DESIGN, CONSTRUCTION AND PERFORMANCE OF A DYNAMIC WALL HOUSE.

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ABSTRACT

The advantages and disadvantages of various ventilation strategies are first examined after which the negative pressure ventilation approach and dynamic insulation as a special case of it are treated in somewhat greater detail. The dynamic wall house built by the author and tested by the Centre for Building Science, University of Toronto is presented for illustration. Here it was shown that all the ASHRAE Standard 62-81 specified ventilation air could be brought in through the walls of the house without incurring unacceptable cooling of wall surfaces. At the same time, about 60 percent of the incoming ventilation air was heated to about 80 percent of the indoor-outdoor temperature difference. The lack of cooling of the wall surfaces and the level of heat transfer to the incoming ventilation air is attributed partially to the very low air velocities in the wall cavity, calculated to be about 4 mm/s at mid height of the wall. The results suggest that the dynamic wall approach can lead to simplified ventilation and enhanced energy performance.

INTRODUCTION

Air quality problems in housing are relatively recent and can usually be attributed to inadequate ventilation in tight houses, new contaminant sources or an improvement in our ability to detect minute quantities of pollutants. This paper is primarily concerned with the supply and distribution of ventilation air.

In traditional housing air supply by natural ventilation was usually more than adequate. Supplied by air infiltration through the enclosure, it was not controlled because air leakage openings were accidental and wind and house stack pressure due to buoyancy of the warm indoor air were weather dependent. Significant stabilization of air supply was however provided by the active chimney which could overpower wind and house stack effects, even to the point where air infiltration was to all rooms. Not only did this assure good air distribution, moisture problems were alleviated by dilution through adequate ventilation rates and because much of the moisture laden interior air was exhausted through the chimney rather than the walls.

But even before the 1973 oil embargo air quality and moisture problems started to appear because airtightness of housing was increasing while electric heating eliminated chimney-driven ventilation. The disappearance of the working chimney meant that the neutral pressure plane was lowered and air infiltration was only to a part of the house; the amount of fresh air had diminished and its distribution had deteriorated. Moisture damage to wood frame construction was however still relatively uncommon, even in regions with extreme outdoor moisture conditions, such as those found in Newfoundland (1).

With the oil embargo motivated escalation of energy prices came also the motivation to build yet tighter houses. The point has been reached where controlled ventilation is a necessity, with only how this is to be accomplished left for debate. Hence this paper which deals with an apparently novel ventilation approach, an approach which, on closer examination, will be seen to be remarkably similar to that in naturally ventilated houses with active chimneys. Only here control over ventilation and energy use is improved. With this approach an attempt is made to build houses where one thing will enhance another; houses where the walls and the mechanical equipment come together to form a coherent whole. But before the negative pressure approach and a special case of it, dynamic insulation, is considered, common ventilation options will be briefly discussed to provide necessary perspective.

VENTILATION OPTIONS

The Balanced Pressure House. The air-to-air heat exchanger is probably the most commonly used ventilation device for low energy housing in Canada. It couples mechanical ventilation with heat recovery from ventilation air. Ideally, flow through the intake and the exhaust fans is balanced; hence the term balanced pressure ventilation. The pressure distribution across the envelope is still determined by wind and house stack pressure and is augmented by the air-to-air heat exchanger when the two flows are not matched. In this context it resembles the electrically heated house; infiltration occurs below the neutral pressure plane and exfiltration above. The amount of air leakage through the envelope is however decreased because of the increased air tightening. Heat recovery is, of course, not possible from air exfiltrating through the envelope. This is one of the reasons for building these houses as tight as possible.

The Positive Pressure House. Technically, this is a much simpler ventilation approach since all the ventilation air is brought into the house through a single intake where it can be tempered before distribution throughout the house. It is used where the ingress of contaminants from the building enclosure, such as decay products from urea formaldehyde insulation or radon gas from the soil are to be excluded from the interior. Similarly, the entry of combustion products from fuel burning devices is prevented.

In this house heat cannot be recovered from the ventilation air. Moisture damage due to increased exfiltration through the envelope is unlikely because one of the major moisture sources, the saturated air infiltrating through the foundation wall, will have been eliminated. Also, what moisture remains is diluted by the controlled ventilation.

An interesting ventilation heat recovery option becomes available here during the airconditioning season when heat from the incoming air stream can be extracted and transferred to domestic hot water by means of a heat pump. The associated dehumidification would also decrease summer absorbtion of moisture by the building interior and its contents, thereby reducing yet another major heating season moisture source.

The Negative Pressure House. The negative pressure house is much like the naturally ventilated house, only here the working chimney is replaced by an exhaust fan which makes it possible to recover heat from the exhaust air and to control the rate of ventilation. House stack and wind pressures are still destabilizing, but by making the envelope sufficiently tight, they can be overpowered by the exhaust fan to improve the natural supply of fresh air directly to all the rooms.

The amount of depressurization obtained depends on the rate at which air is exhausted and the airtightness of the envelope. The first is fixed by the ventilation requirements, such as those of ASHRAE Standard 62-81. The airtightness of the envelope remains then to be established. Unlike the case of the balanced pressure approach where an upper limit to envelope leakiness is required in order to control ventilation energy consumption, no such requirement can be justified for negative pressure houses as long as no air exfiltration through the envelope takes place. This is an important difference and merits some elaboration.

Energy consumption for space heating is reduced by decreasing energy loss. That energy has to be supplied at the rate that it is lost is obvious and not relevant to the energy loss side of the equation. To avoid confusion the two should be kept separate.

Regarding ventilation during the heating season, energy is lost when conditioned air leaves the building, such as through the chimney, through the exhaust of a ventilation device or by exfiltration through the envelope. Because heat cannot be recovered from the air leaking out through the building envelope, this flow should be eliminated. Two conditions must be satisfied for flow to occur: openings must exist for the air to pass through and a pressure difference must be sustained to drive the air through the openings. Eliminating either one of the two will eliminate exfiltration.

When balanced flow air-to-air heat exchangers are used for ventilation and ventilation heat recovery, the pressure driving exfiltration cannot be controlled. The only remaining option is then to eliminate the leakage openings. Hence, the emphasis on envelope airtightness; the door-fan test has become a proxy for energy efficiency.

But if the positive pressure driving exfiltration is eliminated so is the need for airtight construction. There is however a practical limit to how leaky the envelope can be. The rate at which air has to be exhausted to overpower positive pressures due to stack and wind should not exceed the required ventilation rate. Even if all of the added heat could be recovered from the exhaust air the rate at which air is drawn through the envelope must be controlled in order to avoid unacceptable cooling of interior wall surfaces. This is what the design and evaluation of dynamic walls is concerned with. But before proceeding to this phase of the paper another aspect of negative pressure ventilation and the required airtightness of the envelope needs to be addressed, that pertaining to the direct supply of ventilation air through the envelope to all of the rooms. To accomplish this, exhaust at the required ventilation rate should, in addition to overpowering wind and stack, leave an adequate negative pressure across all the walls to distribute the infiltration air according to the ventilation requirements. The following example is included to establish the order of magnitude of expected wind and stack pressures on one hand and a realistic level of depressurization on the other.

