was increased. Because the readings were not drastically different than they would be for a conventional wall, it can be reasoned that conductive heat loss did not increase greatly.

The University of Toronto Dynamic Wall House performed well in this demonstration and technical evaluation. In a preliminary energy analysis using HOTCAN the house, if operated all year round in the dynamic mode, would appear to be less costly to operate.

The results obtained can only apply to this one implementation of dynamic insulation and do not apply to all negative pressure houses.

While successfully demonstrating that the concept works there are still many refinements, confirmations, and experiments to be done. Some of the questions raised by this study and which can only be answered by further research in controlled laboratory conditions are: What is the increase in wall heat loss by conductivity? What is the heat flux through the wall? What role did the dynamic infiltration have in the apparent drying of the house walls? In what temperature range will dynamic insulation be effective? Is the attempted simulation of heat loss performance by HOTCAN accurate?

There are also other questions which need to be answered relating to dynamic insulation. Questions such as how does dynamic insulation impact indoor air quality. Whether the slow infiltration of air into the building increases moisture levels in walls. What effect will rain have on wall moisture levels? How can the benefits of solar radiation be best utilized. What design improvements can be made to the dynamic house, the walls and the air distribution system?

Overall, this project has demonstrated that the University of Toronto Dynamic Wall House implementation of the dynamic insulation concept is a success, in as much that the building does provide a continuous source of prewarmed ventilation air to all rooms of the house without creating drafts or cold wall surfaces.

TABLE 1
Pressures (Pa)

1986 03 date	hour	1-N	CAV	1-W	CAV	1-S	CAV	1-E	CAV	2-N	CAV	2-W	CAV	2-S	CAV	2-E	CAV	Averages 1-NS	1-EW	2-NS	2-EW	Total Avg	
40 L/s flow, E to SE wind																							
13	9:35	8.5	0.1	5.5	1.1	11.0	0.2	13.0	0.0	4.5	1.8	6.0	2.2	8.0	0.0	13.0	0.5	9.8	9.3	6.3	9.5	8.7	
13	12:00	5.0	0.4	3.2	0.4	22.0	1.0	21.0	0.4	4.0	0.7	1.8	0.8	10.0	1.3	16.3	1.1	13.5	12.1	7.0	9.1	10.4	
13	15:00	8.0	0.3	7.2	0.7	13.8	0.9	16.0	0.1	5.0	2.2	5.3	1.8	8.5	1.8	15.5	2.3	10.9	11.6	6.8	10.4	9.9	
14	8:15	7.1	0.6	7.0	1.0	15.2	0.8	2.5	0.4	5.4	1.8	5.2	1.9	8.8	1.8	8.0	1.1	11.2	4.8	7.1	6.6	7.4	
14	13:00	9.4	0.5	8.9	1.0	11.8	1.0	7.7	0.2	7.5	2.3	7.8	2.9	9.9	1.8	7.8	1.4	10.6	8.3	8.7	7.8	8.9	
																							CAV
avg		7.6	0.4	6.4	0.8	14.8	0.8	12.0	0.2	5.3	1.8	5.2	1.9	9.0	1.3	12.1	1.3	11.2	9.2	7.2	8.7	9.1	1.4
std dev		1.5	0.2	1.9	0.3	3.9	0.3	6.4	0.2	1.2	0.6	1.9	0.7	0.8	0.7	3.6	0.6	1.3	2.6	0.8	1.3	1.0	
63 L/s flow, N to NW wind																							
20	19:15	9.6	0.4	14.2	2.2	13.7	1.2	9.8	0.2	5.8	2.3	10.5	3.5	8.0	0.8	7.6	1.2	11.7	12.0	6.9	9.1	9.9	
20	12:15	24.0	1.8	9.8	2.2	12.6	1.5	13.9	0.2	28.0	8.0	5.0	1.6	8.2	1.4	7.0	1.0	18.3	11.9	18.1	6.0	13.6	
20	16:45	15.0	0.8	13.0	2.1	10.4	0.9	10.8	0.4	14.0	4.0	10.0	3.4	7.8	1.2	6.4	1.1	12.7	11.9	10.9	8.2	10.9	
21	11:25	13.8	0.4	22.0	2.0	23.0	0.8	11.8	0.1	7.4	2.4	24.0	7.2	21.0	2.8	8.8	1.2	18.4	16.9	14.2	16.4	16.5	
																							CAV
avg		15.6	0.9	14.8	2.1	14.9	1.1	11.6	0.2	13.8	4.2	12.4	3.9	11.3	1.6	7.5	1.1	15.3	13.2	12.5	9.9	12.7	1.9
std dev		5.2	0.6	4.5	0.1	4.8	0.3	1.5	0.1	8.8	2.3	7.0	2.0	5.6	0.8	0.9	0.1	3.1	2.2	4.1	3.9	2.5	

- first floor avg pressure @40L/s = 10.2 Pa, CAV pressure = 0.55 Pa
- first floor avg pressure @63L/s = 14.2 Pa, CAV pressure = 1.08 Pa

- second floor avg pressure @40L/s = 7.9 Pa, CAV pressure = 1.58 Pa
- second floor avg pressure @63L/s = 11.3 Pa, CAV pressure = 2.7 Pa

- 1/2-N/W/S/E are first/second floor pressures read across the respective wall and referenced to inside pressure.
- CAV are cavity pressures read at the floor and wall immediately to the left.
- pressures were read with a portable digital micromanometer, resolution of 0.1 Pa.

TABLE 2
Cavity Flows (L/s)

date	time	wind (km/h)	avg W	avg S	avg E	avg N	2nd fl avg	1st fl avg	2nd tot	1st tot	total
12	17:00	24 E	0.13	0.28	0.35	0.28	0.27	0.25	15.42	6.34	21.75
13	8:55	18 E	0.17	0.15	0.27	0.21	0.20	0.24	11.17	5.98	17.15
13	11:30	12 E	0.12	0.29	0.35	0.28	0.27	0.27	15.41	5.72	21.14
13	15:00	10 E	0.18	0.26	0.29	0.27	0.25	0.28	14.37	5.80	20.16
14	8:15	9 E	0.20	0.25	0.23	0.22	0.24	0.24	13.65	5.04	18.69
14	12:30	8 E	0.23	0.26	0.26	0.30	0.26	0.25	14.90	5.26	20.15
		avg	0.17	0.25	0.29	0.27	0.25	0.26	14.15	5.69	19.84
		std d	0.04	0.05	0.05	0.03	0.03	0.01	1.47	0.43	1.53
20	16:50	8 NW	0.28	0.22	0.23	0.45	0.28	0.29	15.96	6.59	22.55
20	12:00	30 NW	0.25	0.22	0.26	0.57	0.31	0.32	17.44	6.66	24.10
21	7:40	W	0.36	0.32	0.24	0.30	0.30	0.32	17.18	6.77	23.95
21	11:00	18 W	0.44	0.37	0.28	0.31	0.35	0.34	19.92	7.24	27.16
		avg	0.33	0.28	0.25	0.41	0.31	0.32	17.63	6.81	24.44
		std d	0.07	0.06	0.02	0.11	0.03	0.02	1.44	0.25	1.68

- flows were measured using a calibrated nozzle and hot wire anemometer.

TABLE 3

Wood Drying Experiment

(Weight and Moisture Content)

		Start	Finish	Difference
North Wall	Weight	924.8 g	868.0 g	56.8 g
	Moisture Content	12%	8.5%	3.5%
South Wall	Weight	979.7 g	930.9 g	48.8 g
	Moisture Content	12%	9.5%	2.5%

(Moisture Contents were measured using a Delmhorst Wood Moisture Meter)

TABLE 4

Stud Moisture Content (%)

	E Stud		W Stud	
	Start	Finish	Start	Finish
North Wall				
Outside Edge	11.5	10.3	12.6	11.5
	10.6	10.5	11.5	11.3
Inside adge	10.3	10.0	10.3	10.3
	10.8	9.8	10.7	10.5
South Wall				
Outside Edge	10.6	10.0	10.6	9.3
	10.5	9.8	9.6	8.8
Inside Edge	10.6	10.3	9.7	8.8
	11.0	10.0	10.2	8.8

(Moisture Content was measured with a Delmhorst Wood Moisture Meter)

TABLE 5
Moisture Study

		Vapour Pressure (Pa)					
		North Wall		South Wall			
date	time	reference #14	test #9	reference #21	test #23	house	outdoors
03 20	19.50	527	472	363	415	600	
	19.50	495	463	320	415		
	19.50	511	463	392	415		
03 20	22.00	407	374	308	351	463	
03 21	7.15	184	279	319	331	418	271
	8.00	351	336	328	341	505	271
	10.20	449	463	351	389	569	259
	11.00	528	559	400	415	613	251
	11.25	636	690	494	479	636	243
03 23	11.15	1110	1401	819	872	872	631
	14.05	1320	1492	984	984	983	883
03 30	9.22	1374	1480	1507	1559	1295	1189

- vapour pressures were measured with an electronic moisture sensor and a sling psychrometer

TABLE 6
Tempering Effect

	Wind		
	S,SE	N,NW	
	Flow		
	40 L/s	63 L/s	overall
South	0.83	0.67	0.75
East	0.71	0.59	0.64
North	0.81	0.61	0.71
West	0.92	0.66	0.78
Average	0.82	0.63	0.72

- tempering is defined as the portion of the total outside/inside temperature difference the incoming air temperature is warmed up to.

TABLE 7
Wall Surface Temperatures (C)

Height	W Stud	W Wall	S Stud	S Wall	E Wall	N Wall	N Wall, no hole
	1986 03 12 14:30 medium east wind, cloudy, dull						
top	21.1	21.6	21.1	21.1	21.1	21.1	21.1
upper mid	21.4	21.6	21.1	21.1	21.1	21.1	21.1
lower mid	21.6	21.6	21.1	21.1	20.5	20.5	21.1
bottom	21.6	21.1	20.5	20.5	20.0	20.0	20.5
	1986 03 12 17:00						
top	20.5	20.7	20.0	20.5	20.0	20.1	20.5
upper mid	20.5	21.1	20.5	21.1	19.4	20.1	20.5
lower mid	20.5	20.5	20.5	20.5	19.4	20.0	20.0
bottom	20.5	20.0	20.0	20.0	18.6	18.8	20.0
	1986 03 13 8:55 east wind, 20 km/h, rain						
top	20.0	20.0	19.4	20.0	21.1	20.5	21.1
upper mid	19.4	19.4	19.4	20.0	20.0	20.5	20.0
lower mid	19.0	19.4	18.8	19.2	19.4	19.4	19.4
bottom	19.4	18.8	18.3	18.3	18.3	18.3	18.8
	1986 03 13 11:30 east wind, 20 km/h, rain						
top	20.5	20.5	20.0	20.0	20.5	20.5	21.1
upper mid	19.4	20.0	20.0	20.0	20.5	20.5	20.5
lower mid	19.4	20.0	19.4	20.0	20.0	20.0	20.0
bottom	19.4	19.4	18.3	18.8	18.3	18.3	19.4
	1986 03 13 15:00 south east wind, 18 km/h, 3.5 C, cloudy						
top	20.5	20.8	20.0	20.5	20.8	20.5	21.6
upper mid	20.0	20.5	20.0	20.0	20.5	20.7	21.1
lower mid	20.0	20.0	20.0	20.0	20.0	20.0	20.5
bottom	20.0	20.0	19.4	19.4	18.8	18.8	20.0
	1986 03 14 8:15 south east wind, 8 km/h, rain						
top	20.5	20.5	20.0	20.0	21.1	20.5	21.3
upper mid	19.4	20.0	20.0	20.0	20.5	20.0	20.5
lower mid	19.4	19.4	19.4	20.0	19.6	20.0	20.0
bottom	19.4	19.4	18.8	18.8	18.8	18.8	19.4
	1986 03 14 12:30 south east wind, 8 km/h, 7 C, fog						
top	20.0	20.5	20.5	20.5	20.5	20.5	21.1
upper mid	20.0	20.5	20.5	20.5	20.5	20.5	20.5
lower mid	20.2	20.5	20.0	20.5	20.5	20.0	20.5
bottom	20.5	20.0	20.0	20.0	20.0	19.4	20.0
	1986 03 21 11:15 west wind 15 to 20 km/h						
top	18.8	20.0	20.0	20.5	21.6	21.1	20.0
upper mid	18.8	20.0	20.0	20.5	21.1	20.5	20.0
lower mid	18.3	18.8	19.4	19.4	20.0	20.0	18.8
bottom	18.3	18.0	18.3	18.3	18.8	18.3	18.3

- W/S Stud are wall surface temperatures measured over a wall stud.
- W/S/E/W Wall are wall temperatures measured at the centre of an exterior stud cavity.
- top, upper mid, lower mid, bottom refer to the height at which wall temperatures were measured and represent heights of approximately 2100, 1500, 900 and 300 mm.
- N Wall, no hole are wall temperatures measured in the centre of a cavity on the North wall which had no infiltration hole.
- wall temperatures were read with a hand held infrared pryometer.

