ANALYSIS AND MEASUREMENT OF THE THERMAL BEHAVIOR OF THE WALLS AND SURROUNDING SOIL FOR A LARGE UNDERGROUND BUILDING

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ABSTRACT

In a program designed to ascertain the merits of extending earth-sheltered design concepts to a large commercial structure, measurements and analyses are being conducted at the University of Minnesota. From measurements obtained for the 1978 calendar year at a earth-sheltered building on campus, the dynamic heat transfer interactions between the building walls and the surrounding soil have been demonstrated and experimental verification has been provided for a transient, finite difference heat transfer computer program developed for the analysis of earth-sheltered building envelopes.

Computer generated contour plots detail the influence of the building and the seasonal fluctuations of the soil temperatures while graphically illustrating the thermal storage characteristics of the surrounding soil mass.

Wall heat flux measurements have been made at regular intervals as well as soil temperature and moisture content measurements to determine the effect of different soil types and ground surface conditions around the building perimeter.

INTRODUCTION

Earth-sheltered buildings possess a number of unique physical characteristics whose environmental and energy conserving qualities have produced an increasing public awareness and acceptance of this mode of design. With respect to physical aesthetics, underground space can be integrated into the surface features of a given building site in such a way as to complement or enhance the surroundings. In like manner, it is possible to incorporate subsurface construction such that isolation is provided from the surface environment and no intrusion is apparent to the observer. Thus, a great deal of latitude is afforded to permit construction in areas where surface preservation, population density or air and noise pollution considerations might otherwise render a conventional surface structure undesirable.

An equally compelling consideration concerns the inherent energy conserving qualities which are characteristic of earth-sheltered buildings. Due to the thermal insulation and high heat capacity of the surrounding soil, seasonal outdoor temperature variations are greatly reduced below the ground surface and daily fluctuations are damped out within the first 0.3 m of soil. At the same time, the soil near the building tends to approach thermal equilibrium with the building interior. As a consequence, the temperature gradient through the walls of the structure is markedly reduced with an accompanying reduction in heat

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transfer through the building envelope. Additionally, the large heat capacity of the building walls and the surrounding soil further contributes to creating a stable interior environment whose sensitivity to periodic or random fluctuations in the heating or cooling of the building is largely diminished. (1,2)

In order to evaluate the critical parameters involved in the wall heat exchange mechanisms for earth-sheltered buildings, a program of experimental measurements and numerical analyses has been conducted at the University of Minnesota.

EXPERIMENTAL STUDIES

Williamson Hall is a large underground buiding located on the Minneapolis campus of the University of Minnesota. Two main floors, 3.7-m and 7.3-m below grade level, house the university bookstore as well as the records and admissions facilities and comprise 94 percent of the building's 7710 m^2 of gross floor area. A schematic cross-section of Williamson Hall is shown in Figure 1A. Since the building first went into operation in May 1977, measurements have been made to determine the temperature and moisture field in the ground surrounding the building. By December 1977 the entire instrumentation network was completed and data were being gathered at the five probe group locations shown in Figure 1B. Three different soils (Ridgedale loam, river sand and Moon Valley silt) were used as backfill material for probe groups 1, 2 and 3, while the sand loam in-situ soil originally removed from the building excavation was employed as backfill for groups 4 and 5 and the remainder of the structure.

Each probe group consists of four thermocouple probes and four heat flux gages. Figure 2 provides a schematic cross section of a typical probe group. The thermocouple probes determine the soil temperature field in a vertical plane normal to the building wall. The first three probes are buried within the backfilled region at distances 1.0-m, 2.0-m and 3.0-m from the wall. The fourth temperature probe is located 9.3-m from the building and is situated in the undisturbed in-situ soil surrounding the building. The temperature probes are each equipped with seven thermocouples such that the soil temperatures may be measured from 0.25-m to 7.5-m below the top of the building. For probe groups 2 and 5, however, the fourth temperature probe extends 15-m below the surface of the ground so that the deep soil temperature and the building influence far away can be measured.