The pressure difference across the leeward and windward walls of a two storey house have been plotted in Figure 1. It is made up of: 1) the negative pressure induced by an exhaust fan, taken to be 11 Pa, which is also in the author's dynamic wall house measured value range, 2) house stack for an indoor-outdoor temperature difference of 22 K, and 3) windward and leeward wind pressures of 1.7 and -0.9 Pa respectively. The wind pressure is based on calculated values employing generally accepted pressure coefficients and the mean annual wind speed for 17 weather stations in various parts of Canada, which is in turn adjusted from the 10 m weather station tower value to a height of 4 m above ground in a suburban setting.

One can conclude from Figure 1 that the air supply to the rooms adjacent to the indicated walls should be reasonably uniform. Moreover, in houses of modest size most rooms are located in corners and therefore experience wind effects on two walls at right angles. Also, as the air leakage flow exponent tends to be somewhere between 0.5 and 1.0, the actual air leakage rate differences become somewhat reduced.

The above arguments suggest that internal ventilation air distribution systems may not be needed. It is further suggested that fan-induced pressure can be reduced significantly and still have only infiltration, which means that the enclosure can now be made leakier without incurring a corresponding increase in energy consumption. This does not mean that large leakage openings can be tolerated as they can lead to cold draughts and unacceptable localized wall cooling.

Next, the thermal performance of a wall through which air is infiltrating will be examined.

THE DYNAMIC WALL

It is well known that the ability of thermal insulation to retard heat flow depends on its ability to entrap still air or some other gas, and that when cold air from the exterior blows through the insulation the interior of the wall will be cooled, even to the point where room side condensation can lead to mould and mildew formation on interior wall surfaces (2). But when a gentle stream of exterior air is drawn through the insulation, the stream of air can be warmed up by the heat otherwise lost by transmission through the wall. If the incoming air stream is needed for ventilation purposes and would have to be heated up anyway, then the decrease in heat leaving the wall represents an energy saving. The rate at which heat enters the dynamic wall may be higher than that for a corresponding "static" wall. Insulation which performs such a function of transferring transmitted heat to ventilation air has been termed dynamic insulation (3) and a wall which is designed and built to accomplish this can be then called a dynamic wall.

To illustrate the dynamic wall concept a wall section comprising air permeable insulation on the weather-side and on the room-side gypsum board and the inside air film will be considered. See Figure 2. According to Fourier's law the temperature gradient through any homogeneous part of the wall with a constant coefficient of thermal conductivity is linear as long as we are dealing with steady state heat flow:

$$q = -k \, dt/dx$$

where: q = heat flow rate, W/m^2
k = coefficient of thermal conductivity, $W/m \cdot K$
dt/dx = temperature gradient, K/m

When a flux of cold air is moved through the wall in the opposite sense to heat flow, the wall becomes cooled, as indicated by the broken line in Figure 2. By tracing the new temperature gradient from the cold to the warm-side, the following is seen:

1. At the weather-side of the insulation the slope of the temperature gradient approaches zero; the amount of heat leaving the wall has been reduced and may become zero if radiant heat transfer can also be eliminated. In other words, it is possible to stop transmitted heat from leaving the wall.

2. The slope of the line increases and heat flow increases on approaching the warm-side of the insulation; as heat is neither leaving nor being stored in the wall, it has to be transferred to the incoming air stream.

3. By the room-side of the insulation the air stream has been warmed up but not quite to room temperature. An opening through the gypsum board has to be provided to bring the air stream into the room, but this practical matter will be discussed later.

4. Through the gypsum board the temperature gradient is steeper than it was before, indicating that the rate of heat transfer into the wall has increased, but again, if the incoming air has to be heated, this is not an overall system energy loss.

5. The room-side wall surface temperature has been lowered. This could entail a decrease in the radiant flux from the wall and an increase in the potential for room-side condensation.

The above indicates that yet a second opportunity to reduce energy loss is provided by the negative pressure ventilation approach when the walls are designed and built as dynamic walls. That more heat enters the dynamic wall than its no-air-flow counterpart is again a matter for the supply side of the energy balance equation.

Further analysis of the heat transfer mechanism in a dynamic wall (which was carried out after the presentation of this paper) suggests that the above model is applicable when the air flow rates through the insulation are relatively high. It is now believed that the temperature gradient remains unchanged as long as the rate at which heat is conducted through the still air component of the no-air-flow wall is not greater than the rate at which heat has to be transferred to the incoming air to heat it to room temperature.

If the temperature gradient remains unchanged, then it follows that the rate of heat transferred through the wall by radiation and conduction through the glass fibres remains unchanged during dynamic operation.

In the air between the glass fibres heat transfer takes place as a result of random molecular motion and collisions. With a temperature gradient, molecules moving toward the cold side carry more kinetic energy than those moving toward the warm-side. The heat transfer process through still air could be stopped by cancelling out the molecular movement toward the cold-side by moving the entire air mass toward the warm-side. As far as the heat transfer process is concerned, nothing has changed; only now the air mass is moving relative to the glass fibres. In effect, it is argued that the heat flux moving through the insulation has been stalled.

The calculated flow rate to accomplish the above would, for the author's house, be somewhat less than 0.2 mm per second. At this rate about one half of the ASHRAE-specified ventilation air can be brought in through the insulation while the remainder is drawn in through the usual leakage openings. By pure chance, at the ventilation rate of 40 L/s in the author's house, the above velocity was obtained.

Design Considerations. In the design of the house the following concerns were addressed:

1. Wind cooling of walls where outside air enters the wall without penetrating it and in the process cools the wall construction to near outside temperature.

2. Concealed condensation and possible moisture damage due to the exfiltration of interior air.

3. Increased energy loss due to the exfiltration of interior air.

4. Ease of air barrier installation and inspection.

5. Reduction of transmitted heat loss during the heating season and heat gain during the airconditioning season.

6. Direct supply of ventilation air by infiltration to all the rooms.

7. Control of wall surface and infiltrating air temperatures.

Of the above considerations 1 and 4 were resolved by locating the air barrier on the weather-side of the insulating sheathing. For 7 the envelope airtightness was matched to the ventilation rate to overpower wind and stack effects. The remaining issues were resolved by building the exterior walls to be dynamic insulation walls.

House Details. The house was built on a 9144 x 6706 mm south-facing rubble foundation belonging to an earlier house. The two-storey wood frame house has a floor area of 123 m^2, an exterior wall area of 138 m^2, 18.5 m^2 of sealed double glazed windows, 4.2 m^2 of exterior door and a volume of 316 m^3. It is surrounded by open fields except for a modest wind break on the east side in the form of a sparse pine hedge and a more substantial one on the west side but located some distance away from the house.

The exterior walls comprise: 12.5 mm drywall, 0.05 mm vapour retarder, 38 x 89 mm wood frame wall filled with R-2.1 batt insulation, 38 mm glass fibre insulating sheathing board with a spunbonded polyolefin (SBPO) air and vapour permeable membrane facing out and 25 x 200 mm rough-sawn vertical pine board and batten siding. See Figure 3 for an expanded section through the wall.