TABLE 8

Estimated Annual Space Heating Requirements

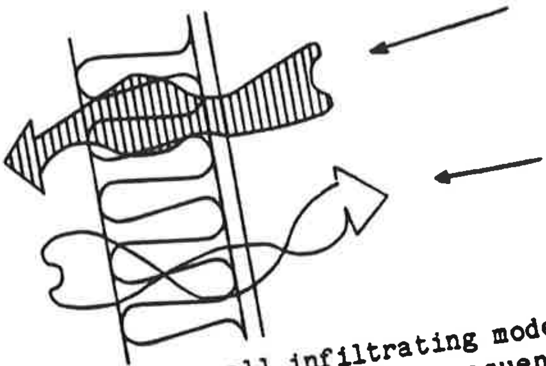
Heat Recovery	Wall R-value		
	100% effective R	90% effective R	
	3.29 m^2 K/W	2.96 m^2 K/W	
0%	Run 1	Run2	Difference
	9 576 kWh	10 048 kWh	6%
80 %	Run 3	Run 4	
on 0.23 ACH	7 813 kWh	8 265 kWh	6%
Difference	18%	18%	14%

(Estimates were made using version 4.02.02 of HOTCAN Energy Analysis Program)

FIGURE 1

Photogragh Showing the Southern Face of the Test House
and Unsheltered Site.

FIGURE 2

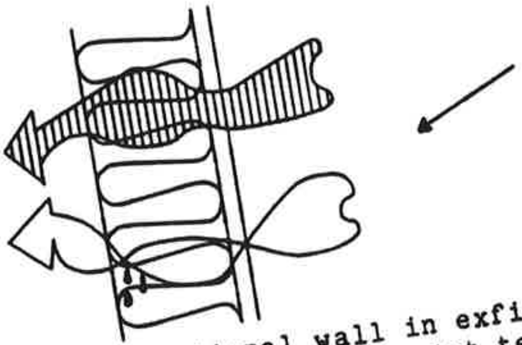


Heat loss primarily by conduction through opaque part of wall.

Infiltrating air essentially at outdoor temperature.

Normal wall infiltrating mode. Incoming air does not "mingle with escaping heat", consequently little of escaping heat is recaptured while incoming air is cold, leading to potential comfort problems.

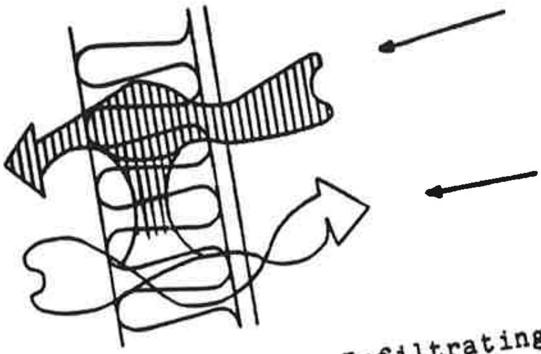
FIGURE 3



Exfiltrating air may shed some of its water when cooled below the dew point.

Conventional wall in exfiltrating mode. Air exiting is cooled below the dew point temperature whereby condensation occurs. No energy recovery from exfiltrating air.

FIGURE 4



Part of escaping heat used to warm incoming air.

Ventilation air enters building in a warmed state.

Dynamic Wall. Infiltrating mode only. Uniform flux c
incoming ventilation air heated by part of escaping hea
Improved energy efficiency both for incoming air and exhaust a
Condensation due to exfiltration is eliminated. Ventilati
air supplied to all rooms.

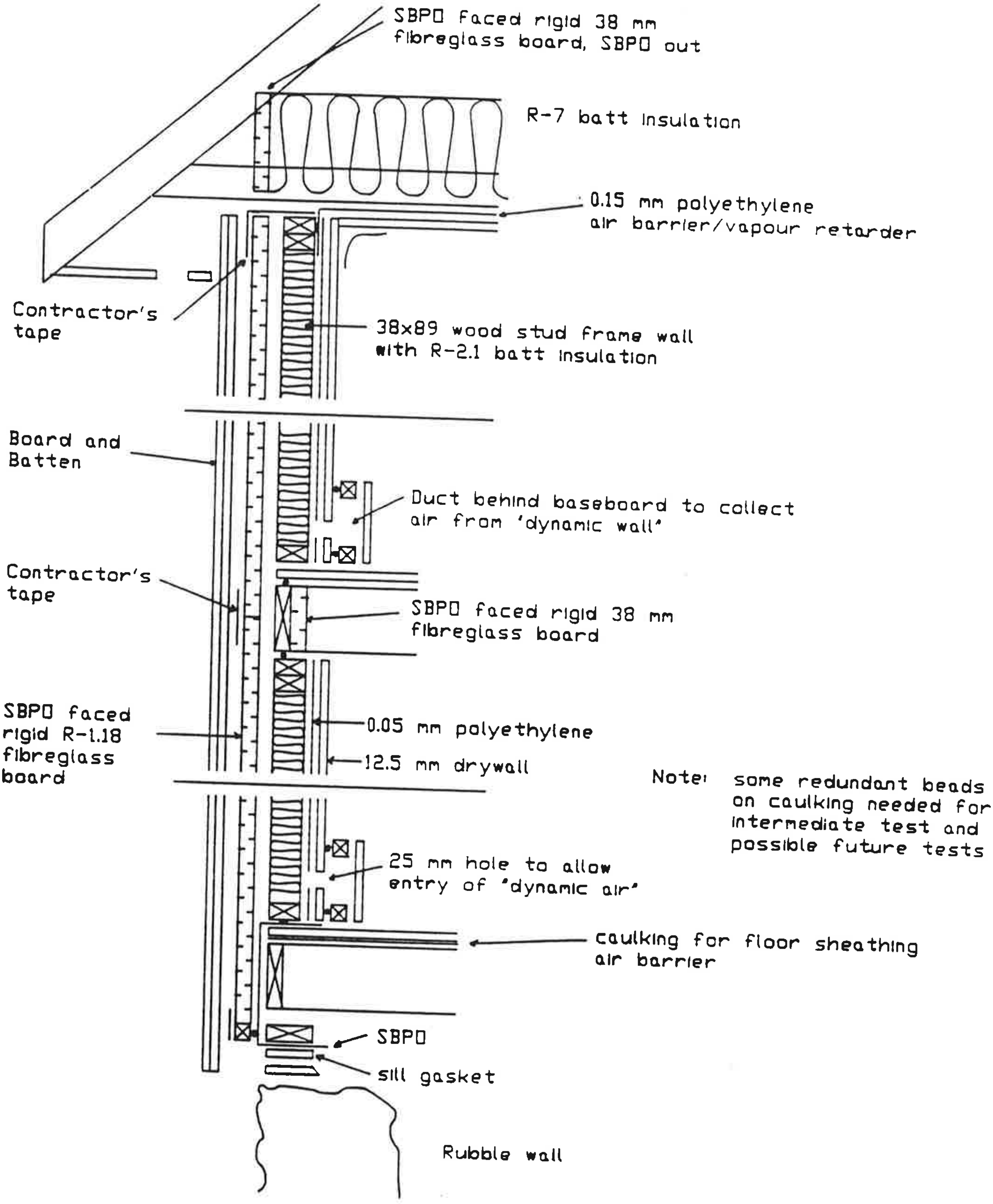
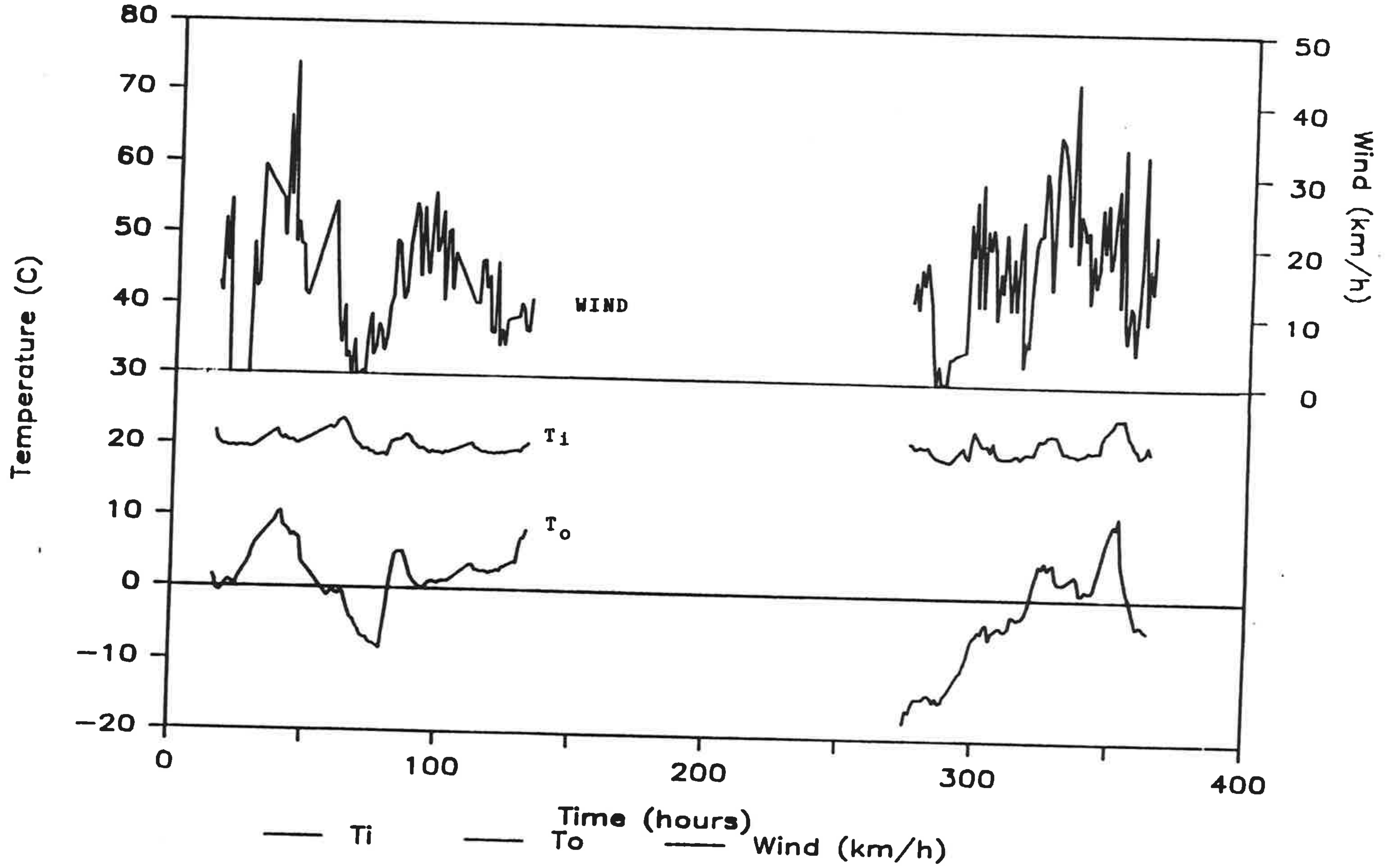