In addition to the soil temperature measurements, the moisture content profile in each of the four soil types was monitored by means of a nuclear soil moisture probe. The probe was lowered into the soil by means of aluminum access tubes which were placed in the ground one meter away from the temperature probes at distances of 1-m, 2-m and 9.3-m from the building wall in probe groups 1, 2 and 3. As shown in Figure 1B, moisture measurements were taken at 1-m and 9.3-m from the building in the in-situ soil of probe groups 4 and 5. The access tubing was installed at the same time as the soil temperature probes and extends to a depth of 7.5-m.

The wall heat flux is measured at the inner and outer surfaces of the wall by means of commercial heat flux gages. The gages are located 0.71-m and 2.54-m below the roof of the building, as indicated by the small black rectangles in Figure 2. A thermocouple for measuring the wall surface temperature is mounted adjacent to each heat flux gage.

The entire building structure is a poured concrete enclosure with a wall thickness of 0.3-m. Thermal insulation is provided by 3.8-cm thick polystyrene covering the roof and extending down the wall to a depth of 1.2-m. A more detailed description of Williamson Hall and the instrumentation can be found in references (3),(4) and (6).

The temperature and heat flux transducers are scanned automatically by means of a microprocessor controlled multiplexing circuit which transmits the analog signals to a sixty channel data logger for conversion to digital output and subsequent recording on magnetic tape. Finally, the recorded data is processed to obtain time averaged values for the wall heat flux and soil temperature data.

A plot of the average monthly heat flux through the interior surface of the building wall 2.54-m below the roof is displayed in Figure 3 for the measurement period January through December, 1978. From the figure a clear delineation of two seperate characteristics is apparent. During the months of the heating season probe groups 2 and 3 exhibit similar behavior with heat fluxes which are 35 to 48 percent less than the fluxes measured for groups 1, 4 and 5. These differences are not consistent with the variations in soil properties from group to group. However, they do correlate well with the variations in surface cover for each of the probe groups. In probe groups 1, 4 and 5 the ground near the building wall is covered with concrete pavement which was kept clear of snow to allow for the movement of pedestrian traffic over the building. In contrast, the landscaping around the building provides a gently sloping bermed surface at the location of probe groups 2 and 3 which has a grass sod surface cover and from which the snow was not removed during the winter. Hence, the added insulation of the undisturbed snow cover on top of grass and 0.5-m to 1.0-m additional soil depth outweighs the variations between soil types. As a result, the data in Figure 3 may be interpreted as an indication that greater significance should be assigned to the surface treatment than to the soil type in determining earth-sheltered wall losses.

The presence of grass cover rather than pavement was not observed to have serious impact upon the soil moisture content near the building. For probe groups 2, 3 and 5 soil moisture contents varied from 15 to 30 percent by volume throughout the year 1-m away from the building. Further away, at 9.3-m, the probe group 5 soil below the pavement maintained a very uniform profile ranging from 15 to 20 percent volumetric moisture content while the soil below the grass cover displayed the 15 to 30 percent moisture content variations characteristic of soil near the building. The fact that the soil moisture content near the building appeared insensitive to surface cover was judged to be a result of the drainage flow off the structure. The roof deck is sloped such that during a rainfall the water drains over the edge and into the surrounding soil. This occurs around the entire perimeter as the walkway pavers are placed on 3.8 cm pedestals to allow a drainage path underneath. The pavement placed directly on the soil is a 10 cm poured concrete slab. Thus, 9.3 m away the local influence of rainwater runoff from the building is not present and the soil moisture content reflects more directly the moisture permeability of the surface. Difficulties with the nuclear soil moisture measurements prevented a more detailed resolution of moisture migration phenomena. However, comparing the measured soil temperatures with the predicted values derived from the analytical studies discussed in the following section revealed that soil property values required an annual variation indicating the dryest period during winter and the largest moisture content during the summer. This correlates with the experimentally observed trends and agrees with expectations that during the winter the formation of a frozen soil layer at the surface and reduced precipitation levels permit local drying of the soil as moisture migrates away from the vicinity of the warm building towards the cooler surrounding soil. Beneath the grass cover a 40 percent variation about a mean thermal conductivity of 2.5-W/mK was predicted in the probe group 2 sand. Below the concrete pavement, the in-situ sandy loam soil exhibited a smaller 10 percent predicted variation about a mean thermal conductivity of 2.0-W/mK.