The wall air barrier, perhaps more appropriately air diffusion retarder and, in the context of the dynamic wall, the air flow control membrane, was formed by the SBPO sheet. Commercially available sheathing tape, specially manufactured for the purpose, provided continuity of the SBPO membrane with door and window frame, the second floor top plate and the ground floor header joist. See Figure 3.

The upstairs ceiling air barrier comprised 0.15 mm polyethylene sheet with acoustical sealant for continuity with the wall air barrier and at lapped joints which were clamped between the bottom chord members of the roof trusses and the 16 mm ceiling gypsum board. Continuity of this air barrier was enhanced by installing all the second storey partition walls after the ceiling gypsum board was in place, thereby eliminating penetration of the polyethylene sheet and the ceiling gypsum board by partition walls. The attic hatch was gasketed and clamped in place.

For airtightness test purposes the first floor tongue-and-groove plywood sheathing was made airtight with acoustical sealant between the floor joists and the sheathing edges. (An unplanned test of this air barrier component was provided by a rain storm during early construction which covered the entire first floor surface with some 10 mm of water. It could only be drained by drilling holes through the floor). Later, a small opening for access to the basement was cut through the sheathing and covered with a gasketed hatch which was screwed in place during testing.

When the house was tested for airtightness with the aid of a calibrated door fan according to standardized test procedures a year after erection but before the wall gypsum board had been installed, it was found to experience 1.56 ACH at 50 Pa. Of this it was calculated that 0.9 ACH was through the SBPO membrane and the remainder through the usual door and window cracks and other unwanted air leakage openings. These include all the nail holes through the SBPO to hold the sheathing and later the siding in place. Had the SBPO membrane been replaced with an air-impermeable membrane but all other things remaining unchanged, the 50 Pa leakage would have been 0.66 ACH. This incidentally demonstrates one of the advantages of locating the air barrier on the weather side of the sheathing where it is not penetrated by electrical wires, joist assemblies and partition walls. In this location inspection of completed work before the installation of the siding is also facilitated.

The apparently redundant beads of sealant in the wall stud line shown in Figure 3 were provided as a backup in case the SBPO membrane had proven inadequate. With minor additional sealing from the inside the interior gypsum wall and ceiling board could be made to act as an air barrier, that is the gypsum board was designed according to the "airtight drywall approach" (4,5).

By March of 1986 the electrical services and an airtight wood stove had been installed and the exterior w were covered with drywall with the joints taped and filled. The second storey gypsum board had also completed as an air barrier. The first storey ceiling gypsum board had not been installed and the top bottom joints were not sealed, nor those around door and window frame.

At this time funding was made available for the evaluation of the performance of the house as a dynamic house by the Canada Mortgage and Housing Corporation. Authorization to carry out this work was unfortunat received rather late which did not provide sufficient time to verify the performance of all the instal instrumentation before the heating season was over. As a consequence, some of the results were deemed tc less than reliable, especially in view of the unsettled weather conditions in mid March when the evaluat was carried out. Overall, the performance evaluation was deemed successful, especially since a variety weather conditions was encountered, providing extremes for evaluation purposes.

DESCRIPTION AND DISCUSSION OF TESTS

Preparation of the House for Dynamic Operation. Before the house was altered for dynamic operation was again tested and found to have an equivalent leakage area of 0.014 m^2 and a leakage rate of 1.33 ACH 50 Pa. For dynamic operation, fifty-four 25 mm diameter holes were drilled through the second sto exterior wall drywall at 100 mm from the floor, at the centres of 400 mm stud spaces. Twenty-five simi holes were drilled through the first storey drywall. On retesting, the equivalent leakage area was found have increased to 0.017 m^2 and the 50 Pa ACH to 1.51, nearly the same value that was obtained two ye earlier without any wall drywall in place. This suggests two things: the airtightness is primarily provi by the taped SBPO membrane, and the membrane airtightness had not deteriorated significantly. A dire comparison of the first-year value of 1.56 ACH and the third-year 1.51 can not be made in that the holes we not drilled through the drywall of all of the stud cavities while penetrations for the chimney and electric services were also added after the first set of measurements.

In order to satisfy the ASHRAE Standard 62-81 minimum ventilation requirements of 5 L/s continuously to eve habitable room and an intermittent ventilation capacity of an additional 25 L/s, 40 and 65 L/s respective had to be exhausted. This was accomplished by means of a rheostat-controlled centrifugal fan which exhaust air through a 100 mm diameter tube into the crawl space. Flow was monitored by measuring the pressure dr in the 100 mm diameter entry tube, itself calibrated against a sharp edged orifice. This approach also ma it possible to show that the fan flow was insensitive to pressure variation across the fan, such as th caused by opening of windows or exterior doors. The fan was, however, found to be sensitive to line volta fluctuations which could vary flow by as much as 5 L/s. House performance was evaluated at both exhau rates, namely 40 and 65 L/s.

Pressure Across and Flow Through the Walls. After the equipment had been installed and the hou prepared for monitoring there were two four-day periods of intensive monitoring. Coincidentally, the wi directions during these periods differed by 180 degrees while temperature approached -20°C during part of t time. Days with bright sunshine were interspersed with heavily overcast conditions while wind spee measured at the house, ranged from calm to over 30 km/h.

Pressure differences between the outside and the inside, between stud cavities and the inside and air flo through the holes connecting the stud cavities with the inside are presented in Figure 4. This has been do for two ventilation flow rates: 40 L/s while E to SE winds ranged from 8 to 18 km/h and 63 L/s with 8 to km/h winds from N to NW. These are average values from five and four pressure reading and six and four fl rate reading sets respectively for the two flows in question.

From Figure 4 it is clearly evident that wind direction does affect pressure difference across the wal Similarly, calculated first and second storey pressure differences due to stack action were found to agr remarkably closely with measured values. During the first set of measurements the mean outside temperatu was +4.5°C and -12.2°C during the second. While the pressure differences were reasonably large, so was t measured wind speed. This notwithstanding, the flow through the openings in the drywall was found to be le sensitive to pressure difference, as indicated in Figure 4. That all the walls were in an infiltrating mo is largely attributed to the relatively large degree of depressurization due to the specified exhaust rate respectively 9.1 and 12.7 Pa for the two exhaust rates with respect to mean external pressure. That the me second storey infiltration rate of 0.26 L/s per opening is 0.01 L/s higher than the corresponding value f the ground floor, whereas the ground floor mean depressurization is 2.2 Pa larger due to stack action, believed to be caused by the relative lack of airtightness of the first storey drywall. Addition ventilation air would have entered the downstairs space through cracks at the top and bottom of the drywall.

The pressure drops from stud cavity mid-height to the room, shown in Figure 4, are relatively small for t first storey walls while for the second storey they are somewhat higher. This indicates the relatively sma contribution of the drywall to the overall airtightness.