FIGURE 5

Wall Details
University of Toronto Dynamic Wall House
Bentinck Township

FIGURE 6



Wind and Temperature

FIGURE 7

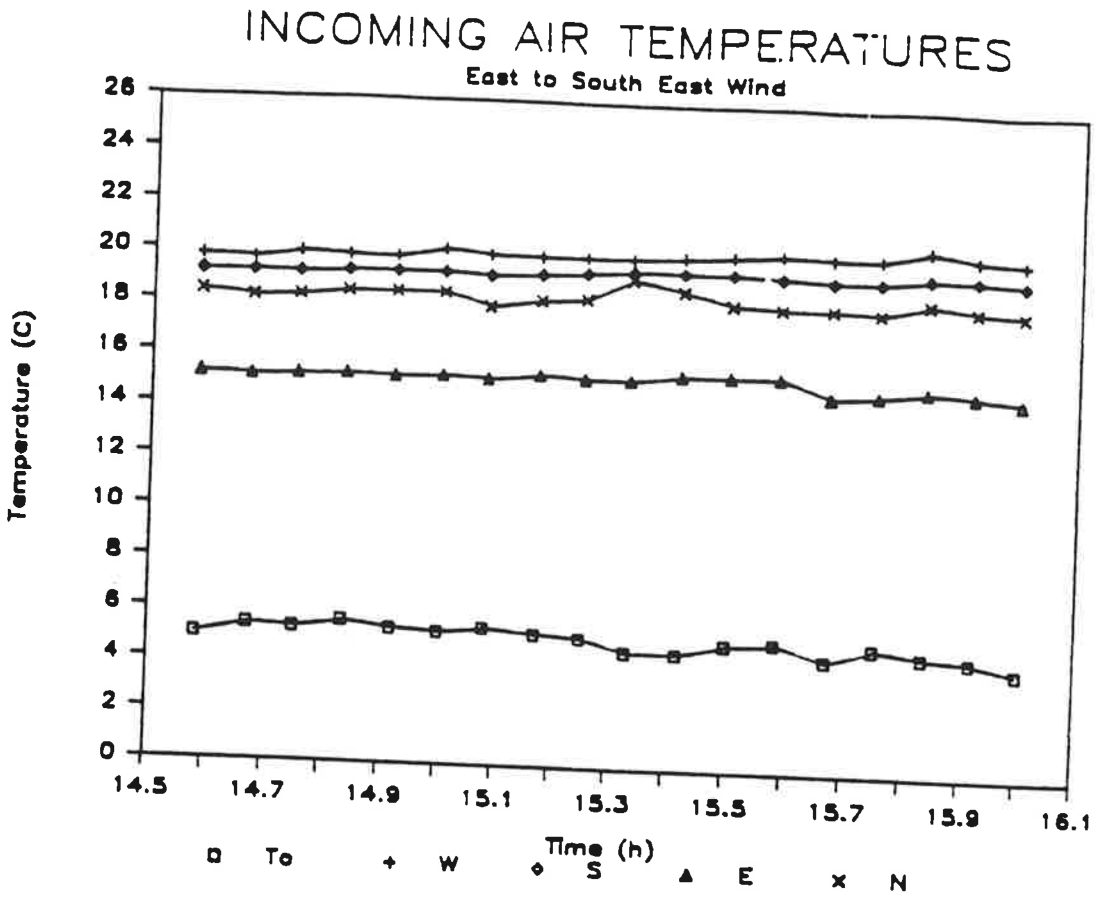


FIGURE 8

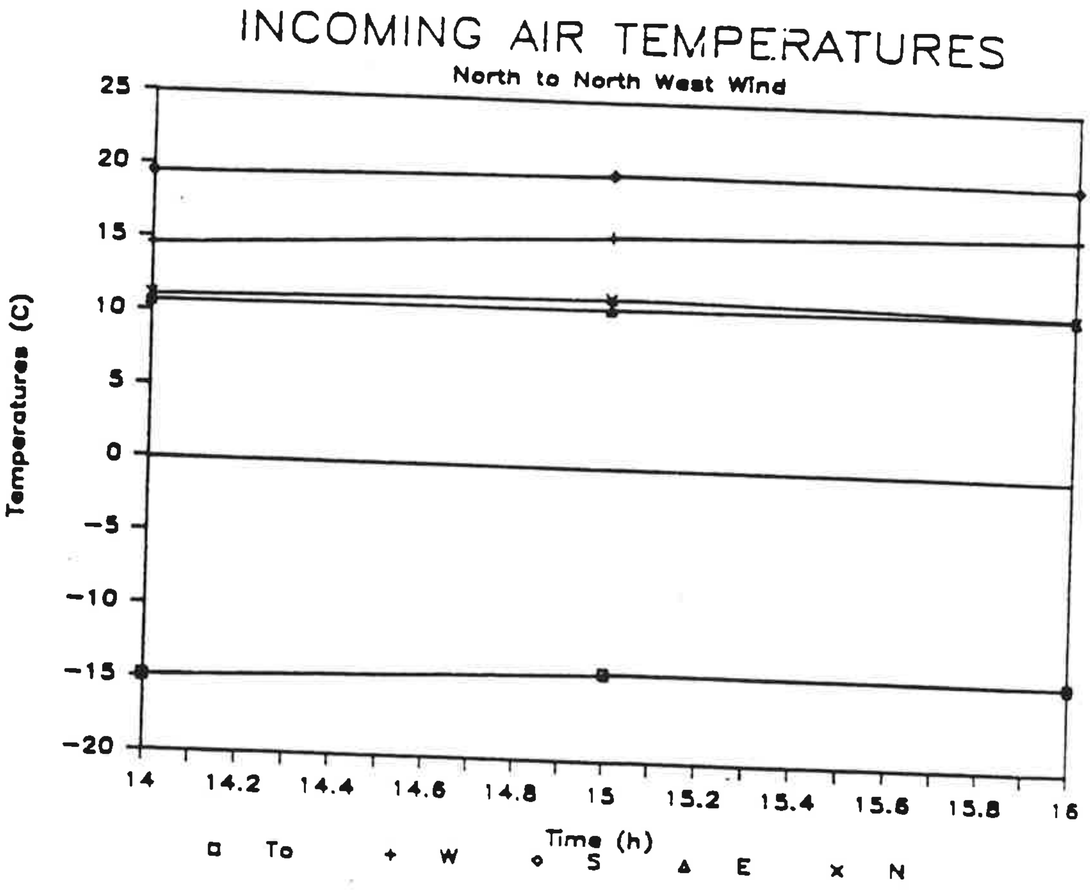


FIGURE 9

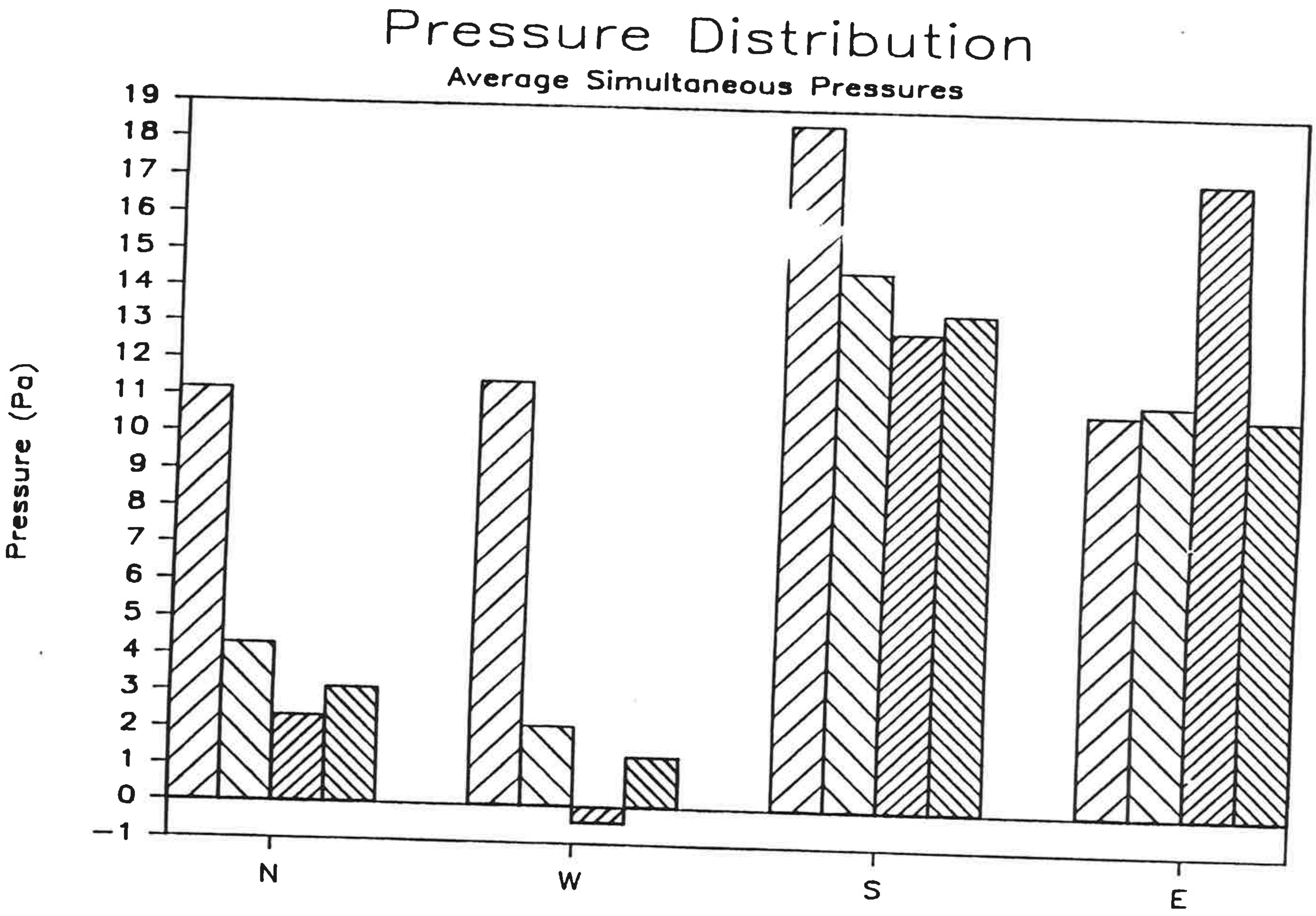

Pressure Distribution
Average Simultaneous Pressures
Pressure (Pa)
19
18
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
−1
N
W
S
E