During the summer and autumn months, the wall heat loss in Figure 3 is seen to drop to very low values with a slight heat gain being registered at some probe group locations. At this point, the differences between probe groups no longer attain significant proportions at the 2.54-m depth. An explanation for this behavior can be gained from examining the soil temperature profiles shown in Figures 4 and 5. The circles in Figure 4 illustrate the average monthly soil temperatures as measured in probe group 2 during February 1978 while in Figure 5 they represent the July 1978 averages. The solid lines in Figures 4 and 5 are predicted profiles which will be discussed later. From the beginning of September 1977, the average outdoor air temperature remained below the 23°C interior building temperature and by December 31, 1977, the outdoor air temperature had fallen to -10°C. With the duration and severity of the winter, a well established winter temperature profile can be observed during February, Figure 4, in which the temperature gradients result in a flow of heat from the building walls toward the ground surface in the upper 5.0-m of the soil while below this level the heat flow is downward toward the deep ground which is at a temperature of 13.8°C. It is observed that the soil within 3.0-m of the building wall is 4°C to 9°C warmer than the soil temperatures 9.3-m distant from the wall. This effect becomes more pronounced as one proceeds deeper into the soil where the influence of the ground surface conditions diminishes and the presence of the building becomes the more dominant factor. While warming of the outside air temperature began in mid-February, the average daily temperature of 23°C did not occur until the end of May. Consequently, by July less than two months have passed during which time there would be significant warming of the soil by the atmospheric conditions and a clearly defined summer warming characteristic cannot be established by July. In Figure 5, this is evidenced by the inflection in the soil temperature profiles which occurs near the building wall at a depth of approximately 4-m. Due to the damping of the temperature wave and the phase lag induced by the heat capacity of the soil, the seasonal variations in the atmospheric temperatures have little effect below this level for the soil 9.3-m from the building. In addition, within 3.0-m of the wall it can be seen that the building temperature and the deep ground temperature are the dominant factors in controlling the temperature gradiants below this 4-m depth.

Nearer the surface, the average outdoor air temperature of 24°C for July is within 1.5°C of the building interior temperature resulting in diminished horizontal and vertical soil temperature gradients. This is seen in Figure 5 as the temperature profiles draw together at shallower levels and also is reflected by the small magnitude of the heat flux measured through the building walls from June through October (Figure 3).

ANALYTICAL STUDIES

As a means of establishing a more generalized understanding of the sub-surface thermal environment and to extend the interpretation of the experimental data, a transient two-dimensional finite difference computer program was developed to model a cross-section of the building and the surrounding soil. In the program the interior building air temperatures were modeled after those which occurred within Williamson Hall with convection boundary conditions utilized as the heat transfer mechanism at the wall, ceiling and floor surfaces. Measured daily average outside air temperatures and the average daily solar flux provided the exterior conditons. A thorough description of the computer program and its implementation is found in reference (6). Agreement between the soil temperature profiles was achieved for each of the twelve months of the study as shown for February and July in Figures 4 and 5. As stated previously, the circles in the figures are the average monthly soil temperatures obtained by measurement. The data symbols are of radius equal to 0.25°C. The solid lines present the average monthly soil temperatures determined from the analytical model.

