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IN SITU MEASUREMENTS OF FRAME WALL THERMAL RESISTANCE

by W.C. Brown and G.D. Schuyler

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RÉSUMÉ

On a utilisé des appareils de mesure de la transmission de chaleur et des calorimètres pour rechercher les facteurs qui influent sur les mesures de la résistance thermique en place des murs à ossature de bois. Ces facteurs sont : l'orientation des murs, la durée des mesures, le déphasage thermique, les effets de la température moyenne et l'heure des mesures. On a également utilisé ces mesures pour déterminer la résistance thermique en place de l'isolant et l'effet des éléments de l'ossature sur la résistance thermique globale du mur.

Une bonne connaissance des effets dynamiques sur un mur d'essai est indispensable pour obtenir des résultats précis. On a obtenu des mesures de résistance thermique précises pour des murs à ossature en bois à partir des valeurs des différences de température et de la transmission de chaleur sur une période continue de 24 heures (des corrections appropriées ont été effectuées pour tenir compte du déphasage de la transmission de chaleur et pour l'effet de la température moyenne). Toutes les autres méthodes de mesure ont conduit à des résultats moins précis (mais acceptables) ou tout à fait inacceptables.

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In Situ Measurements of Frame Wall Thermal Resistance

W.C. Brown **G.D. Schuyler**

INTRODUCTION

In predicting the thermal performance of a wall, one of the most important characteristics to be determined is the steady-state thermal resistance of the wall. For this reason, measurement of thermal resistance was chosen as the starting point for a field investigation of wall thermal performance. The investigation was designed:

1. to determine the effects of various factors on the accuracy of the measurement of wall thermal resistance,

2. to compare measured resistance with that predicted from the thermal properties of the wall components,

3. to determine the effects of framing members on overall wall thermal resistance.

Factors studied to meet the first objective included wall orientation, length of measurement period, thermal lag, mean temperature, and time of measurement.

Heat Flow Meters (HFM, see Appendix A) were installed in the walls of a house to measure heat flow, Q, through insulation, and thermocouples were placed on the inside and outside surfaces to measure temperature difference, ΔT, across insulation. The results were used to determine the resistance of the insulation and the effects of various factors on the accuracy of the measurement of resistance. A calorimeter (see Appendix B) and an HFM were installed together in a second house to measure heat flow Q in a similar wall section.[1] These results were used to determine the effects of framing members on overall heat flow and thermal resistance through the wall.

The investigation was carried out in two of four test houses used by the Division of Building Research, National Research Council of Canada (DBR/NRCC), in cooperation with the Housing and Urban Development Association of Canada for studies of energy use in single-family dwellings.[2] Built in 1977, the houses are located in the Ottawa area (4674 °C days). The walls are wood frame 38 × 89 mm stud walls at 406 mm on center (O.C.) (nominal 2 × 4 in., 16 in. O.C.) and the stud space is filled with mineral wool insulation (RSI 2.1 [R 12]).* The outside of the stud wall is finished with 25 mm (1 in.) fiberboard sheathing, RSI 0.5 (R 3), and horizontal aluminum siding. The inside of the stud wall is finished with 38 × 38 mm (nominal 2 × 2 in.) horizontal furring and 12 mm (0.5 in.) gypsum board. The furring is at 406 mm (16 in.) O.C. and is filled with RSI 0.9 (R 5) mineral wool insulation. The HFM's were built

* Thermal resistance, SI units, m^2K/W, and conventional units ft^2 h°F/Btu

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around this insulation. A schematic drawing of the wall is shown in Fig. 1. The thermal resistance of the components through the insulation is RSI 3.78 at 24°C (R 21.5 at 75 F) mean temperature. Assuming parallel heat flow and ignoring the effects of fasteners, the overall thermal resistance of the wall is calculated to be RSI 3.53 at 24°C (R 20.0 at 75 F) mean temperature.

HEAT FLOW METER RESULTS

Thermal Lag and Integrating Period

The steady-state thermal resistance of a wall can be determined by integrating heat flow, Q, and surface temperature difference, ΔT, measurements with respect to time until the ratio of the integrals becomes constant. The value of the constant ratio is the steady-state thermal resistance. If Q and ΔT were sinusoidal, the ratio of the integrals of Q and ΔT over one period would give the steady-state resistance. In the field, however, ΔT is not sinusoidal, and is not, in fact, stationary. The period of integration required to give a constant ratio is therefore unknown. In addition, the signal is not truly periodic and the wall introduces a lag between Q and ΔT, so that the integration period for Q should be lagged behind that for ΔT by the delay of the wall in order to obtain accurate results.