FIGURE 10

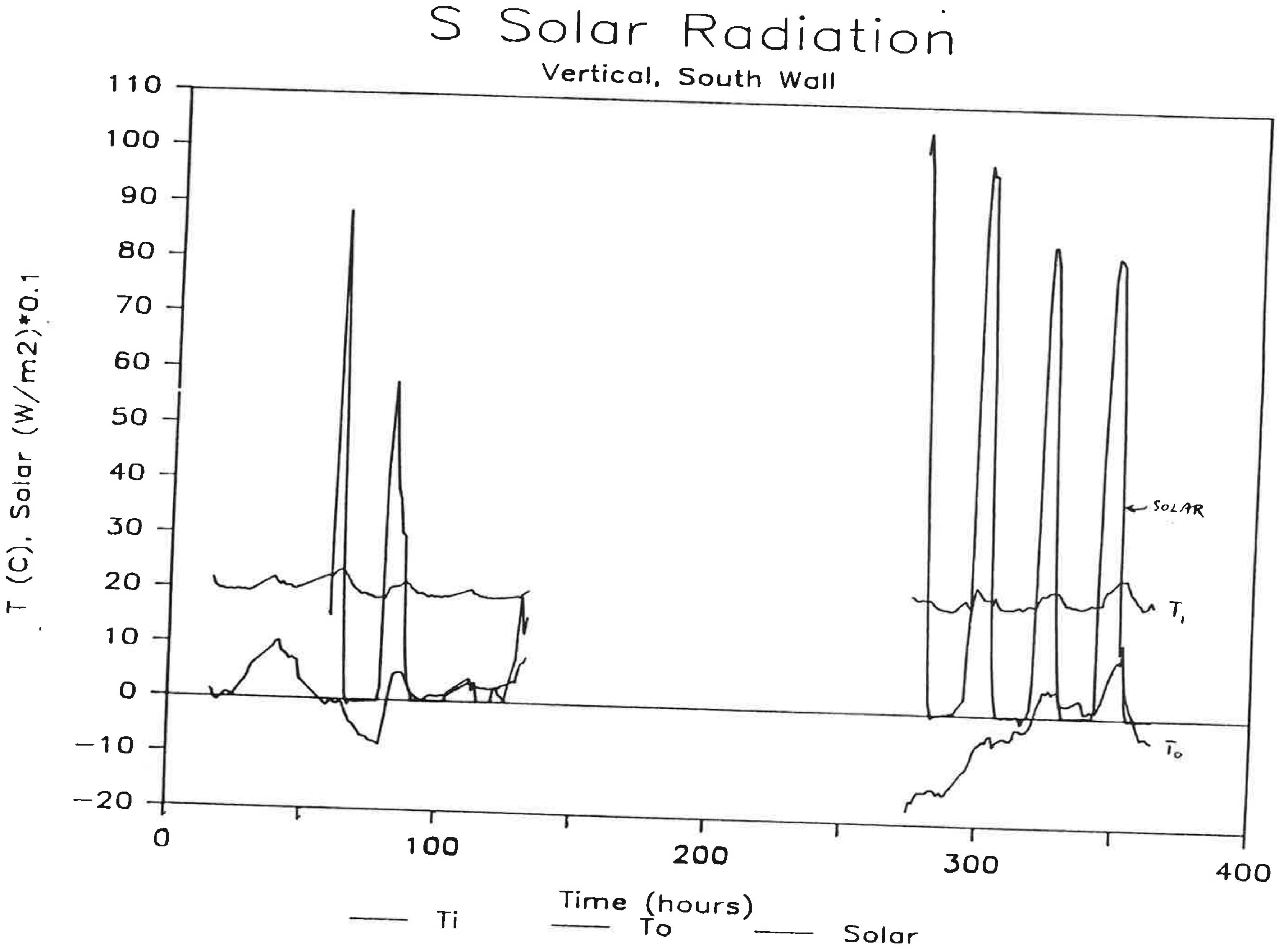

S Solar Radiation
Vertical, South Wall
T (C), Solar (W/m2)*0.1
110
100
90
80
70
60
50
40
30
20
10
0
−10
−20
0
100
200
300
400
Time (hours)
SOLAR
T_i
T_o
Ti
To
Solar