From the results of the numerical study a contour plot of the isotherms within the ground surrounding the building was constructed for each month. Figures 6 and 7 provide representative examples of the winter and summer ground temperatures, respectively, based upon the predicted average monthly temperatures. In each figure, a cross-section of Williamson Hall appears to the left while the below ground portion of neighboring Folwell Hall can be seen on the right, 18.6-m away. The contour lines in the figures represent isotherms within the soil. A temperature difference of 2°C occurs between adjacent isotherms. Thus, in Figure 6 the February ground temperatures are seen to vary vertically from -3°C at the surface midway between the two structures to the deep ground temperature of 14°C and to reach values of 22 to 23°C for the soil bordering the building envelopes. At the bottom of the wall of Williamson Hall and beneath the floors of the buildings the spacing between isotherms is expanded indicating relatively small temperature gradients and low heat losses in these areas. In contrast, the isotherms near the surface are tightly compressed due to the large temperature difference between the 23°C interior air and the -11.2°C average outside air temperature showing a pronounced flow of energy from the buildings and the ground towards the surface. Comparing Figure 6 with Figure 7, the June soil temperature contours, it can be observed that the warming influence of the earth-sheltered building now extends as much as 10 m into the ground below, an advance of 5-m in four months. In addition, the thermal storage capacity of the surrounding soil and its ability to serve as a substantial heat sink is graphically illustrated by the enclosed cell of soil at 12°C which is a lingering remnant of ground cooling during the previous winter. Thus, at a time when conventional surface structures are experiencing a heat gain from the outside air and solar flux, this region of soil serves to provde a steady cooling environment for the earth-sheltered structure.

Note that the presence of solar insolation has produced a ground surface temperature of 26°C contrasted with an average monthly outside air temperature of 22°C. This is a reflection of the significance of the surface treatment as reflected in the work of Kusuda (7) who demonstrated that the summer surface temperatures of bare soil or grass can range 3°C above or below the average monthly air temperature while a black asphalt surface could average 9°C warmer than the air temperature. Kusuda's results were drawn from open field conditions whereas the presence of a nearby earth sheltered structure will produce some warming of the soil below and, hence, of the surface temperatures.

Completing the annual cycle with the numerical predictions, it was found that following nine months of operation the soil temperatures near the building established repeatable cyclic patterns indicating that the initial warming period for this regime was completed. Further away from the building, the deep ground temperature continued to exhibit warming from the building for more than a year, however this effect produced no significant variation in the earth-sheltered envelope losses which are dominated by the temperatures within the first 3-m of soil.

Figure 8 presents the variation with depth of the heat flux through the inner surface of the wall for February and July as predicted by the numerical analysis. For the winter case, the heat loss near the ceiling is largest as a low thermal resistance path is found through the roof. This decreases with increasing depth until a sharp rise in heat flux is observed at the bottom edge of the wall insulation indicating that this insulation has not been carried to a sufficient depth to isolate the wall from the thermal influence of the surface. Below this level, the wall losses drop steadily to a nearly uniform value below the depth of 4-m. During the summer, only a slight heat gain is observed near the ceiling primarily due to heating from absorbed solar energy at the ground surface. Below the wall insulation, the soil is seen to continue to draw heat from the building at rates which increase to values equivalent to those observed during the winter below the 4-m depth. The interior temperature of the building was allowed to rise from 23°C to 25.6°C during the summer which produced higher summer cooling rates at the foot of the building as the thermal mass of the soil below acted to resist this change in temperature. Due to the small magnitude of the July wall heat fluxes at the 1.2-m depth, a clear delineation of the wall insulation's bottom edge is not discernable on the inside surface of the structure as is the case in the February heat flux profile.