The temperature difference across a wall and the heat flow through a wall change primarily because of changes in exterior surface temperature; these changes are caused by the daily cycle of the ambient air temperature and solar radiation. Although the diurnal temperature cycle has an equal effect on all wall orientations, solar radiation affects the south wall to the greatest extent and, to a lesser extent, the east and west walls. As a consequence, the south wall experiences the most rapid changes in exterior surface temperature, with a corresponding increase in the magnitude of the higher frequency components of the surface temperature. In addition, the effects vary from day to day because of cloud cover variations. The south wall, therefore, experiences greater variation in ΔT and Q than the north wall and the apparent value of thermal resistance is correspondingly affected.

A sample of ΔT and Q data collected from the walls under test (Fig. 2) shows that there is one dominant delay period between the two sets of data. This can be determined by finding the delay that produces the maximum cross-correlation between temperature difference and heat flow (Fig. 3). The delay with the maximum cross-correlation is 2.5 h. This agrees well with the delay that is evident from a visual inspection of Fig. 2. Significantly reduced scatter should be expected in the calculated thermal resistance values if the Q data are lagged by 2.5 h behind the ΔT data.

Fig. 4 shows how the integrated thermal resistance, calculated with 2.5 h lag in Q, approaches a constant value as the integration period lengthens. In fact, for the six periods shown, both north and south orientations settled to within ±5% of the seven-day value after 24 h. In addition, it shows that a delay in Q reduces the magnitude of the variations in calculated resistance. Integration periods shorter than 24 h may also produce acceptable results (±5%) and will be discussed later.

Mean Temperature Effects

As the thermal resistance of insulating materials changes with mean temperature, one should expect to see variations in the thermal resistance caused by changes in ambient temperature. The 24 h thermal resistances are plotted as a function of mean temperature (Fig. 5). These indicate a linear relation between thermal resistance and mean temperature. A comparison of the mean temperature corrected and uncorrected resistances (Fig. 6) shows that an apparent seasonal variation and scatter have been reduced by correcting for mean temperature.

One point to notice is the difference between the 0°C thermal resistances for north and south walls (Fig. 5). The north wall shows RSI 4.45 at 0°C (R 25.3 F at 32 F) while the south wall shows RSI 4.28 (R 24.3), a 4% difference. It includes the variability of the insulation as manufactured, modification of performance by exposure, and measurement error. The normalized mean temperature coefficients for the north, 0.0059, and south, 0.0058, walls are quite close, indicating that the walls have the same mean temperature dependence but slightly different resistances.

Time of Day

The observation that a 24 h integration period is satisfactory does not make allowances for the start time of the integration. Comparisons of 24 h integrations starting at different times of the day showed that start time had little effect. If one chooses the start time correctly, however, a much shorter integration period may give satisfactory results (Fig. 4); with a start time of midnight, an integration period of a few hours is adequate.

To investigate the start time of integration, an integration period of 4 h was applied to the data. Comparison of the means and of the standard deviations for 4 h resistance calculated from various start times (Tab. 1) shows that unlagged data give generally unpredictable results for both north and south orientations and all start times. Lagged data give satisfactory results for both orientations if integration starts near midnight, but the results become progressively worse, especially for the south wall, if the start time is such that the integration period approaches daylight hours. If daylight hours are included in the integration period, the results are unacceptable.

COMPARISON OF $\bar{Q}$ FROM HFM AND CALORIMETER

In comparing the measurements of Q made by the HFM with those made by the calorimeter, the most obvious difference is the quantity being measured. The HFM measurement does not include heat flow through any framing members, while the calorimeter measurement includes heat flow through all but the top and bottom plates. As the calorimeter measures heat flow at the inside surface of the gyproc and includes the lags of the framing members, it should indicate a longer lag between Q and ΔT than does the HFM, which measures heat flow at a plane within the wall and does not include framing members. The cross correlation of the measured heat flows (Fig. 7) shows that the calorimeter heat flow lags the HFM heat flow by approximately 0.5 h.