FIGURE 11

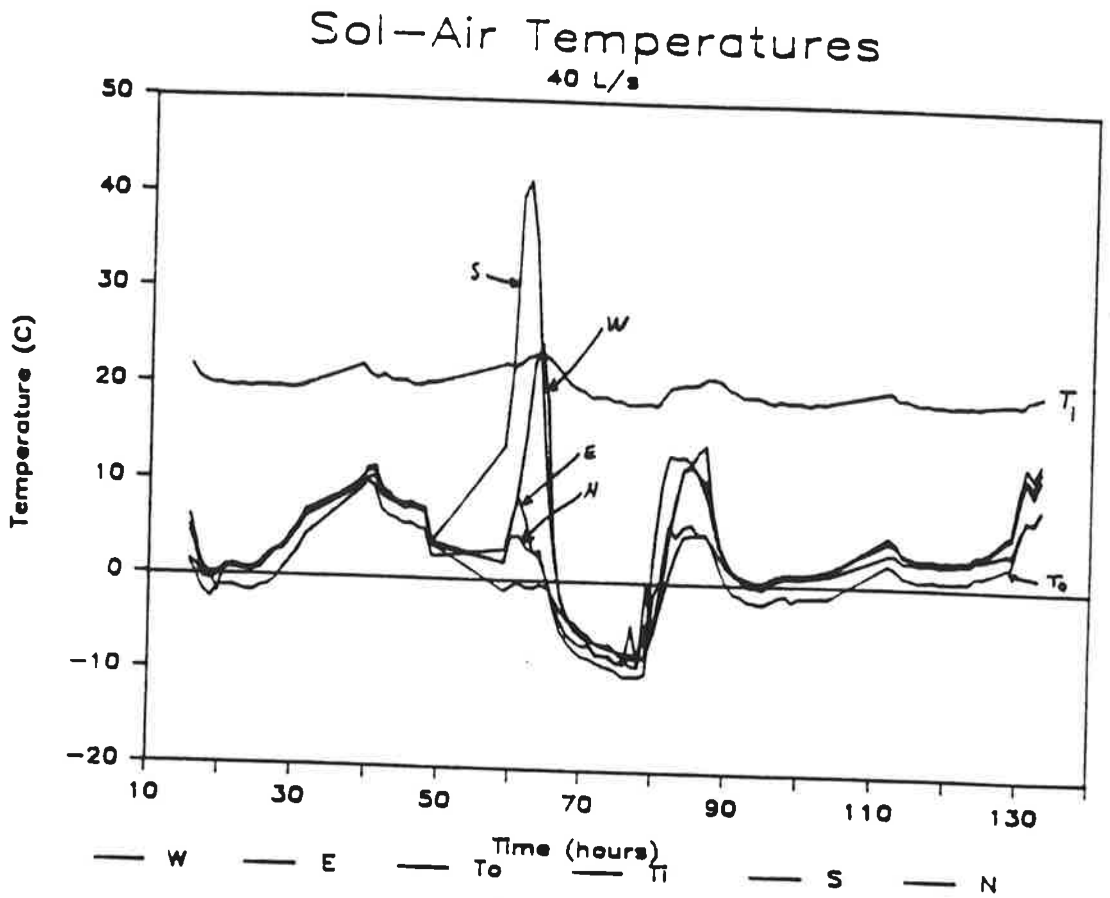


FIGURE 12

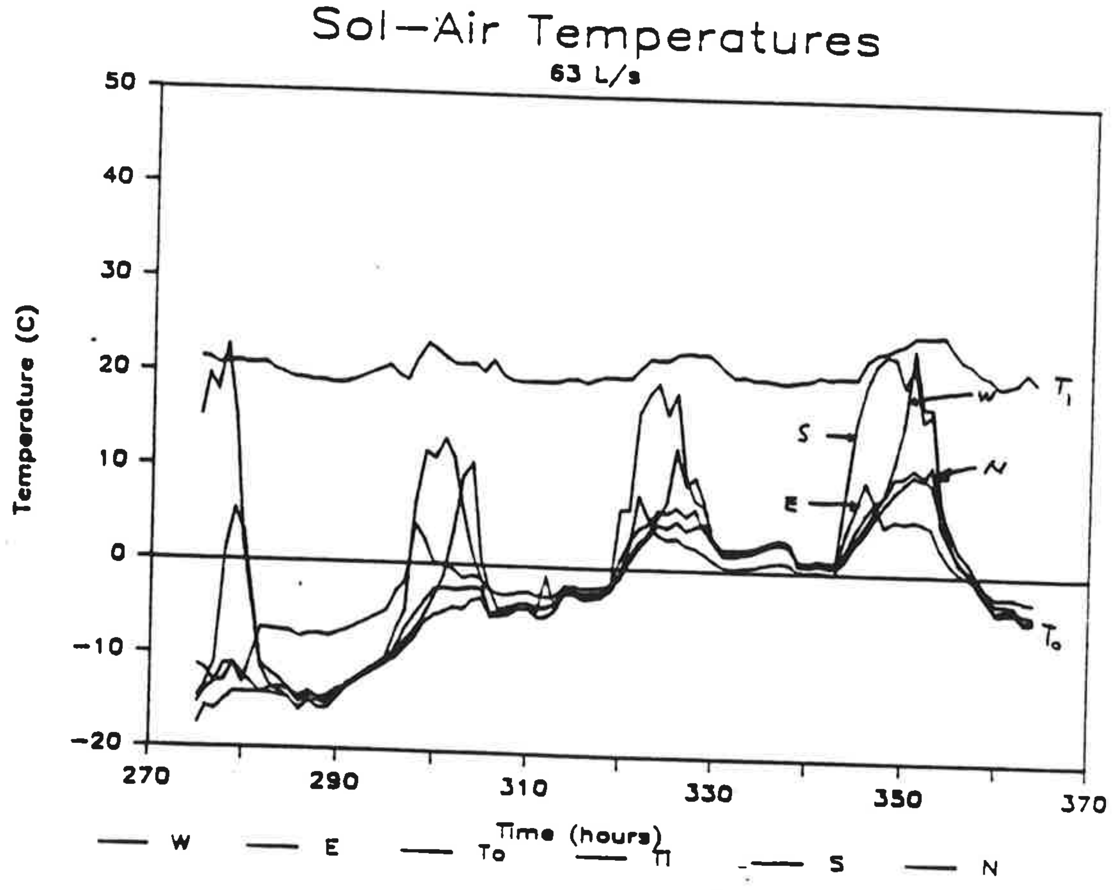


FIGURE 13

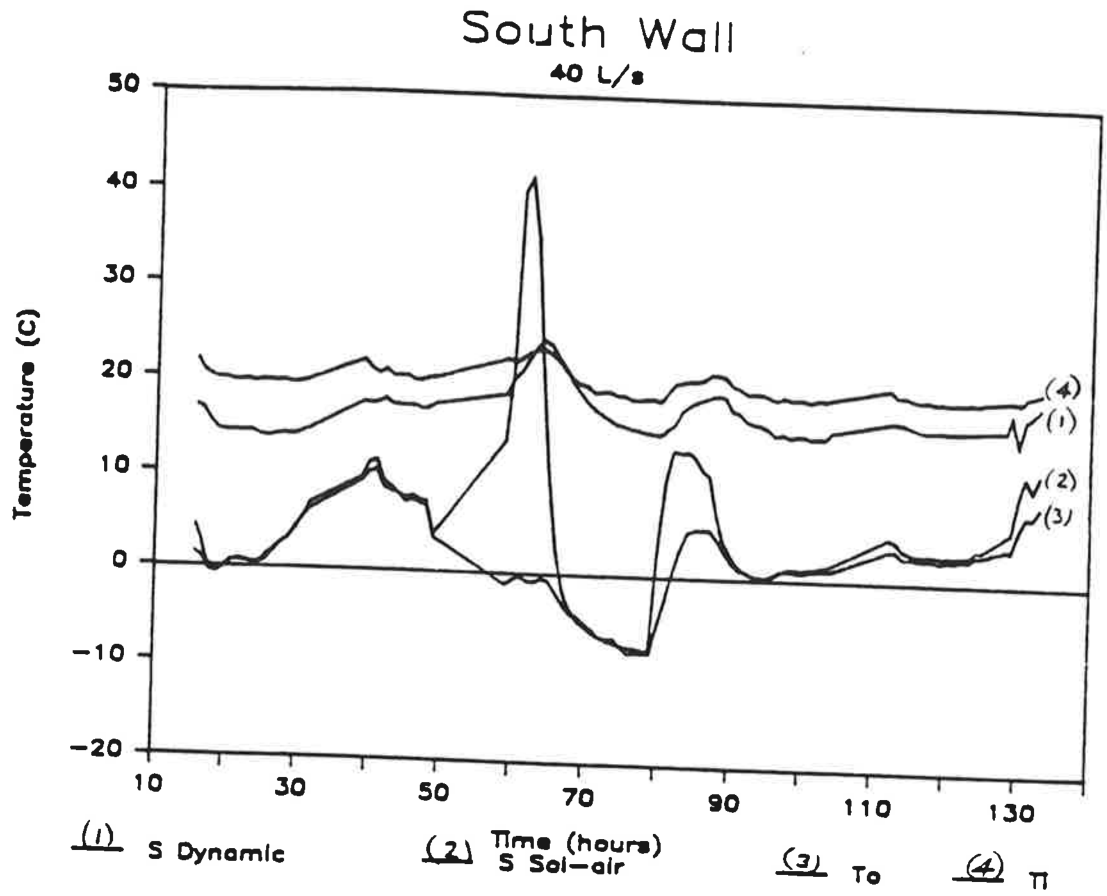


FIGURE 14

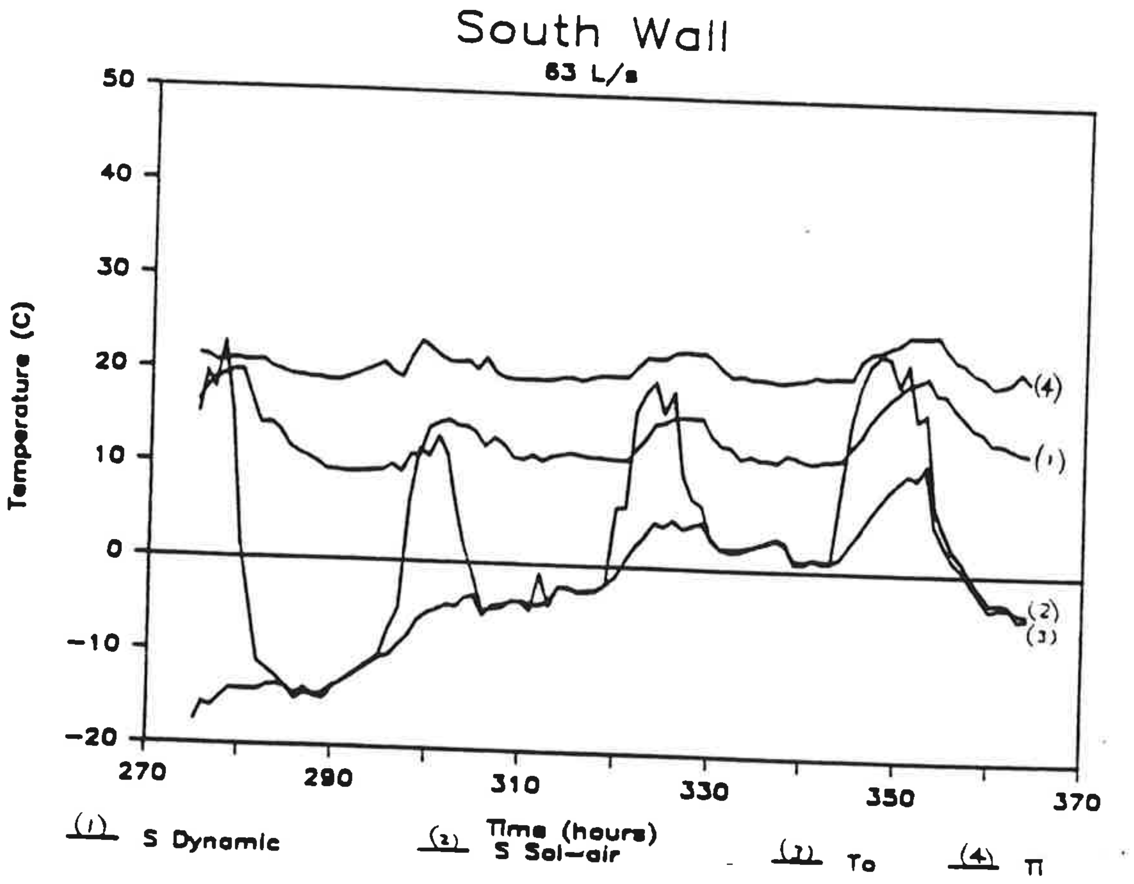