The total measured volume of ventilation air that entered through the holes drilled into 79 of the 1 equivalent full height stud cavities in the house was slightly less than half of the total ventilation ra of 40 L/s. It is conservatively estimated that about 60 percent of the total ventilation air would fall in the dynamic air category where the air remains sufficiently long in the stud cavity to pick up significa heat from heat otherwise lost by transmission. The measured values also suggest that air other than th diffusing through the SBPO membrane is drawn in through the stud cavity holes, that is air leakage through small flaws in the air barrier such as nail holes. In view of the airtightness of the second floor drywall there is good reason to believe that most of the air leakage through the opaque part of the wall entered the interior through the holes drilled into the drywall. Air leaking between window sash and frame would not be included in this category where significant heating of the infiltration air cannot take place.

Tempering of the Dynamic Air. In Figure 5 room temperature, dynamic air temperature, wall surface temperature and outside air temperature are plotted for a 120 hour period for the south-facing wall for a the house infiltration rate of 40 L/s. Here it is seen that the temperature of the dynamic air is quite close to room temperature and indeed higher for a short period of bright sunshine when the outside wall surface temperature itself reached about 40°C.

The same pattern is repeated during a 100 hour monitoring period plotted in Figure 6 when outside temperature was, on the average, lower and when ventilation was at the rate of 63 L/s. Now the incoming air temperature is lower but still above 10°C. Solar contribution, with a characteristic phase shift, is again evident. North wall values corresponding to those of Figure 6 are presented in Figure 7. Here the solar effects, while weak, are still present.

Detailed analysis of the dynamic-outdoor temperature and the outdoor-indoor temperature differences revealed that the degree of tempering of the dynamic air was sensitive to the ventilation rate but not the indoor-outdoor temperature difference. The first has to do with the length of time the air remains in the wall before entering the room while the second reflects the direct contribution of indoor-outdoor temperature difference to transmission loss on one hand and the heat demand to increase the temperature of the incoming air on the other. At 40 and 63 L/s the dynamic air was heated to 83 and 62 percent respectively of the indoor-outdoor temperature difference.

One of the major concerns about negative pressure ventilation is the cooling of the inside wall surface by the air stream moving through the wall. Measurements with the aid of an infrared camera and thermocouples did not reveal any anomalies in wall temperatures. Further temperature monitoring with an infrared pyrometer on all the walls at 2100, 1500, 900 and 300 mm above floor level; over studs and between studs, and for one stud cavity in the North wall with no ventilation air drawn through the cavity confirmed this. Eight sets of observations on four separate days with varying temperature and wind conditions and during one day with outside temperature at -6°C while the ventilation rate was 63 L/s again supported what the infrared camera had indicated.

The average measured inside wall surface temperature difference over the measuring height was 1.4 K while the largest individual value of 2.8 K was observed during the 63 L/s ventilation rate period when outside temperature was also low. Much of this temperature difference was also, no doubt, reflected in the inside room temperature gradient. This was unfortunately not verified by measurement.

An independent indication of the effect of ventilation air movement through a stud cavity on wall surface temperature is provided by the comparison of the ventilated and unventilated cavity surface temperature variations: the average differences between the top and the bottom of the wall for the two cases were identical.

The mean temperature difference between the ventilated cavity and the stud was 0.2 K while the calculated value was 0.4 K. On the average, the ventilated stud cavity was still warmer than the stud. The above indicates that drawing ventilation air through the wall cavities did not, for this house, result in unacceptable wall surface temperature variations. The failure to measure the vertical room air temperature gradient meant that the temperature drop over the interior air film could not be determined. This notwithstanding, surface temperature measurements in an actual house can not be sufficiently reliable to draw any conclusions about the rate at which heat enters such walls.

Calculated Air Movement Through the Dynamic Wall. An explanation for the lack of cooling of the dynamic walls can be found from the analysis of air flow through the wall.

If all of the ventilation air, 40 L/s, were to be drawn through the SBPO membrane, the entry velocity through the membrane would be slightly less than 0.3 mm/s. After the air stream has penetrated the SBPO membrane, it would be reasonable to assume that it continues to move toward the warm side of the wall as the air permeability of the glass fibre insulating sheathing is lower than that of the glass fibre batt insulation. Once in the stud cavity, the air stream would move in the plane of the wall toward the opening in the gypsum board at the bottom of the wall.

By mid height of the wall the ventilation air flow rate would have reached 4 mm/s, and when entering the room through the 25 mm diameter hole it would be moving with a speed of 500 mm/s. Subjective evaluation of the effect of the incoming air stream on comfort suggested no cause for concern. When the baseboards are installed, the velocity of the air stream entering the room will be reduced.

The average length of time it would take the air stream to complete the passage through the wall would be slightly under ten minutes. Apparently this is ample time to complete the necessary heat transfer and air mixing.

Concern has been expressed about glass fibres becoming dislodged by the incoming air stream. The above air speed calculations do not support this concern, except perhaps for the immediate volume of insulation surrounding the opening in the gypsum board.

Associated Energy Savings. While mimic box heat flux measurements were taken, they were considered unreliable in the light of the large wall surface temperature fluctuations caused not only by unsteady outdoor temperatures but also large solar gain in the south-facing wall where these measurements were taken. Anderlind and Johansson (3) suggest that it is possible to build a "heat tight" wall, a wall where all the heat that enters the wall through its room-side face is transferred to the ventilation air drawn through it. This then means that no heat leaves through the weather-side surfaces of the wall. If the air so heated is needed for ventilation purposes, a net energy saving has resulted. The associated ventilation rate would, however, exceed that required, for example, by the ASHRAE standard 62-81.

At the 40 L/s ventilation rate in the author's house the flow rate through the insulation would have been too low to significantly cool the wall and thus to reduce radiant and through-the-fibres conducted heat flow through the wall. Based on theoretical considerations, it is however believed that nearly all of the heat conducted through the still air in the insulation was recovered in the dynamic wall. This would have sufficed to heat the incoming air by the observed 80% of the indoor-outdoor temperature difference.

An additional energy saving is realized from the ability of the wall to more efficiently capture solar heat, as illustrated by Figures 5 to 7.

An opportunity for heat recovery from the ventilation exhaust stream by means of a heat pump is realized by the dynamic wall approach. During the airconditioning season the same heat pump can be used to provide airconditioning by reversing the air flow to pressurize the house. If the heat pump recovered heat is put into domestic hot water an incentive is created to operate the ventilation system through the year and, in case of failure, to assure speedy repair.

Internal Ventilation Air Distribution Systems. The measured ventilation air flow distribution suggests that as long as the house is in the negative pressure operation mode, every room gets fresh air more or less in proportion to its opaque wall area operated in the dynamic mode. Exhaust from individual rooms could be provided, for example, by undercutting doors. Exhaust air, in turn, could be picked up in the lavatories and the kitchen and ducted to the single exhaust fan.

If, on the other hand, the house is to be pressurized during the airconditioning season, then fresh air supply to every room should be provided, preferably with high wall exhaust. The air would now leave the house through the walls, thereby again retarding the entry of heat, but this time from the outside. In this mode the problem of radon gas ingress during the airconditioning season will have been alleviated. During the negative pressure operation period other measures must be taken in areas with high radon gas content in the air of the soil.

Theoretically, a continuous air space formed under the basement floor slab by a bed of crushed stone or mineral fibre insulation could be depressurized with respect to the basement. The same fan that depressurizes the house could also depressurize this space. Not only would the heat be extracted from this air, the operation of this system would be maintained as mentioned earlier if it is tied to a necessity such as the domestic hot water system.