Fig. 8 shows that the ratio of the whole wall heat flow, as measured by the calorimeter, and heat flow through the portion between the framing members, as measured by the HFM, is 0.78. That is, the framing members and fasteners reduce the overall wall resistance to 0.78 of the insulation resistance. This ratio is lower than the 0.93 ratio calculated assuming parallel heat flows and using estimates of the thermal resistance of the components.[3]

Combining this factor of 0.78 with the measured resistance through the insulated portion of the wall (Fig. 6) gives an overall wall resistance of RSI 3.40 at 0°C (R 19.3 at 32 F) mean temperature. This compares well with the measured resistance of a similar wall specimen (2.4 × 2.4 m [8 × 8 ft]) tested in the DBR/NRCC guarded hot box facility. The result from that test was RSI 3.61 at -7°C (R 20.5 at 19.4 F) mean temperature and 55 K (99 F) temperature difference. The estimate of the resistance through the insulation (RSI 3.78 at 24°C mean temperature) compares well with the measured result from the HFM at the same mean temperature (RSI 3.68 south or RSI 3.83 north).

As the measured resistance through the insulation compares well with that predicted from the separate resistances of the components and the overall resistance value compares well with a laboratory measured value, the measured ratio of resistances (heat flows) appears to be valid. The difference between the measured (0.78) and predicted (0.93) ratios is probably due to the fasteners used to hold the wall together and to non-parallel heat flows in the wall.

ERROR

Although 24 h data with time lag and mean temperature correction can produce good results (±5%), the most accurate way to determine the required corrections is from data collected over an extended period of time. A quicker and still acceptable way to obtain the appropriate time lag is by visual inspection of the ΔT and Q curves. In the example studied, the time lag from visual inspection agreed well with that obtained from cross correlation analysis. There is no quick way to obtain the mean temperature correction. It would be appropriate, however, to record the mean temperature at which each measurement was made.

It may be advantageous in some cases to ignore one or both of the corrections and to accept a larger scatter in the results. Tab. 2 shows the mean, normalized by the 0°C mean temperature value of Fig. 5; the standard deviation; and the 99% confidence interval for several cases ranging from both corrections to no corrections.[4] The results for the south wall, which has larger variations in Q and ΔT because of solar radiation, are as good as those from the north wall. As would be expected, larger errors exist if corrections are not made, but results can be expected within ±10% of the correct value, even if no allowance is made for time lag and mean temperature effects.

While acceptable results have been obtained for the frame wall used in this study, other types of walls may produce less accurate results. For example, brick veneer walls with a vented air space would be less amenable to this approach; exterior temperature would have to be measured at the inside surface of the air space. Solid concrete walls, with longer dynamic effects, might require longer integration periods than those used for this study. The results from such walls should be assessed very carefully before they are accepted.

CONCLUSIONS

Reasonably accurate (±10%) values of in situ frame wall thermal resistance can be obtained from heat flow and temperature difference data integrated over a 24 h period. Values accurate to ±5% can be obtained if corrections are made for both wall time lag and mean temperature dependence. These corrections can be determined from analysis of several days' data; or a reasonable correction for time lag alone can be determined from visual inspection of 24 h heat flow and temperature difference curves. Tradeoffs between accuracy and the number of corrections applied are summarized in Tab. 2.

There is virtually no difference in measurement accuracy for a north facing or shaded wall and a south facing or sunny wall for 24 h integrated data. Similarly, there is little difference in accuracy between 24 h integrated data, corrected for lag and mean temperature, and corrected 4 h integrated data as long as the 4 h integration period occurs around midnight. The accuracy of 4 h data becomes progressively worse as the integration period approaches daylight hours and becomes unacceptable if daylight hours are included.

Thermal resistance measured through insulation installed in the field agrees very well with values predicted from resistances of individual components. The ratio of resistance for the wall to that of the insulation between the framing members (0.78) is less than that predicted by a simple parallel heat flow calculation (0.93). This may be partially explained by a reduction in the thermal resistance of the wall components due to nails, especially the reduction in the resistance of the insulating sheathing board by the large number of aluminum nails used to fasten the siding.