FIGURE 15

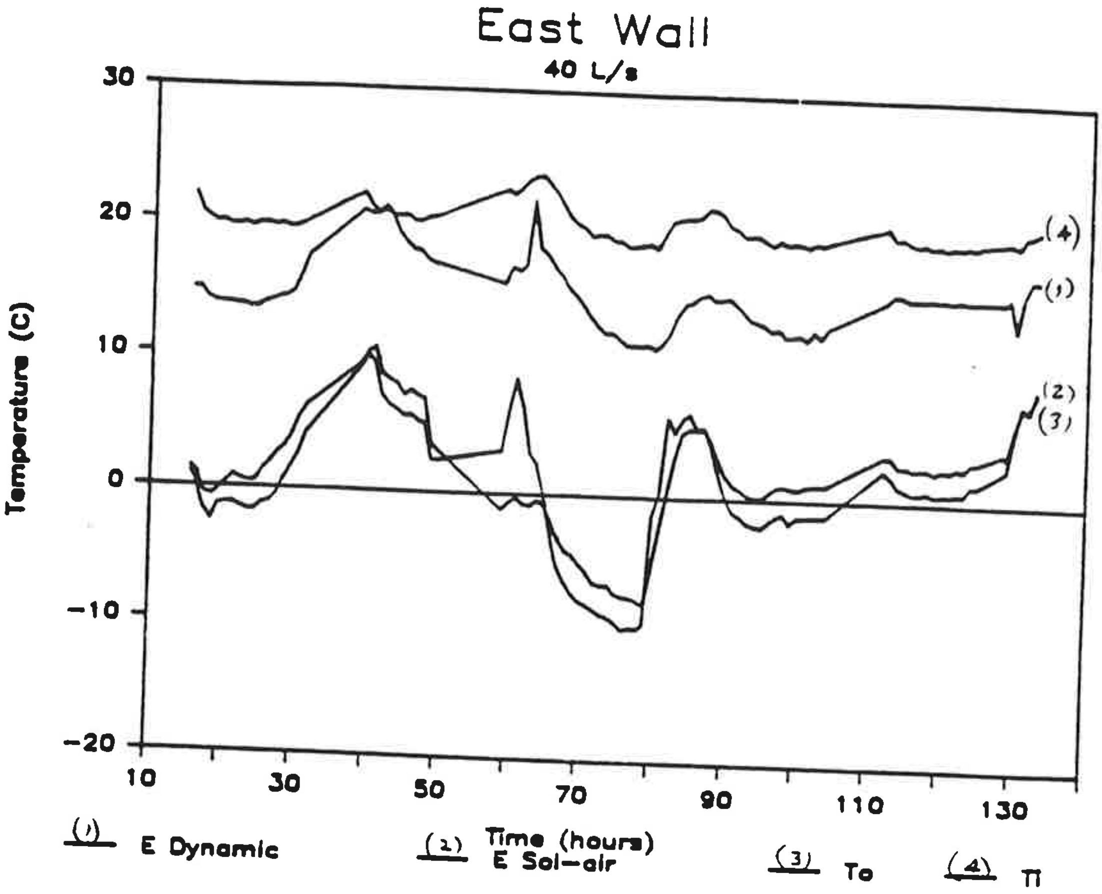


FIGURE 16

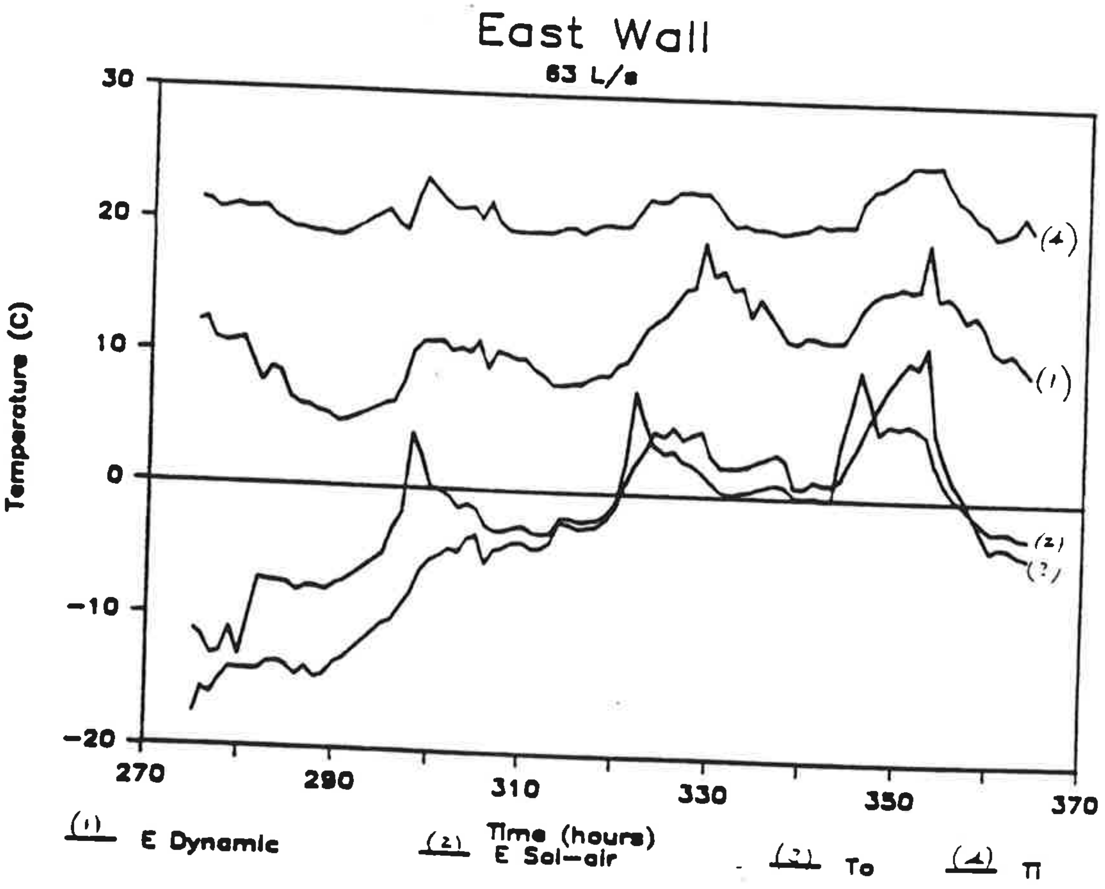
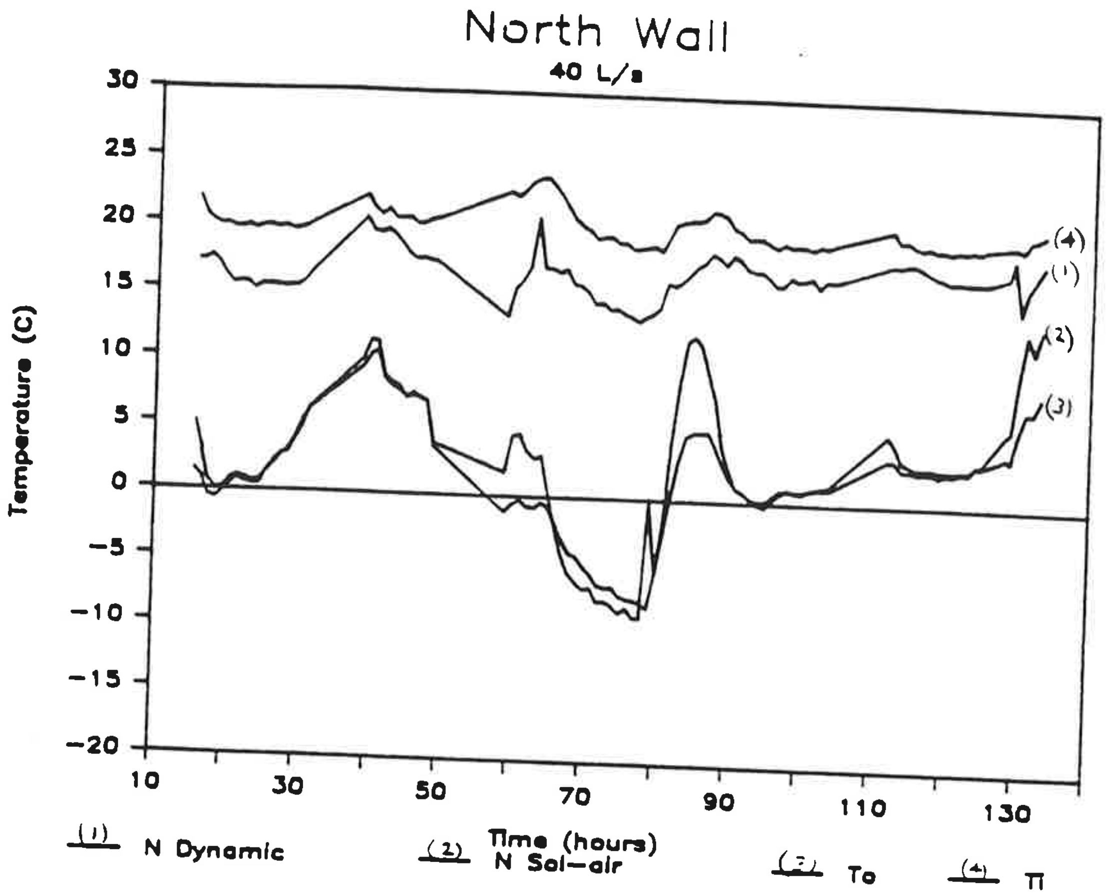
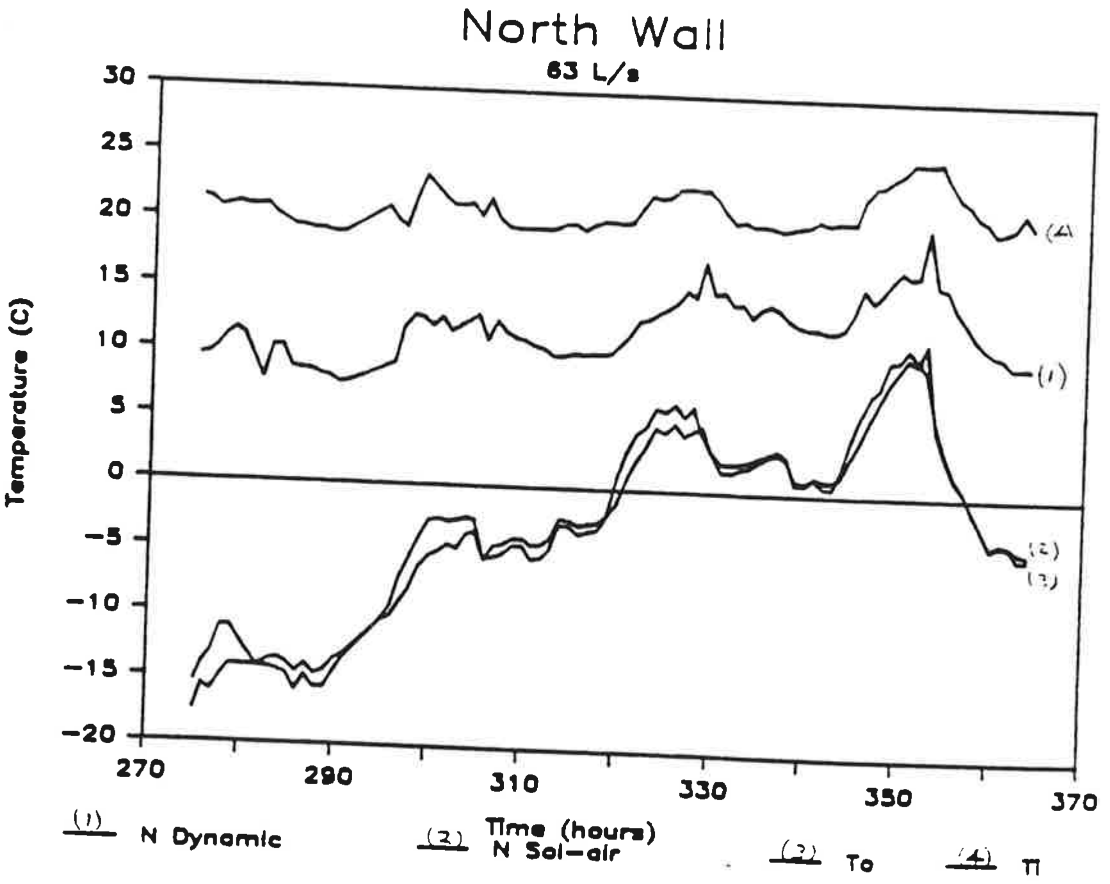