Wall Drying. As expected, the operation of walls in the dynamic mode promoted drying of the wall construction. This is due to the decrease in the relative humidity of the incoming air streams as it is heated up in the wall, enabling it to absorb moisture from surrounding materials. For example, during a nine-day period the average vapour pressure of the ventilation air brought in through the North wall was raised by 321 Pa above that of the outside air while that for the South wall was raised by 150 Pa. As the average loss of stud moisture during the months of March and April was only 0.7 percent, it is believed that most of the absorbed moisture came from the pine siding, which incidentally would be drier in the South wall.

The stud moisture content before the commencement of the study was close to 10 percent reflecting the drying provided by passive solar heating over the three-year period when the house was under construction and unheated. Over the two months the house was monitored the average stud moisture decrease was 0.7 percent. Yet, during the same two month drying period two wood studs taken from an unheated shed and placed in ventilated wall cavities in the north and south walls of the house lost respectively 6.5 and 5.2 percent moisture by mass.

That drying of the wall construction did occur is clear. How much of this is to be attributed to dynamic operation and how much to the general drying of exterior walls in heated houses where also exfiltration of interior air is not taking place can not be established from the available data.

Operation of Combustion Devices. As a demonstration of the operation of a combustion applicance in a negative pressure house the airtight wood stove with its combustion air supply from the interior of the building was fired. In spite of the house pressure being negative and the chimney in a backdrafting mode a fire could be easily started without undue spillage of combustion products into the building. Once the chimney had heated up it maintained a powerful draft. Some 200 minutes after the fire died down but while the chimney temperature was still 50°C, significant spillage of Carbon Monoxide (CO) was detected by the monitoring equipment located at a distance of 100 mm from the combustion air intake.

During the ensuing 200 minute monitoring period the CO concentration rose from about 90 ppm to about 120 ppm. At this point the test was terminated. In any house, and especially those operated deliberately in the negative pressure mode, fossil fuel burning devices should be aerodynamically uncoupled from the house.

Future Developments. The basic concept of dynamic insulation was introduced about a decade ago in Sweden. A dynamic wall house was built in 1978 but appears to have met with limited success. It is stated that "in spite of the high level of thermal comfort achieved the projected energy savings were not realized" (6).

It often happens that new concepts have to wait for the development of new materials before they can be put into practice. This appears to be the case with dynamic insulation; a spunbonded polyolefin membrane had to be developed to provide the precise control of air entering the insulation. It must also be added that agreement has not been reached about the heat transfer mechanisms when mass transport is imposed on heat flow through a wall.

The precision called for in the experimental work to verify theoretical models is much higher than one is accustomed to in building science laboratory and field work. A very small surface temperature change in a wall can lead to a significant change in the rate at which heat enters a wall. Eventually we should be able to predict the performance of such walls under variable wind, air temperature, solar radiation, and air flow conditions.

While the energy conservation potential for dynamic wall houses is excellent, such houses will only become a part of building practice if they can be built economically and reliably within the constraints imposed by the building industry.

CONCLUSIONS

This Dynamic Wall House Project suggests the following:

1. An air barrier can be formed by SBPO on the exterior face of sheathing where its installation and inspection are facilitated. It was also shown to have retained its airtightness characteristics over a three-year period.

2. A simple and effective way of supplying and distributing ventilation air to all the rooms in a house was achieved.

3. At normal ventilation rates the incoming ventilation air was tempered to over 80 percent of the inside-outside temperature difference.

4. No comfort problems due to reduced thermal radiation due to the cooling of exterior walls or cold draughts from the ventilation air were perceived, even under cold and windy conditions.

5. Drying of the wall construction took place during the dynamic operation mode.

6. Combustion of fossil fuel should only take place in systems hermetically sealed from occupied space.

While the energy savings associated with the dynamic wall house described in this paper have not been monitored, theoretical considerations presented in this paper and by others (3) suggest that a significant amount of the energy required to heat the ventilation air can be recovered from heat otherwise lost through the walls. In the meanwhile, much theoretical, design and evaluation work remains to be done to fully realize the potential of the dynamic wall approach.

ACKNOWLEDGEMENTS

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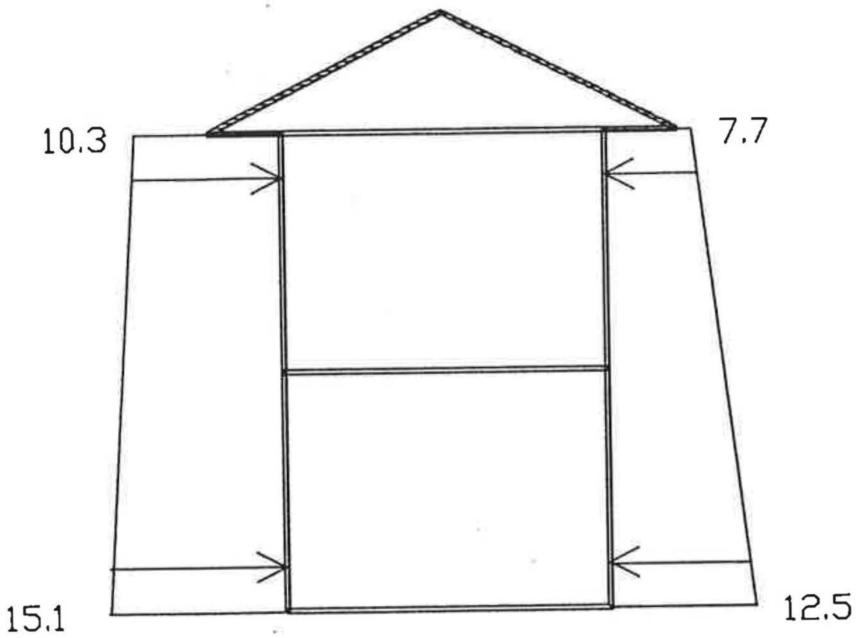

Figure 1. Net wind, stack and exhaust pressures across the windward and leeward walls of a two storey house.