REFERENCES

1. Brown, W.C. and Schuyler, G.D., "A Calorimeter for Measuring Heat Flow Through Walls," Proceedings of the ASHRAE/DOE Conference on Thermal Performance of the Exterior Envelopes of Buildings, Kissimmee, FL, December 1979.

2. Quirouette, R.L., "The Mark XI Energy Research Project - Design and Construction," National Research Council of Canada, Division of Building Research, Building Research Note 131, October 1978.

3. ASHRAE Handbook - 1977 Fundamentals Volume, American Society of Heating, Refrigerating and Air-conditioning Engineers, New York, NY.

4. Hays, W.L., Statistics, Holt, Rinehart and Winston, Inc., 1963.

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TABLE 1

4 Hour Resistances for Various Integration Start Times

Start h	South RSI/RSI_{ms}	South σ	North RSI/RSI_{mn}	North σ
Without Lag in Q				
0	1.04	0.050	1.05	0.060
4	1.00	0.046	1.02	0.054
8	0.71	0.225	0.92	0.068
12	0.92	0.543	0.90	0.101
16	1.27	0.245	1.06	0.063
20	1.10	0.107	1.08	0.123
With Lag in Q				
0	1.01	0.021	1.02	0.024
4	1.02	0.041	1.02	0.030
8	0.86	0.401	0.99	0.028
12	0.88	0.098	0.93	0.063
16	1.04	0.060	0.99	0.037
20	1.02	0.033	1.02	0.036

NOTE: All RSI values adjusted for T_m as per Fig. 5

RSI_m mean 24 h resistance as per Fig. 5

σ standard deviation

TABLE 2

Comparison of Measurement Precision for Various HFM Measurements

Computation Plan			South			North		
P	d	T_m	RSI/RSI_{ms}	σ	99% CI	RSI/RSI_{mn}	σ	99% CI
24 h	Y	Y	1.00	0.018	±0.046	1.00	0.012	±0.031
24 h	N	Y	1.00	0.034	±0.088	1.00	0.032	±0.083
24 h	Y	N	0.94	0.028	±0.073	0.96	0.028	±0.072
24 h	N	N	0.95	0.039	±0.099	0.96	0.040	±0.102
4 h	Y	Y	1.01	0.021	±0.055	1.02	0.024	±0.062

NOTE: All integration periods start at midnight

P integration period

d 2.5 h delay in Q (Y - Q delayed, N - Q not delayed)

T_m mean temperature correction (Y - corrected, N - not corrected)

RSI mean resistance

RSI_m mean 24 h resistance with corrections for d and T_m

$RSI_{ms} = 4.28\ m^2\cdot K/W$, $RSI_{mn} = 4.45\ m^2\cdot K/W$

σ standard deviation

99% CI 99% confidence interval - 99 readings out of a 100 should fall within this range of the mean[4]

APPENDIX A

HEAT FLOW METER

The meters used in the investigation were constructed from the same materials as make up the section of the wall they replace. Figure A-1 shows their construction and placement within the wall. The meters were made with a 12-junction thermopile across the insulation layer as well as a separate thermocouple on each surface for temperature measurement.

Measurements taken at each HFM location were:

- T_{ao} outside air temperature (150 mm from the surface)
- T_{ai} inside air temperature (150 mm from the surface)
- T_{so} outside surface temperature
- T_{si} inside surface temperature
- T_i temperature of outer surface of HFM
- E thermopile output

The output from each meter was calibrated at one mean temperature, using an ASTM C518 HFM apparatus, at DBR/NRCC. In addition, the dependence of the output upon mean temperature was measured for one HFM and applied to all others.

APPENDIX B

CALORIMETER

The calorimeter used in the investigation was constructed of two layers of foil-backed rigid glass fibre insulation.[1] The total wall thickness was 10 cm, with a thermal resistance of RSI 2.8 (R 16). It was 1.2 m wide by 2.1 m high (4 × 7 ft) and contained a 150 W heating cable. The heater was controlled to maintain zero temperature difference across the calorimeter walls, and temperature difference was sensed by an 18-junction thermopile. The calorimeter was mounted on the inside surface of the wall for which heat flow was to be measured. Measurements included:

- T_o outside air temperature
- T_i room air temperature
- E energy supplied to the calorimeter

Readings were taken continuously by a computer-based data acquisition system.