CONCLUSION

Experimental and analytical studies of the temperature field around an earth sheltered building provide information about the heat transfer through the building envelope. The ability of the surrounding soil mass to act as a large thermal reservior to reduce both the severity and the rapidity of the seasonal variations in temperature which occur in Minneapolis, Minnesota, has been illustrated by the contour plots of the soil isotherms generated by the transient computer program. As a result of the duration of the Minnesota heating season, the surrounding soil is sufficiently cool to provide cooling of the building walls throughout the summer while surface warming during the summer produces a milder environment surrounding the building in winter. For the purpose of comparison with conventional structures, it is convenient to calculate the equivalent thermal resistance which for the walls of Williamson Hall during February was 3.85-m^2 C/W (R=21.8-hr ft^2 F/BTU). Since the only insulation placed on the walls is a layer of high density polystyrene 3.8-cm thick covering the top 1.2-m of the wall, this clearly illustrates the effectiveness of the earth cover in providing thermal insulation. However, due to the significant thermal storage effects within the soil the R-value comparisons actually provide an inadequate measure of the transient wall performance of a high mass structure as evidenced by the continued cooling of the walls during the summer.

The numerical analysis provided evidence that it is desirable to insulate the roof and upper wall sections of an earth sheltered structure to a depth of 3.0-m. For surfaces below this level, added insulation provides only a small reduction in winter heat losses while the isolation of the building from the thermal storage capacity of the surrounding soil may even deem deep insulation detrimental to overall building performance.

In addition, it was observed that while warming of the soil far from the building continues for a number of years, the transient warming period near the wall is virtually complete within 9 months of the start of operation for the building HVAC system. Variations of less than 1.0 percent in the monthly wall heat flux were observed following the first year operation. This was observed to be due to the fact that the soil temperatures within 3-m of the building wall exerted the greatest influence upon the building heat losses while temperature gradients rapidly dropped below 0.5 C/m outside this region.

From the data collected over the calendar year 1978, it was found that the envelope losses through the walls of Williamson Hall show a stronger dependence upon the ground surface cover than upon the soil type. This suggests that the primary determinant in selecting a backfill soil type for an earth sheltered structure should be the mechanical integrity of the soil, i.e. its water drainage properties and compaction characteristics. Modification of the thermal regime surrounding the building can best be accomplished by means of the manner in which paved areas and vegetated areas are arranged on the surface, variations in the depth of the surface cover and the quantity and location of insualtion on the walls and ceiling.

BIBLIOGRAPHY

1) Bligh, T.P., Energy Conservation by Building Underground, Underground Space, v. 1, pp. 48-62, 1976.

2) Eckert, E.R.G., The Ground Used as ENergy Source, Energy Sink or for Energy Storage, Energy, v. 1, pp. 315-323, 1976.

3) Eckert, E.R.G., Bligh, T.P., and Pfender, E., Energy Conservation by Subsurface Construction: Heat Transfer Studies in a Large Underground Building, NSF(RANN), 1 through 3, Progress Report, 1976-78.

4) Eckert, E.R.G., Bligh, T.P., Pfender, E., Energy Exchange Between Earth-Sheltered Structures and the Surrounding Ground, 1978 Midwest Energy Conference, Chicago, Nov. 9-21, 1978.

5) Mostaghimi Tehrani, J., Measurement of Thermal Conductivity of Soils, M.S. Thesis, University of Minnesota, 1978.

6) Shipp, P.H., Thermal Characteristics of Large Earth-Sheltered Structures, Ph D. Thesis, University of Minnesota, 1979.

7) Kusuda, T., The effect of ground cover on earth temperature, NBS report 10373, Feb., 1971.

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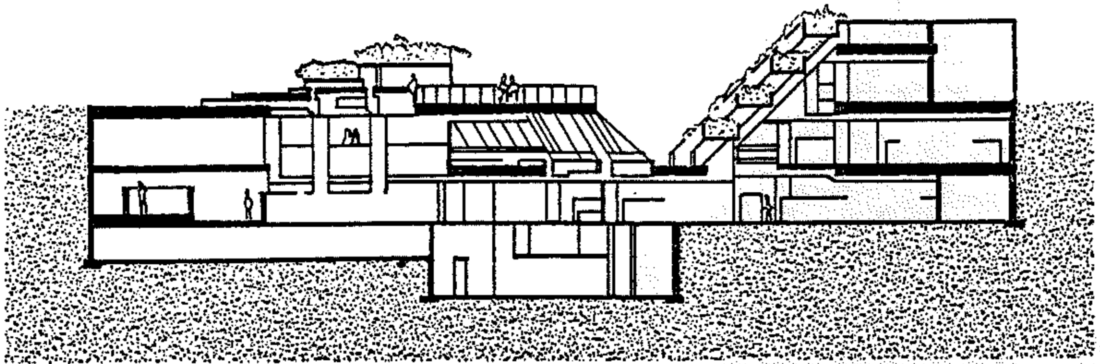