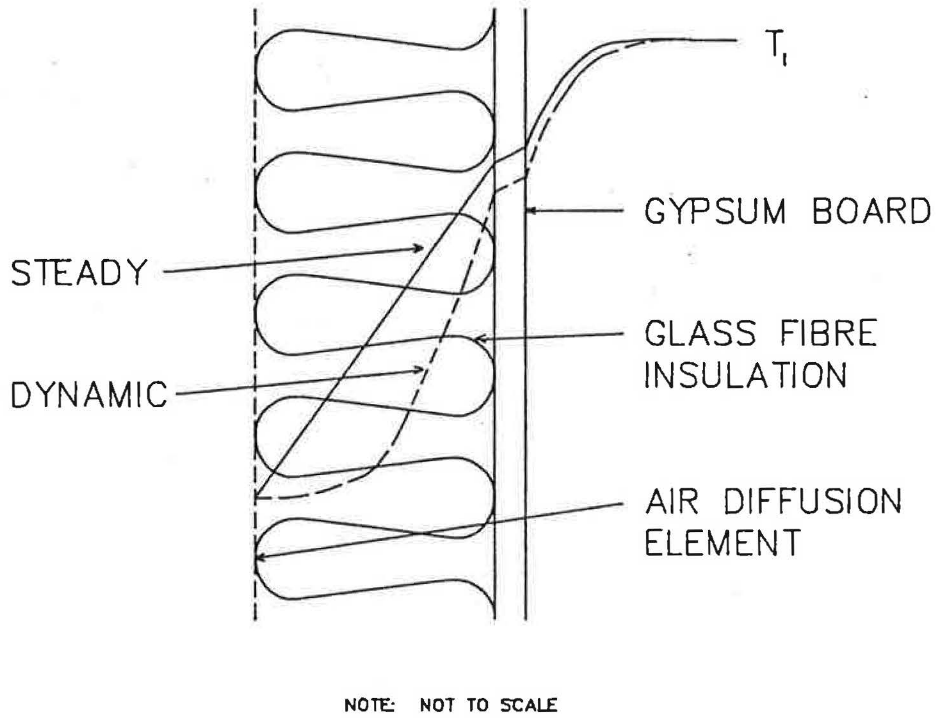

Figure 2. Temperature gradients through a wall comprising inside air film, gypsum wall board, and glass fibre batt insulation where the solid line represents steady state conditions with no air flow while the dotted line represents steady state conditions when a uniform flux of air move from the cold to the warm side.

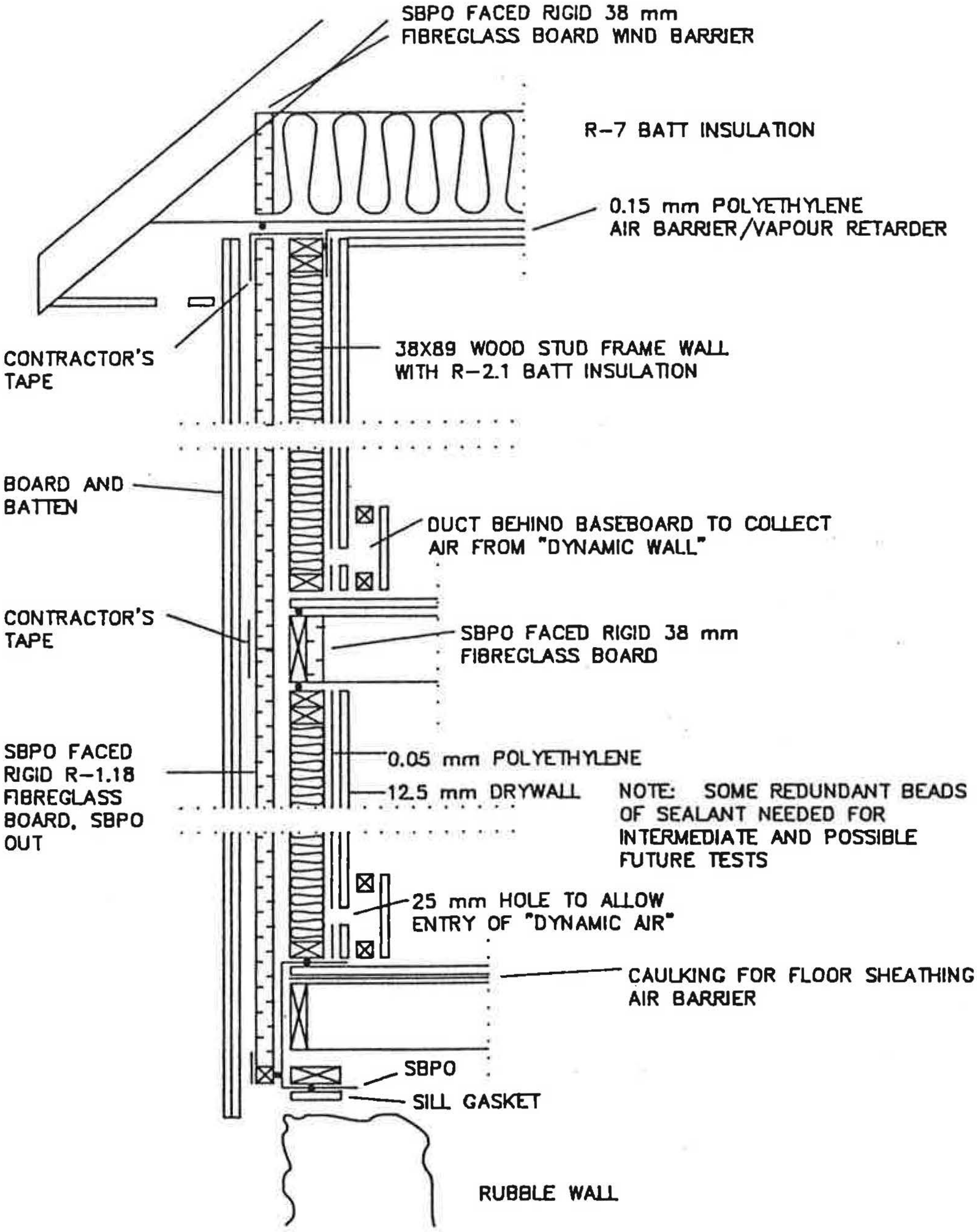

Figure 3. Expanded section through the wall of the dynamic wall house.