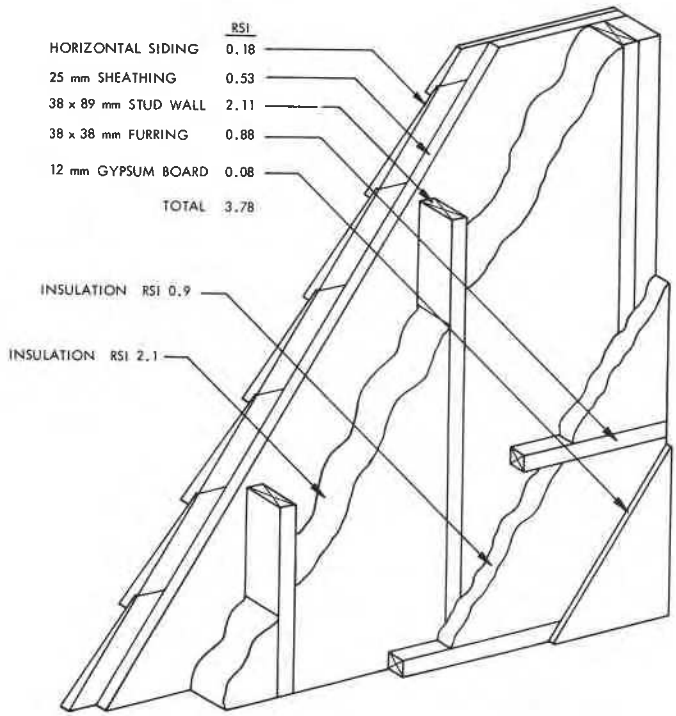

Figure 1. Schematic of test wall

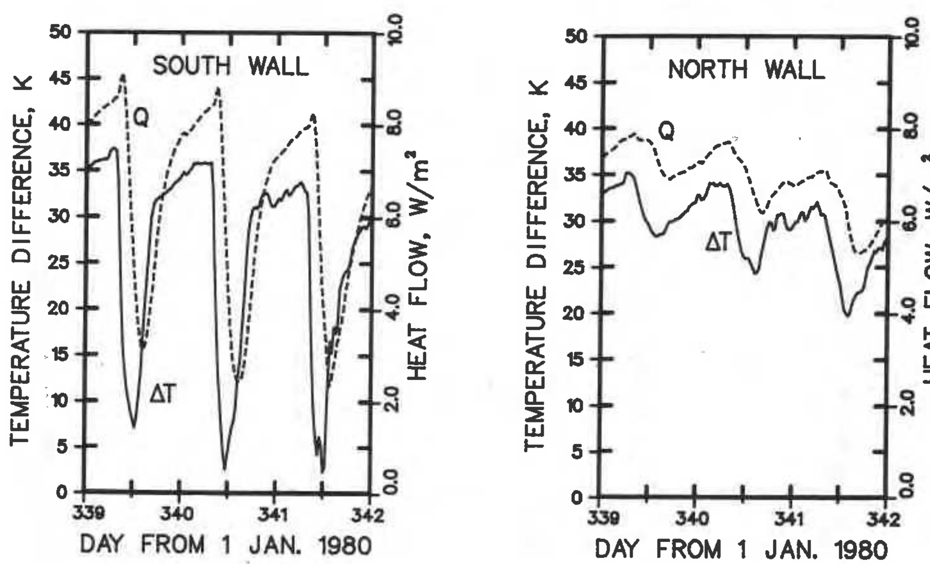

Figure 2. Temperature difference and heat flow vs time

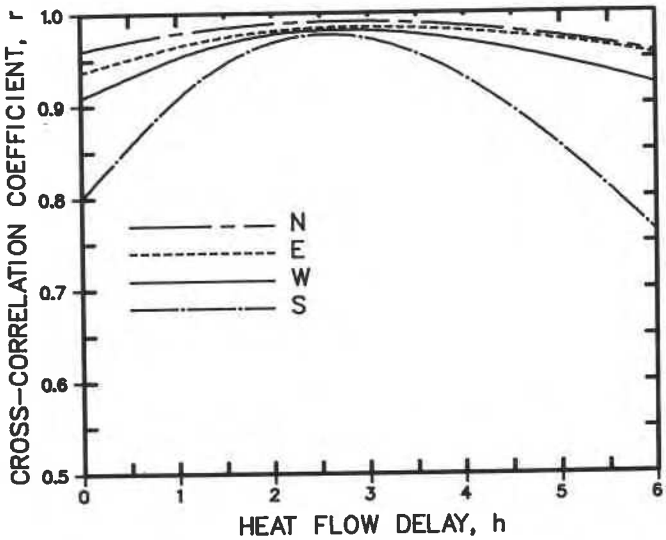