FIGURE 17


North Wall

40 L/s

FIGURE 18


North Wall

63 L/s

FIGURE 19

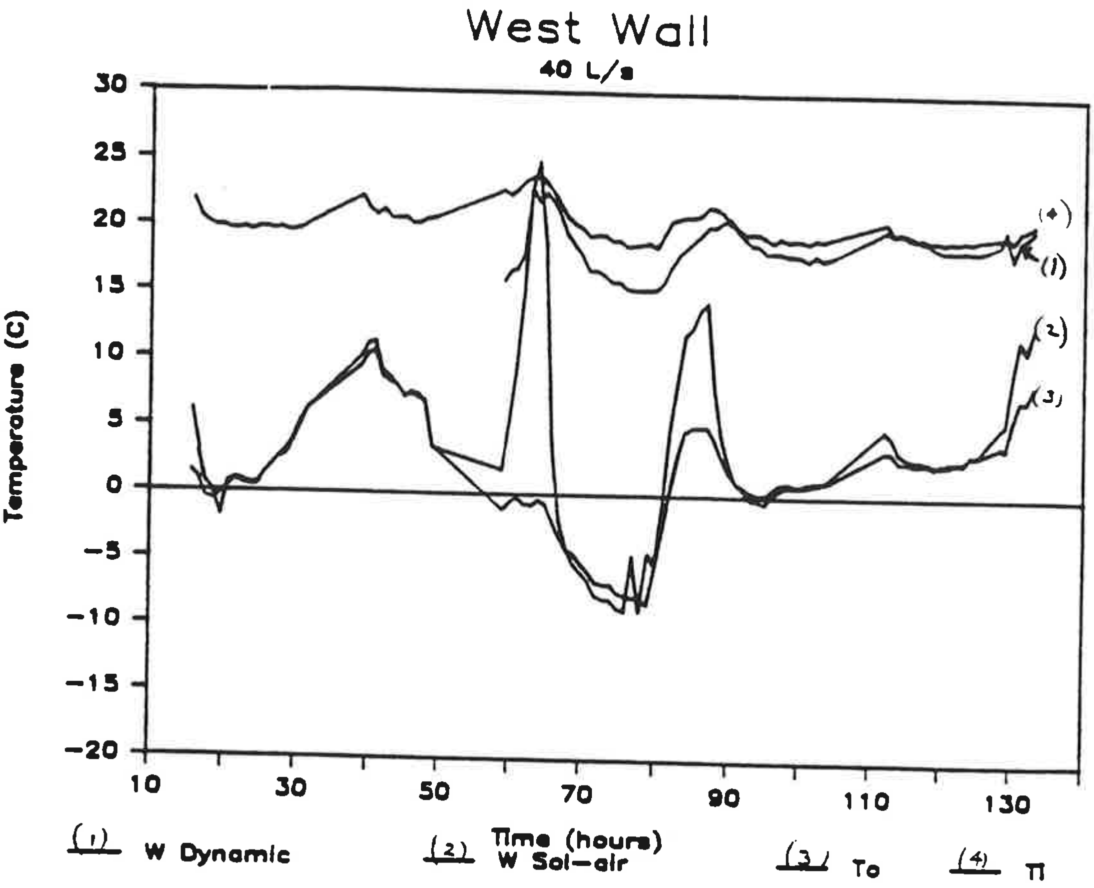


FIGURE 20

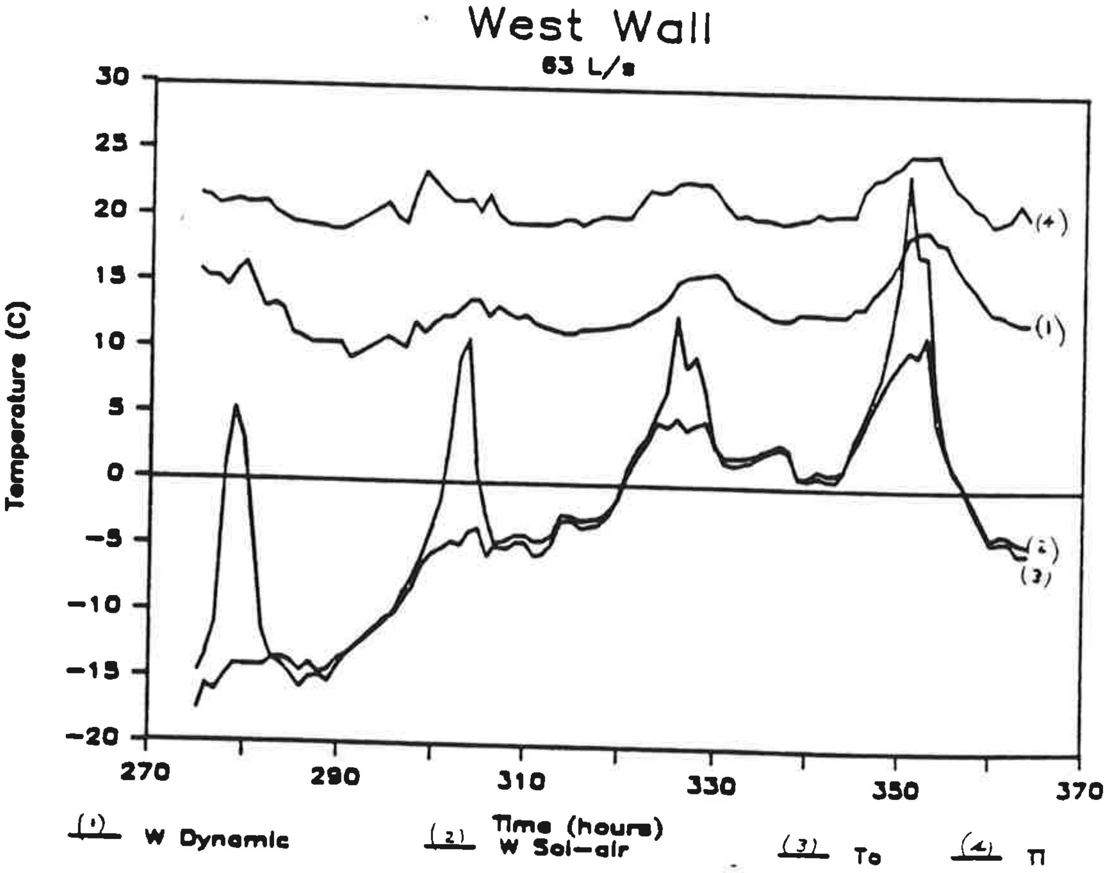


FIGURE 21

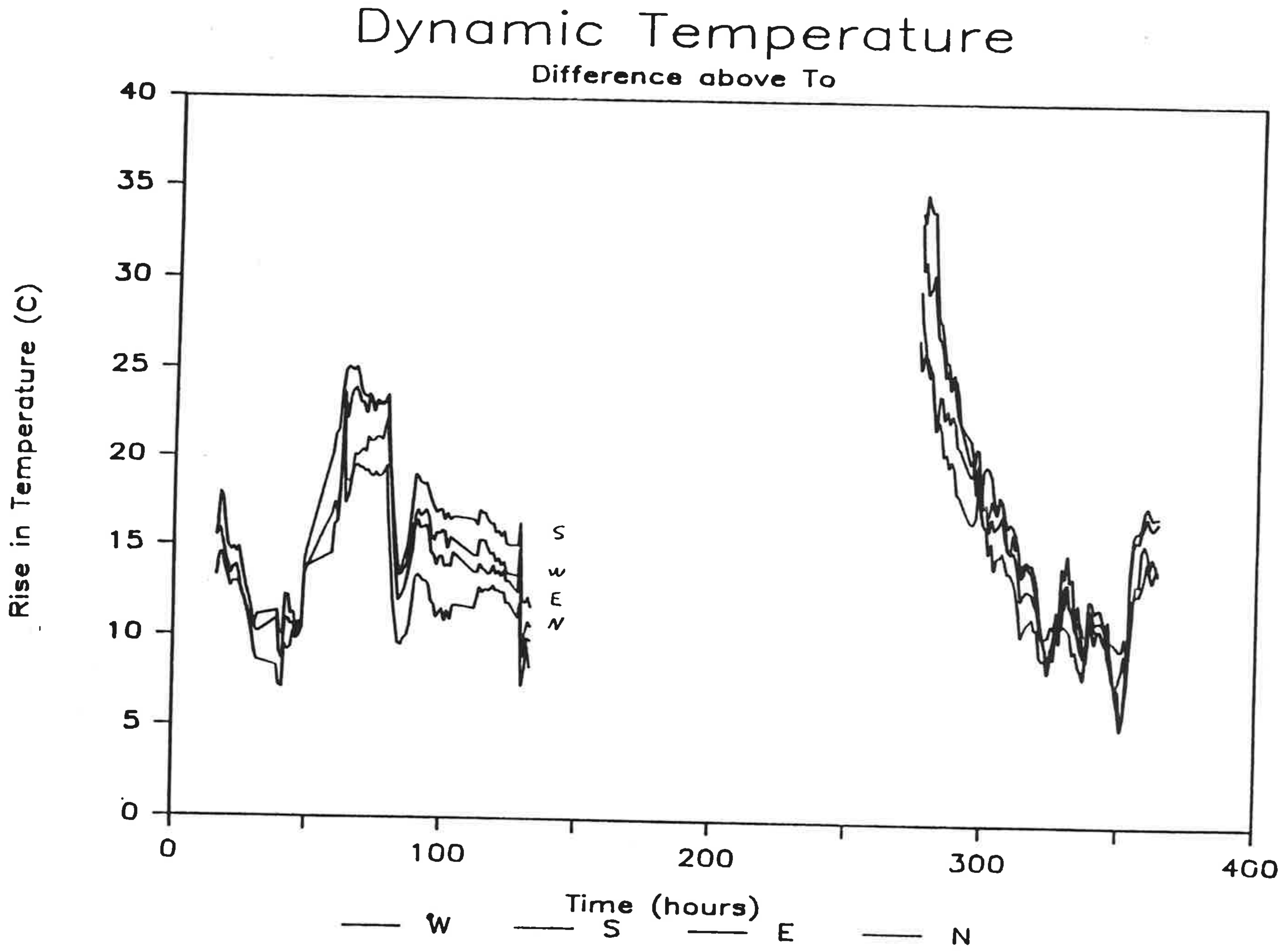

Dynamic Temperature
Difference above To
Rise in Temperature (C)
40
35
30
25
20
15
10
5
0
0
100
200
300
400
Time (hours)
S
W
E
N
W
S
E
N

FIGURE 22

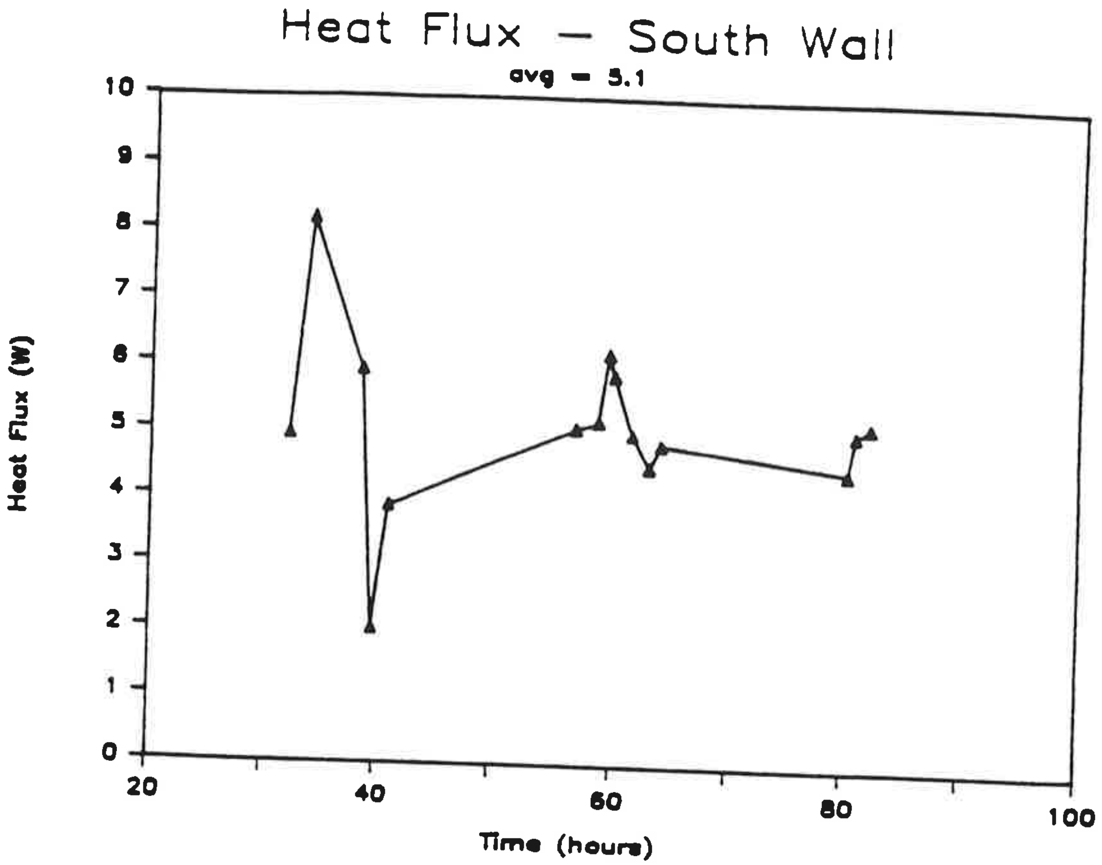


FIGURE 23

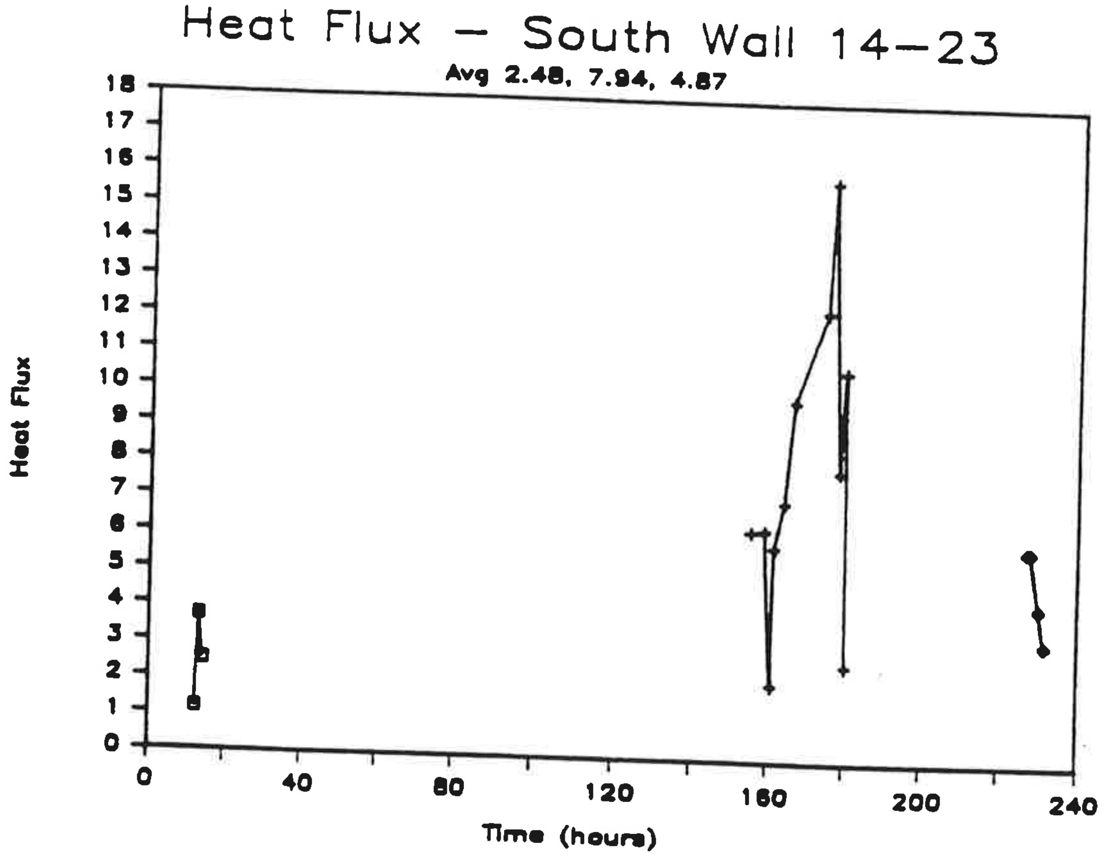
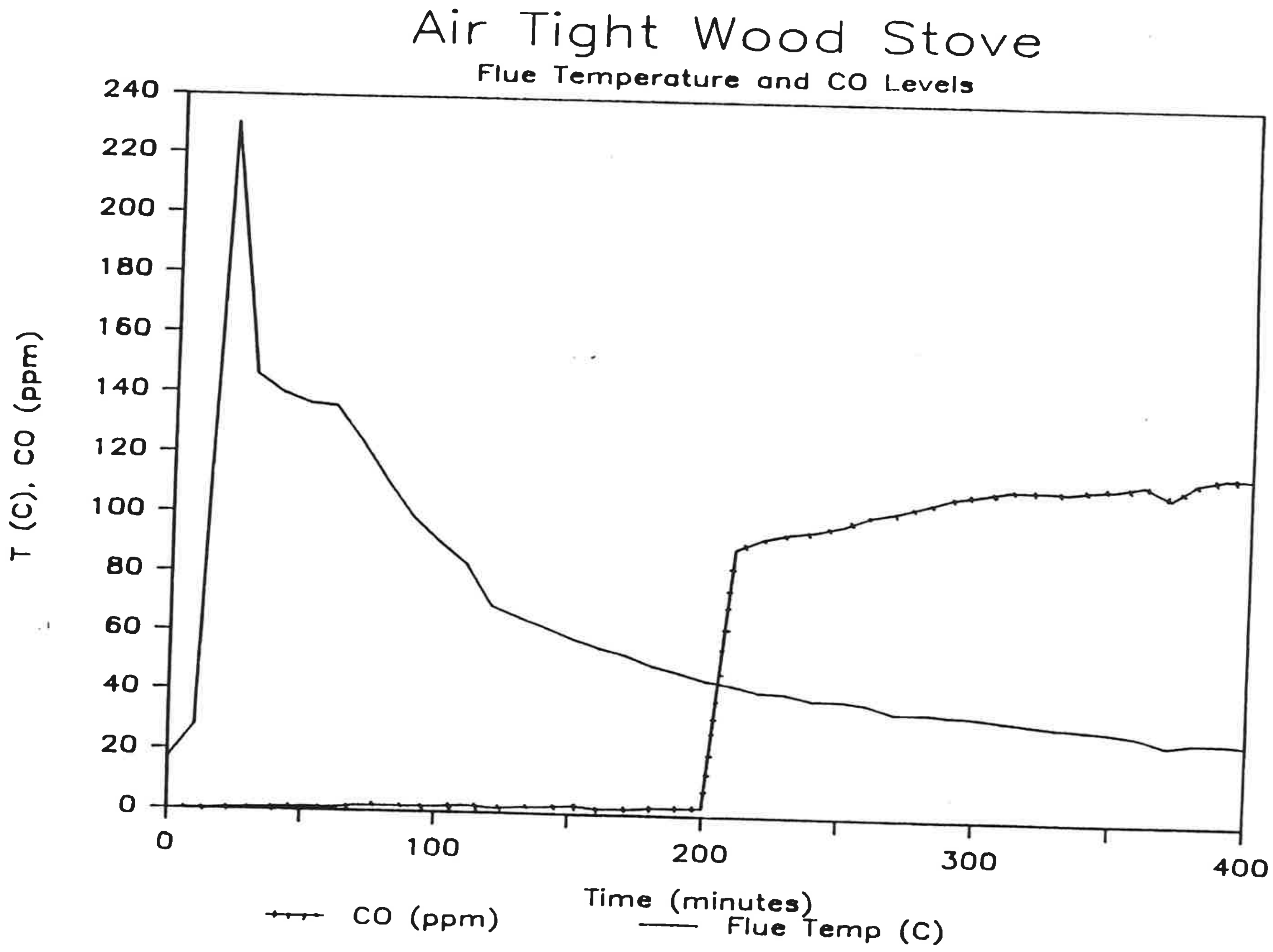


FIGURE 24


Air Tight Wood Stove
Flue Temperature and CO Levels
T (C), CO (ppm)
240
220
200
180
160
140
120
100
80
60
40
20
0
0
100
200
300
400
Time (minutes)
CO (ppm)
Flue Temp (C)

(b) The rate at which moisture is being introduced into the air by the normal occupational processes associated with living

(c) The rate at which humid air in the building is exchanged for drier air from outside the building.