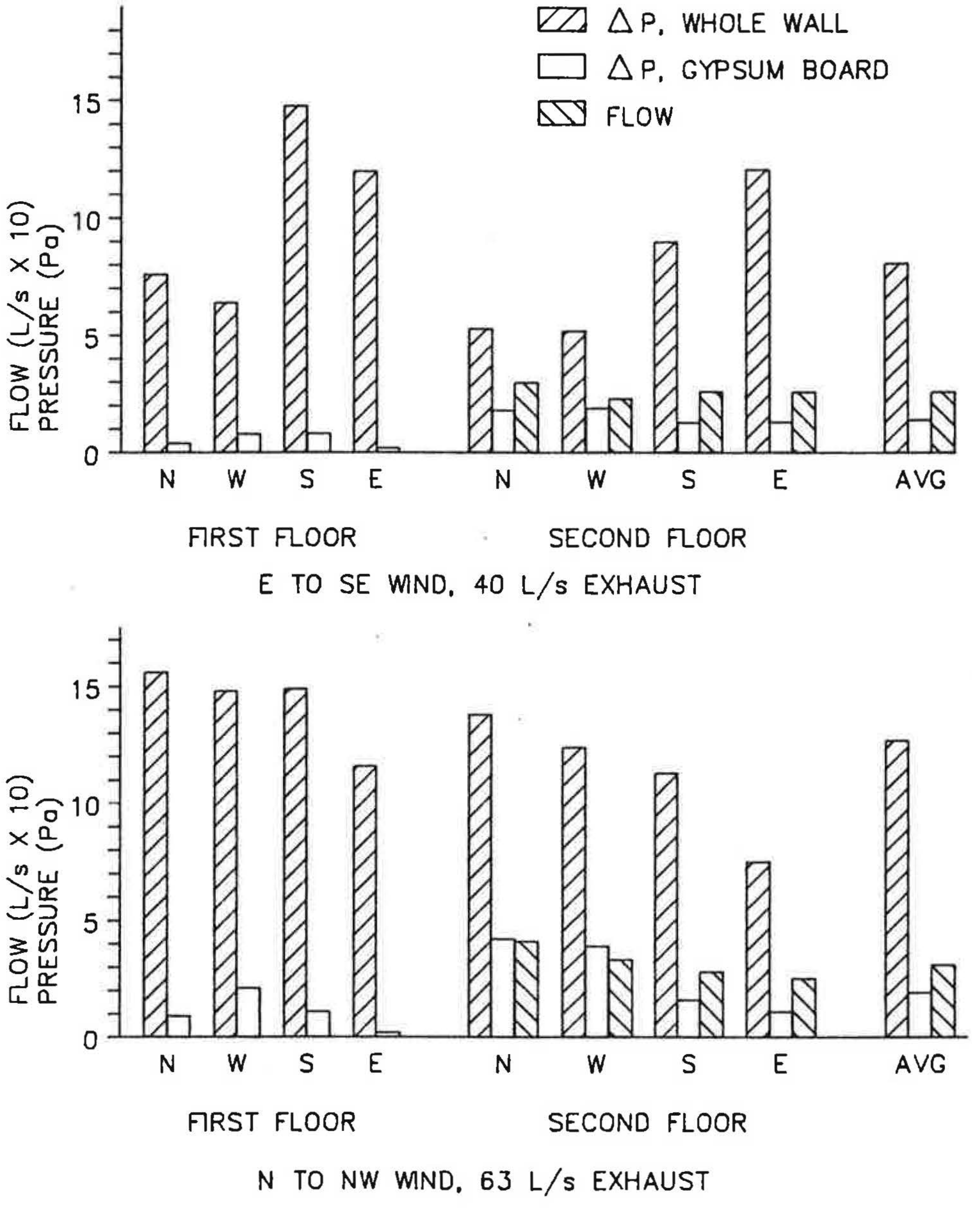

Figure 4. Pressure drop across the entire wall, the gypsum wall board and flow per stud cavity for the four walls with different wind directions and ventilation exhaust rates.

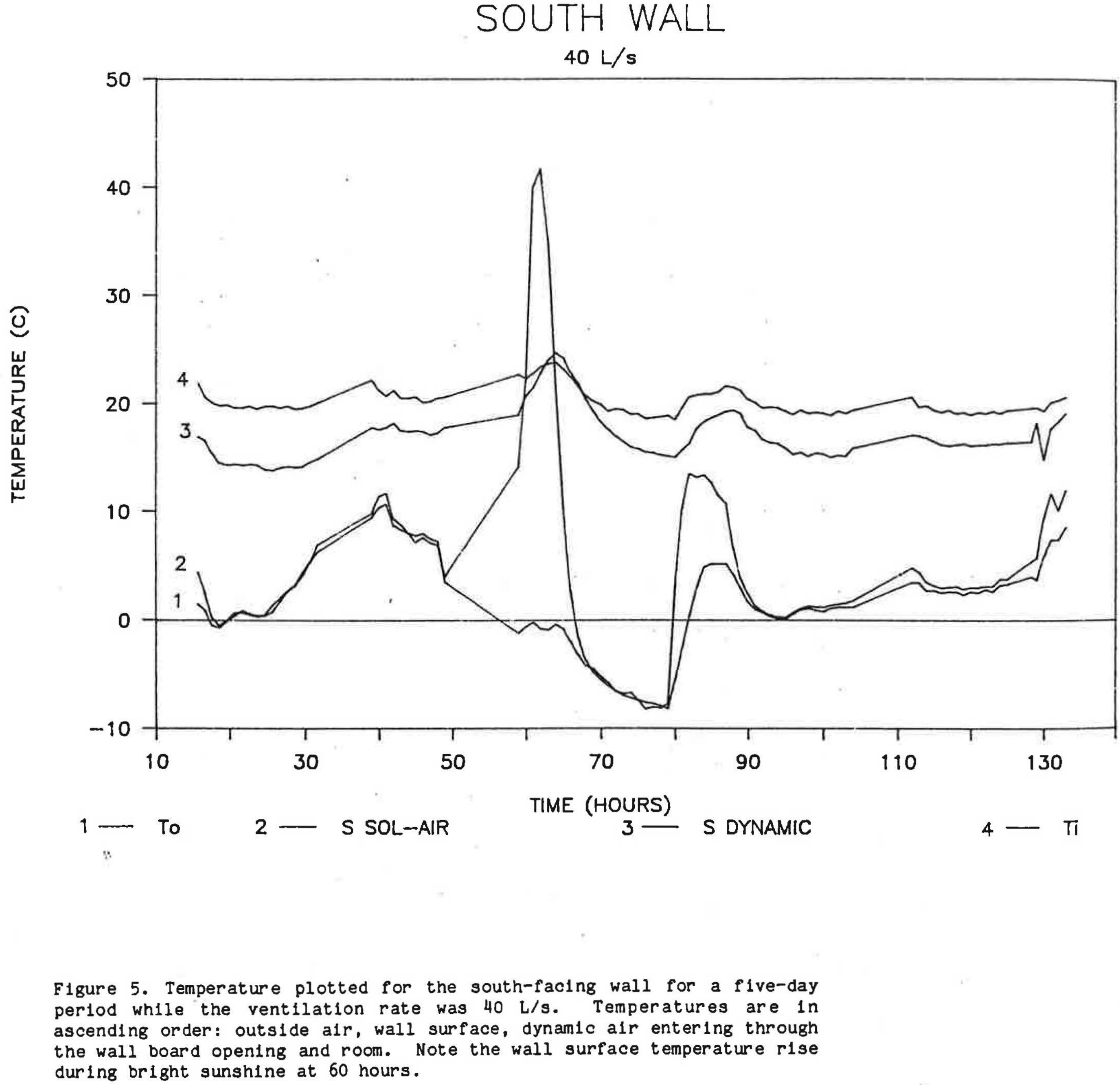

Figure 5. Temperature plotted for the south-facing wall for a five-day period while the ventilation rate was 40 L/s. Temperatures are in ascending order: outside air, wall surface, dynamic air entering through the wall board opening and room. Note the wall surface temperature rise during bright sunshine at 60 hours.