Figure 3. Cross-correlation coefficients for differect orientations

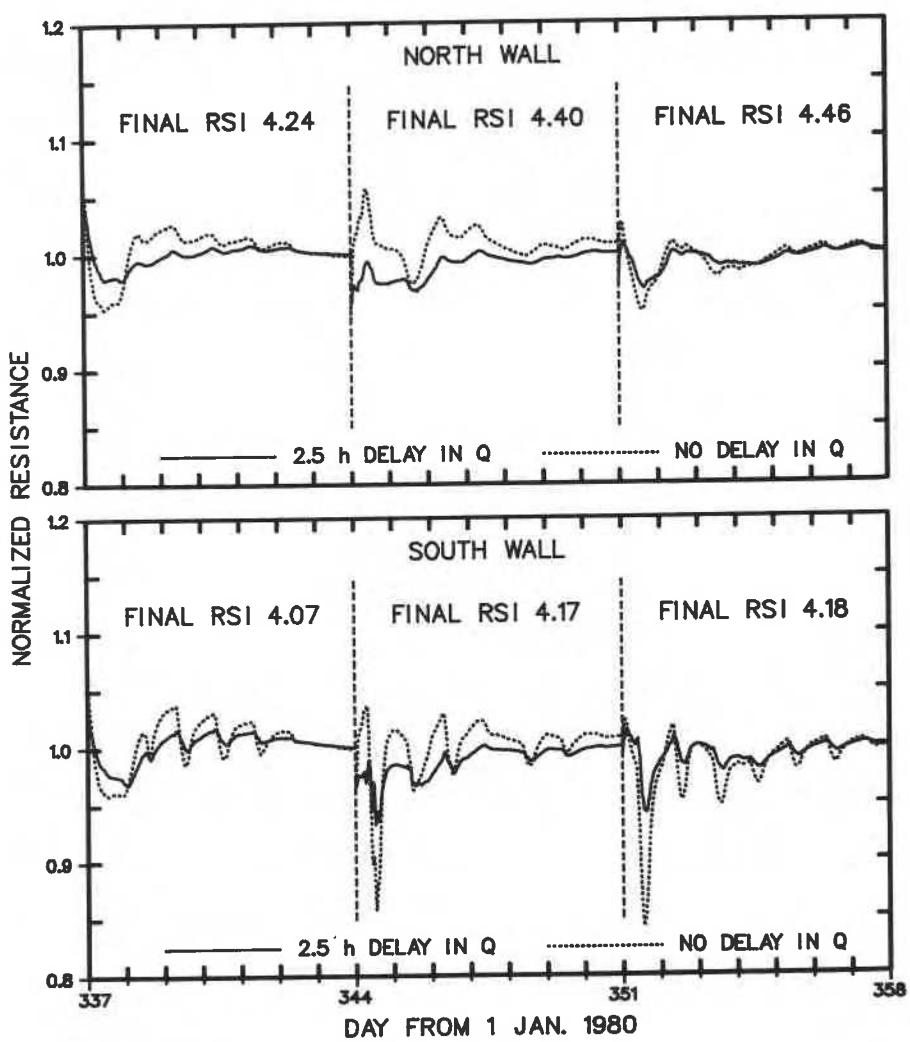

Figure 4. Cumulative HFM resistance

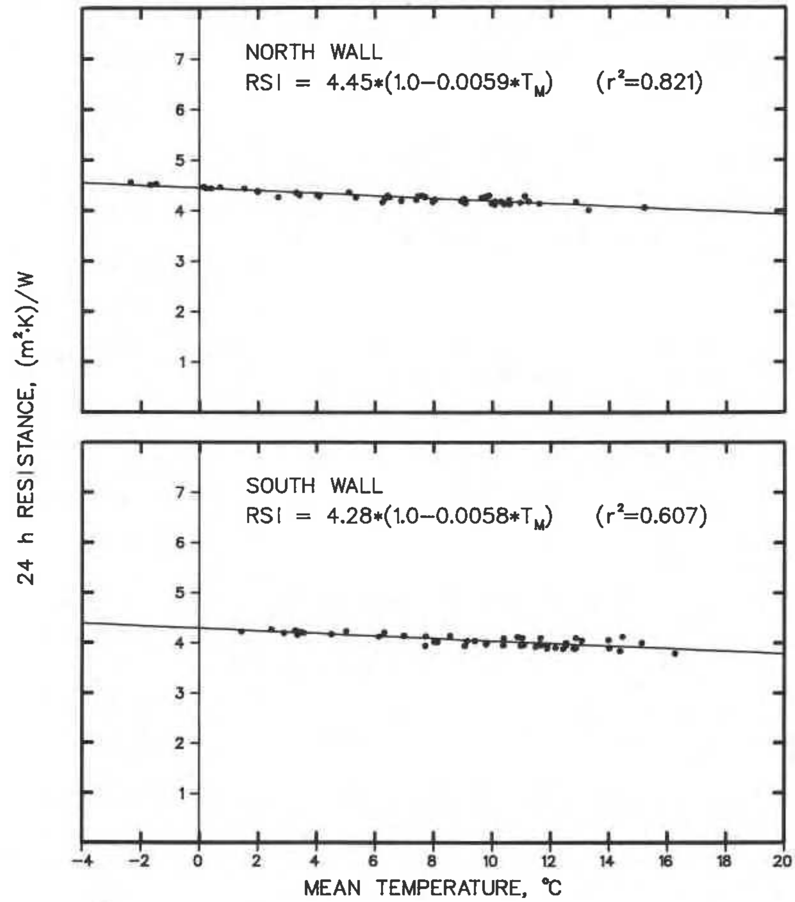

Figure 5. 24h resistance vs mean temperature (delay 2.5h)