Figure IA: SECTION THROUGH BOOKSTORE

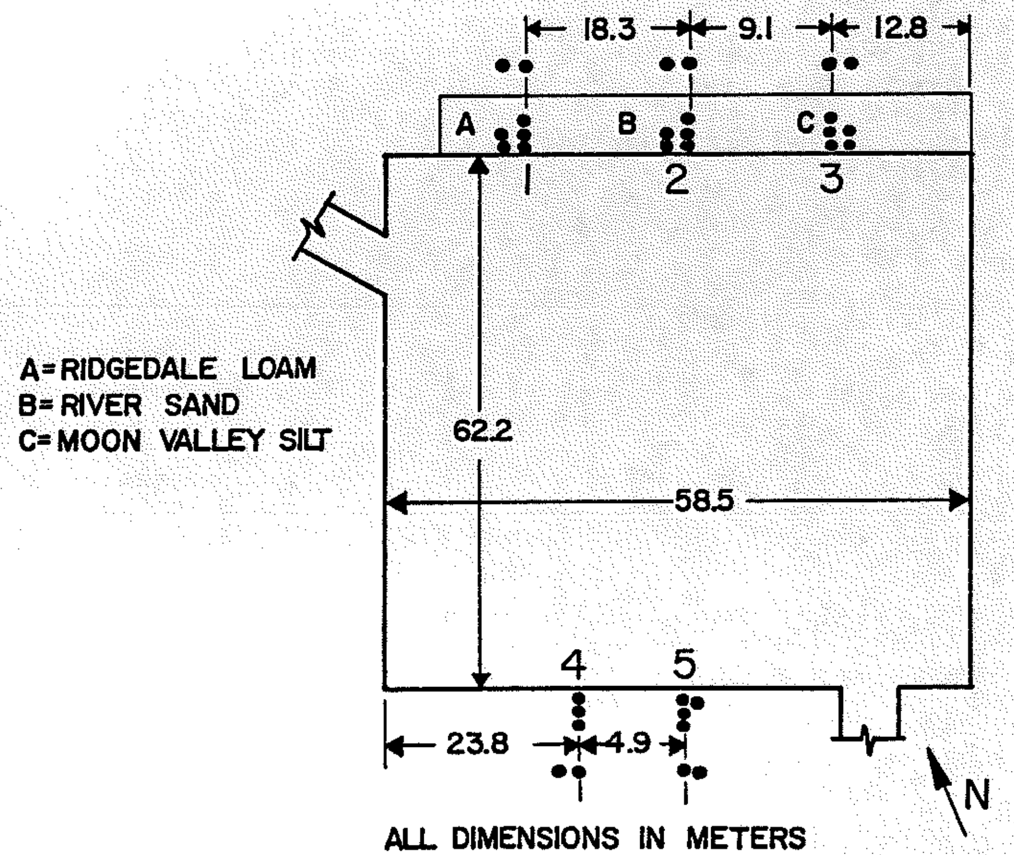

Figure IB: LOCATION OF THE FIVE PROBE GROUPS AT WILLIAMSON HALL

PROBE GROUP 2 AND 3