The architect and his advisers have the responsibility of including sufficient thermal insulation in the fabric of the building and of ensuring that it is in the best possible place relative to the other components of the structure to reduce the risk of surface or interstitial condensation. The architect also has the responsibility of making provision for the building to be easily and conveniently ventilated, to enable the occupant to achieve a satisfactory rate of exchange of air.

Thus the architect can provide a dwelling which will be free of significant condensation *provided that* it is used within the limits of his design, in respect of heating and ventilation.

The ventilation of bedrooms

The effect of ventilation on the dew point of the air in a bedroom

The changes in the dew point of the air in a bedroom occupied by two sleeping adults, under differing conditions of ventilation are seen in fig 1. The four graphs show how the dew point temperature of the air changes over a period of four hours, under five conditions of ventilation – 0, ¼, ½, 1 and 2 air changes per hour.

It can be seen how even a small amount of ventilation will prevent the disastrous rise in the dewpoint which results from no ventilation at all.

In fact a room with no specific provision for ventilation may have an air change rate of as little as a quarter or a half, while an opening of 0.005 m^2, possibly formed by a window open to an extent of no more than a 5 mm gap, is sufficient to increase this rate to one or even two air changes an hour.

Humidity and temperature conditions in a bedroom during the day

The following table lists typical readings of temperature and humidity taken in bedrooms during visits made in the daytime. They were taken in three different houses where mould growth had been found to occur. It can be seen that they cover a range of temperatures which indicate an insufficient heat input in half the cases, but in all cases the relative humidities and dew point temperatures indicate that there is an unacceptably low level of ventilation.

Air temperatures °C	Relative humidity %	Dewpoint temperature °C
17	77	13
16	80	12.6
12	82	9
15	71	10
12	75	8
10	87	8

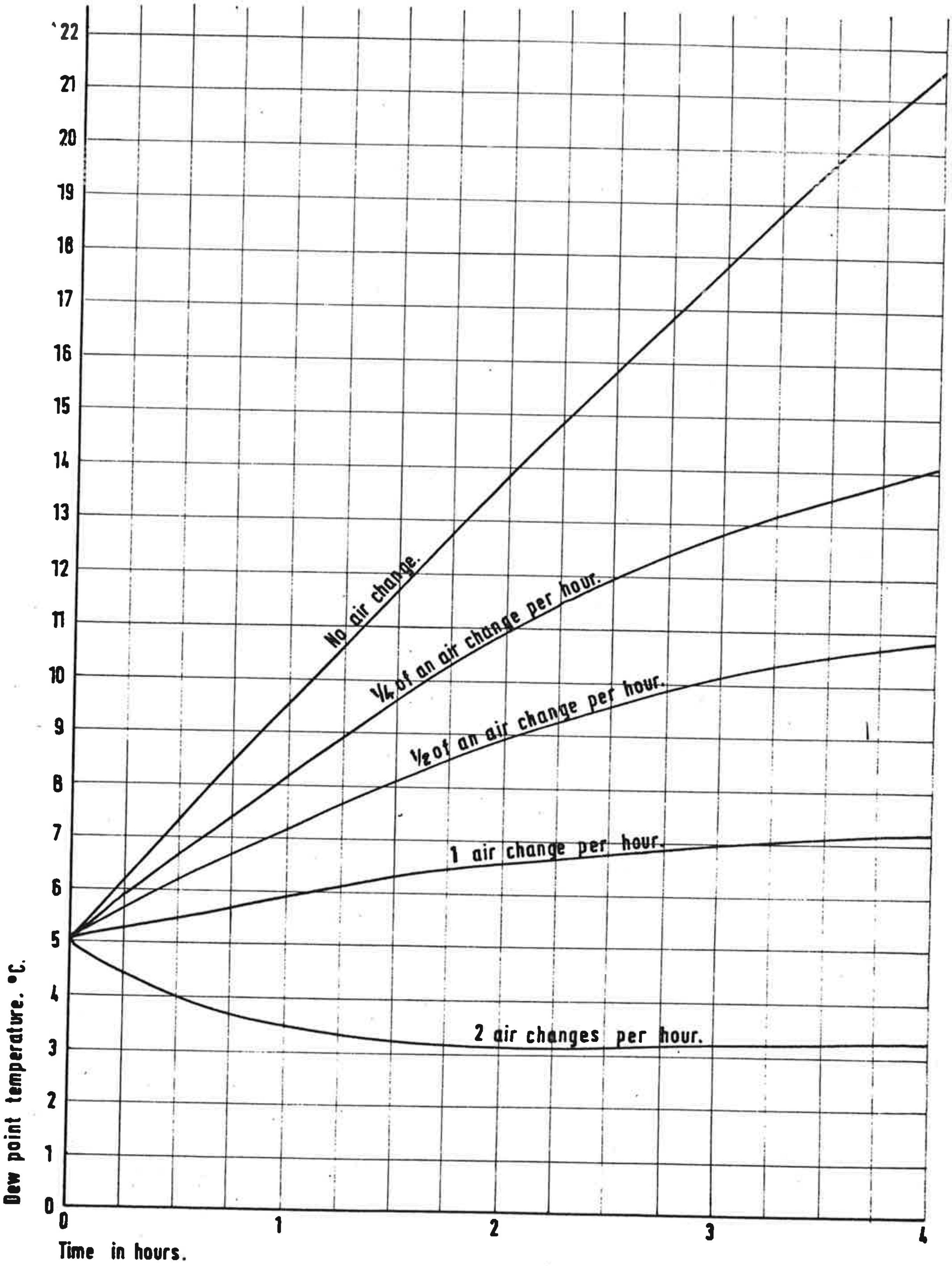
The temperature of the wall surfaces in these rooms were, at the time of the investigations, slightly above the dew point temperatures but it is clear from fig. 1 that this situation would be reversed soon after the occupants went to bed, with a resultant accumulation of condensation on the walls.

The pressure of water vapour in a poorly heated bedroom will often be lower than that in the warmer parts of the house. This pressure difference will drive water vapour from the warmer rooms to the colder and this is one of the reasons why condensation problems are so often found in bedrooms and why the ventilation of bedrooms can be so effective in combating condensation.

Mould growth on a bedroom ceiling

A striking example of the effect of ventilation was seen in an end of terrace house of virtually traditional construction.

A complaint had been received of extensive mould growth on the ceiling of a bedroom. The investigating officers found, in addition to the mould growth, that the plasterboard had become so sodden with condensation as to require complete replacement of the ceiling. It was noted that the window was closed. They then inspected the roof space and found that the glass fibre insulation had been omitted from above the ceiling of both back bedrooms the other one of which was adjacent to the flank wall of the terrace.



22
21
20
19
18
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
Dew point temperature. °C.
0
1
2
3
4
Time in hours.
No air change.
1/4 of an air change per hour.
1/2 of an air change per hour.
1 air change per hour.
2 air changes per hour.

Figure. 1.

The investigating officers then inspected the other bedroom, expecting to find a similar condition but, instead, found that there was no sign of mould in the room. The window which has a vertically sliding sash, was open to provide a gap of about 5 mm. On discussing the matter with the occupier, the officers were informed that the mould infected room was that of her son, who could not be persuaded to open the window, while the other room was that of her daughter, who always kept the window slightly open.

Ventilation and economy

When one advises an occupier of a dwelling affected by condensation to increase the amount of ventilation, he often replies that he cannot afford to open the windows and lose heat from the house. It has however been the experience of the writer, that in many instances the occupants of one of a pair of virtually identical dwellings have complained of chronic mould growth and high heating bills and have limited the ventilation to the absolute minimum while the occupants of the other maintain a few windows open to a very small extent and in consequence do not suffer from condensation, enjoy a fresh atmosphere and pay no more and, in many cases, less for their fuel than those who eschew ventilation. The reason for this may be that those who reduce ventilation to a minimum may increase their heat input to the house in an attempt to counteract the discomfort resulting from high concentrations of water vapour, carbon dioxide and odours.

Changes in circumstances leading to an increase in the risk of condensation

A change from an old house to a new one

Several cases have been encountered where tenants have moved from dwellings having suspended timber floors and open fireplaces to a house having concrete floors and no flues, or where the building itself has been modernised and timber floors replaced with concrete, fireplaces blocked and windows and doors draught-proofed.

In either case the occupants are accustomed to a building which is subject to a great deal of adventitious ventilation and do not readily develop the habit of ventilating their dwelling, with the result that they find themselves suffering from the effects of increased humidity. Condensation forms on the floor, windows and walls and mould-growth soon develops.

A change in the method of heating

It is very noticeable that as open coal fires have given way to the more convenient gas and electric fires and as, in many cases, fireplaces have been removed and their flues taken out of effective use, so the incidence of condensation and mould-growth has increased.

Conclusions

The increase in the occurrence of problems of condensation and mould growth over the last two or three years is largely due to economic and social reasons.

We are rapidly coming to the end of a fuel glut, the like of which we will not see again, and the consequent rise in fuel prices has resulted in a reduction in the consumption of fuel for heating and a tendency to reduce ventilation in order to limit heat losses.

In many families today both husband and wife go out to work and the total heat input to the fabric of the dwelling is much less than when one member of the household remains in all day and heating is continuous, albeit at a lower rate.

The use of unflued propane gas and oil heaters – which have the advantage that payment for the fuel is made in small amounts at the time of purchase – has led to an enormous increase in the amount of water vapour generated in many dwellings.

Many modern houses have been built without flues. Doors and windows are made to closer tolerances. There has been a tendency to construct floors of concrete instead of timber. Houses are thus constructed to be more air-tight and the installation of additional draught-proofing reduces adventitious ventilation still further.

Occupants must compensate for this reduction in ventilation by making full use of all equipment provided and especially by leaving bedroom windows open to the extent of a few millimetres at night. Alternatively, where, as is often the case, occupants take active steps to eliminate any ventilation, it may be necessary to consider the installation of a concealed system designed to provide a reasonable amount of tamper-proof, draught-free, permanent ventilation. However, the achievement of all these properties in any system presents a considerable design problem.

Enquiries

Any members of staff requiring further information or advice on the topic of ventilation in relation to condensation, should contact one of the following –

J C D Twiston-Davies of Materials Information Group, Ext 8205
I R Bealby of Scientific Branch, Ext, 4637
A R Thomas of Housing Department, Ext 4886.

Previous bulletin reference

Bulletin No. 125 (2nd Series) dated December 1979, item 5 – *Prediction of the condensation risk.*

JCDT-D/3908/1223C/(–)