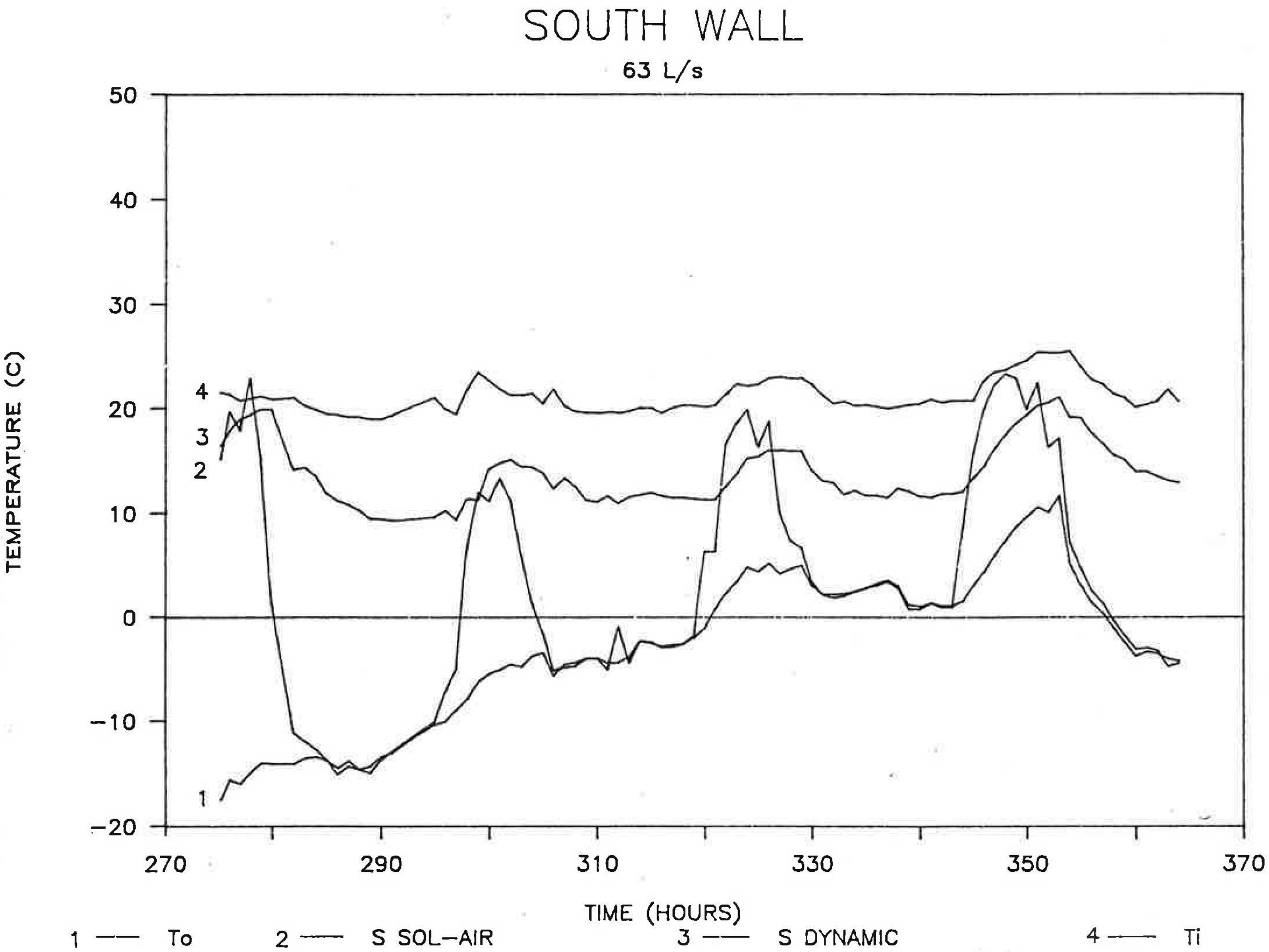

Figure 6. Temperature plotted for the south-facing wall for a four-day period while the ventilation rate was 63 L/s. Bright sun on the first day is followed by hazy sun on the remaining three.

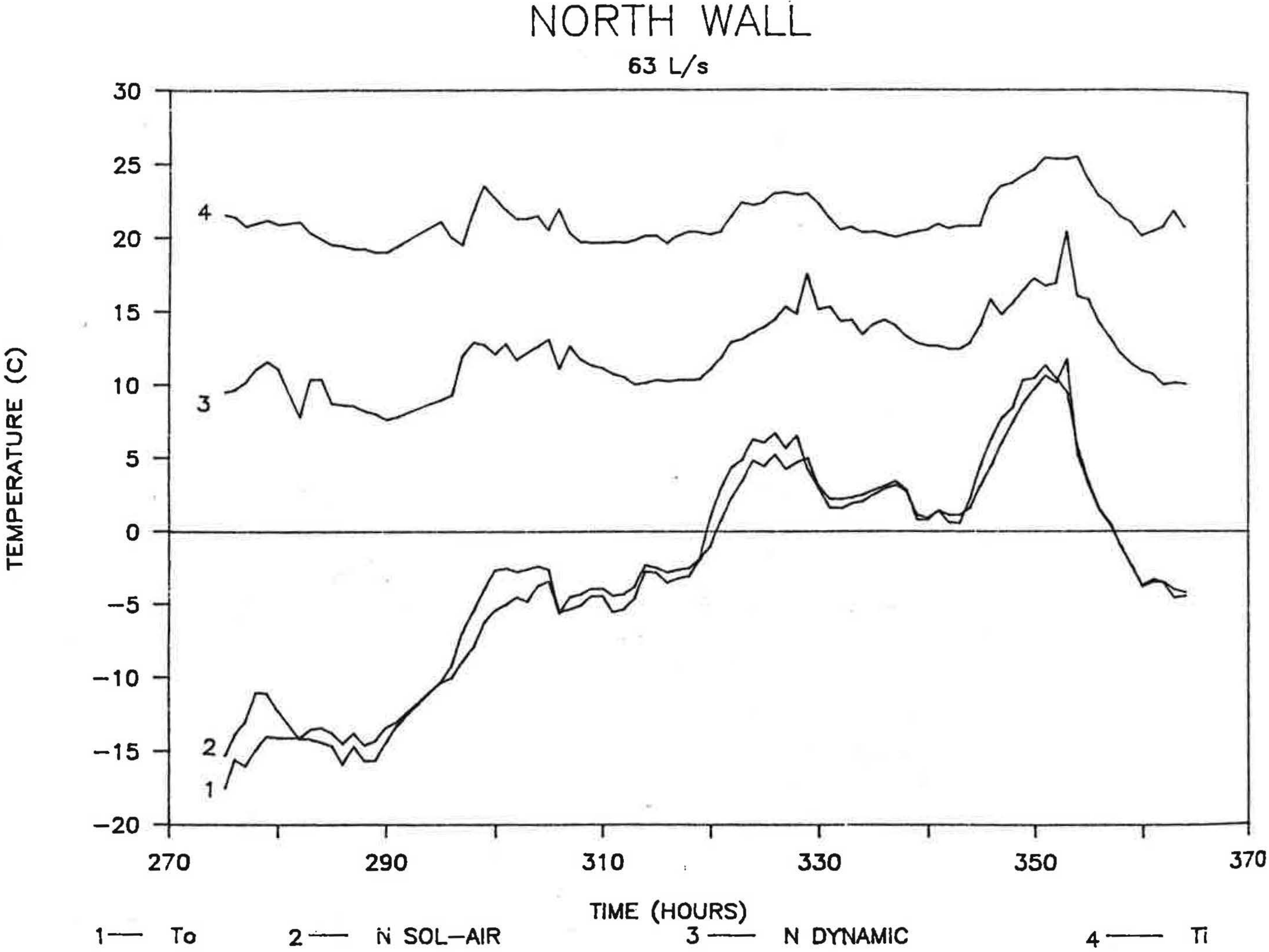

Figure 7. As Figure 6 but for the north-facing wall.