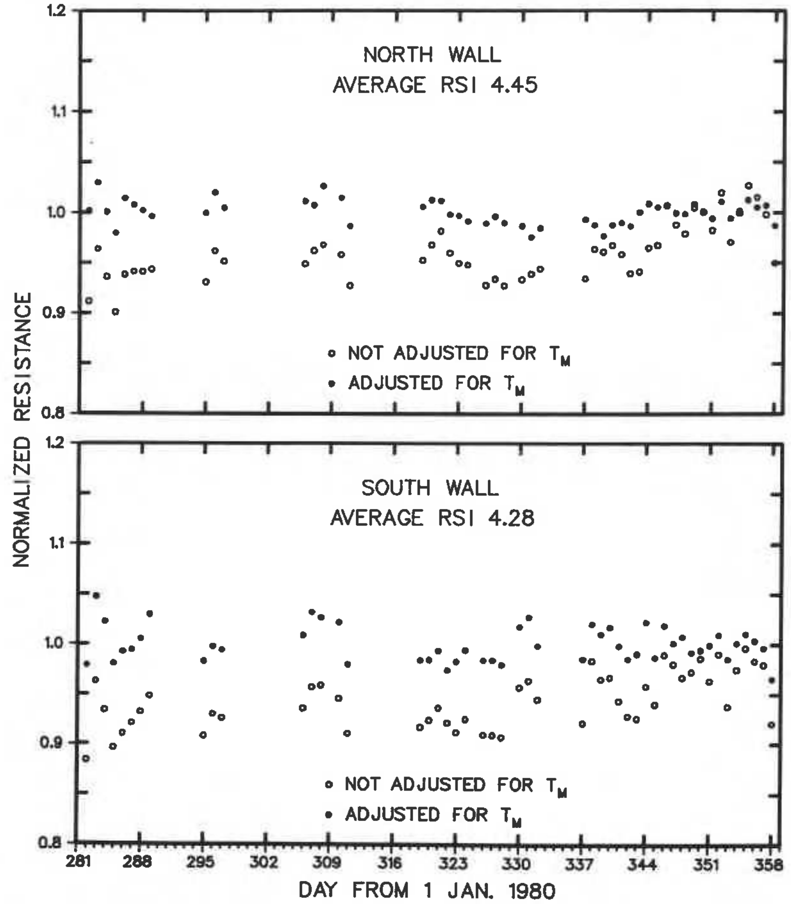

Figure 6. 24h resistance (delay 2.5h) vs time of year

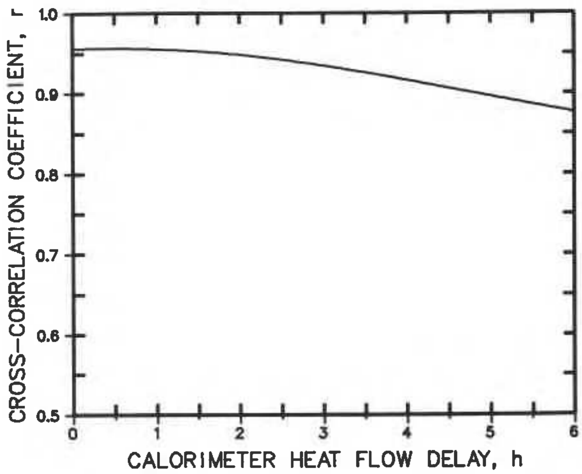

Figure 7. Cross-correlation coefficient for calorimeter and HFM heat flow

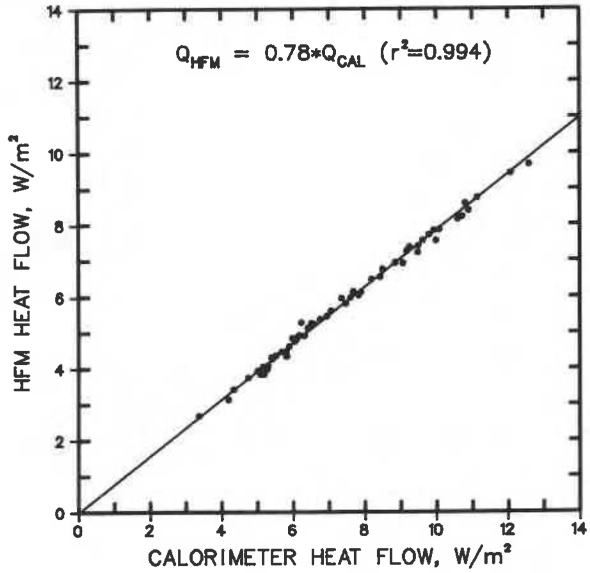

Figure 8. 24h HFM heat flow vs calorimeter heat flow (delay 0.5h)

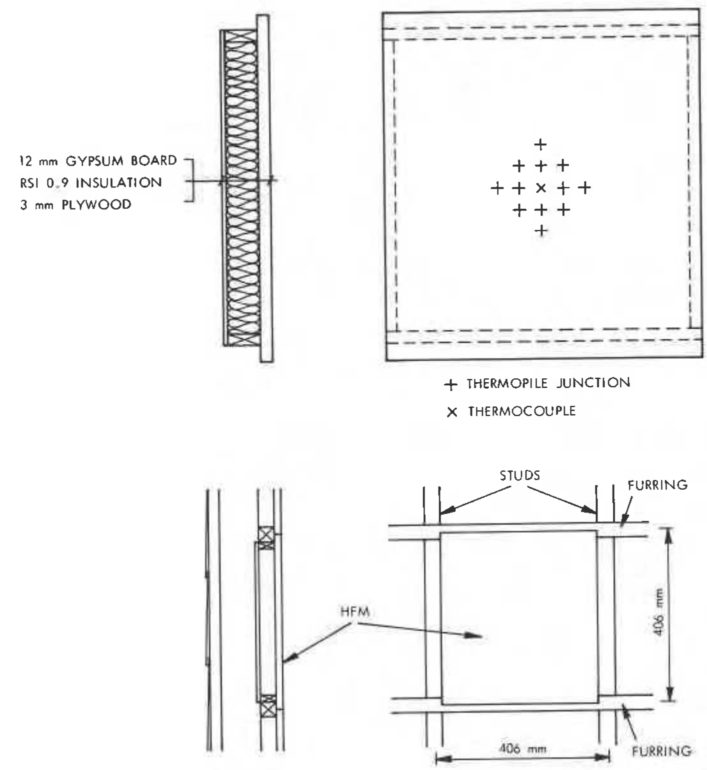

Figure A-1. Construction and location of HFM in test wall

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