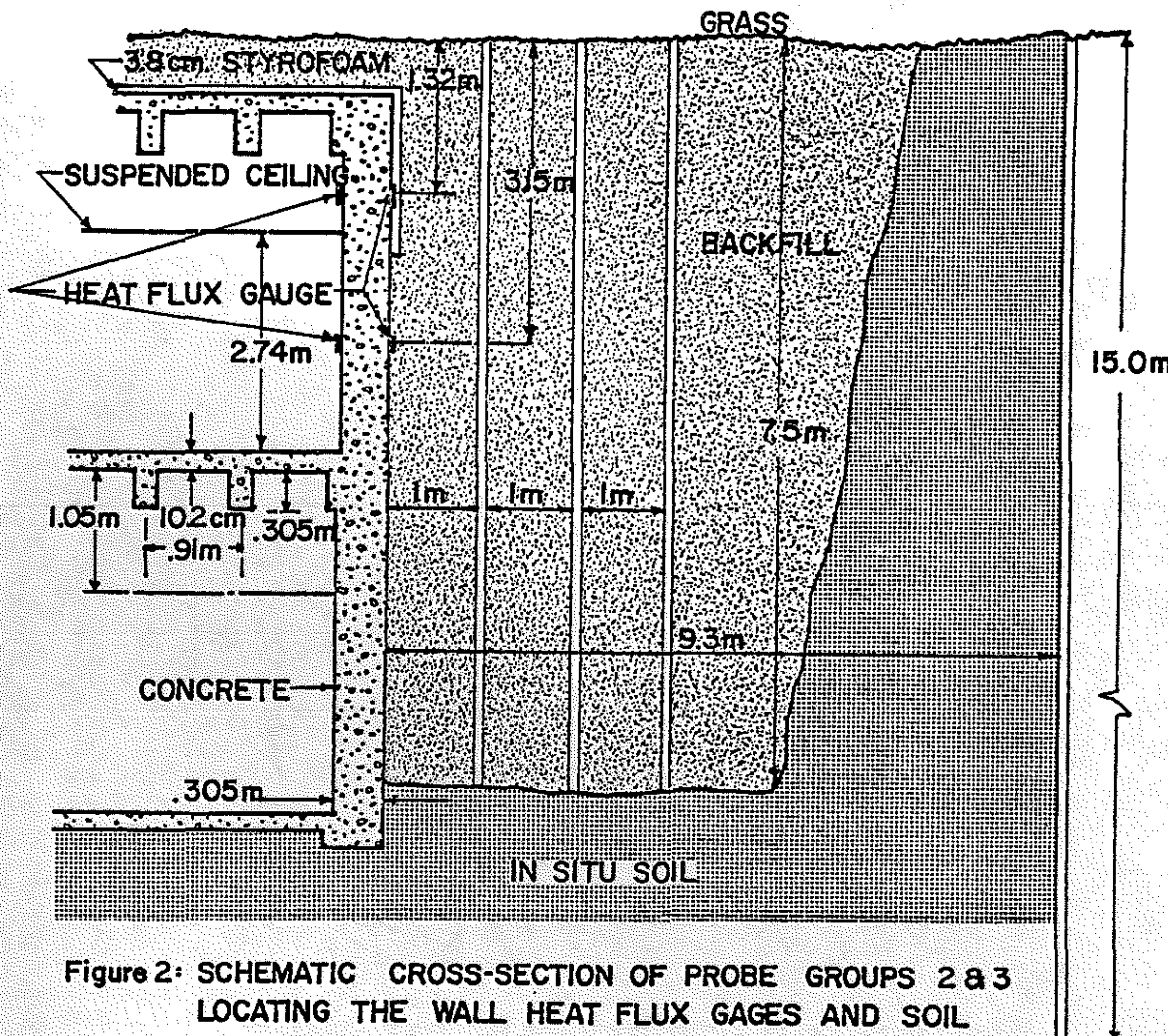

Figure 2: SCHEMATIC CROSS-SECTION OF PROBE GROUPS 2 & 3 LOCATING THE WALL HEAT FLUX GAGES AND SOIL TEMPERATURE PROBES

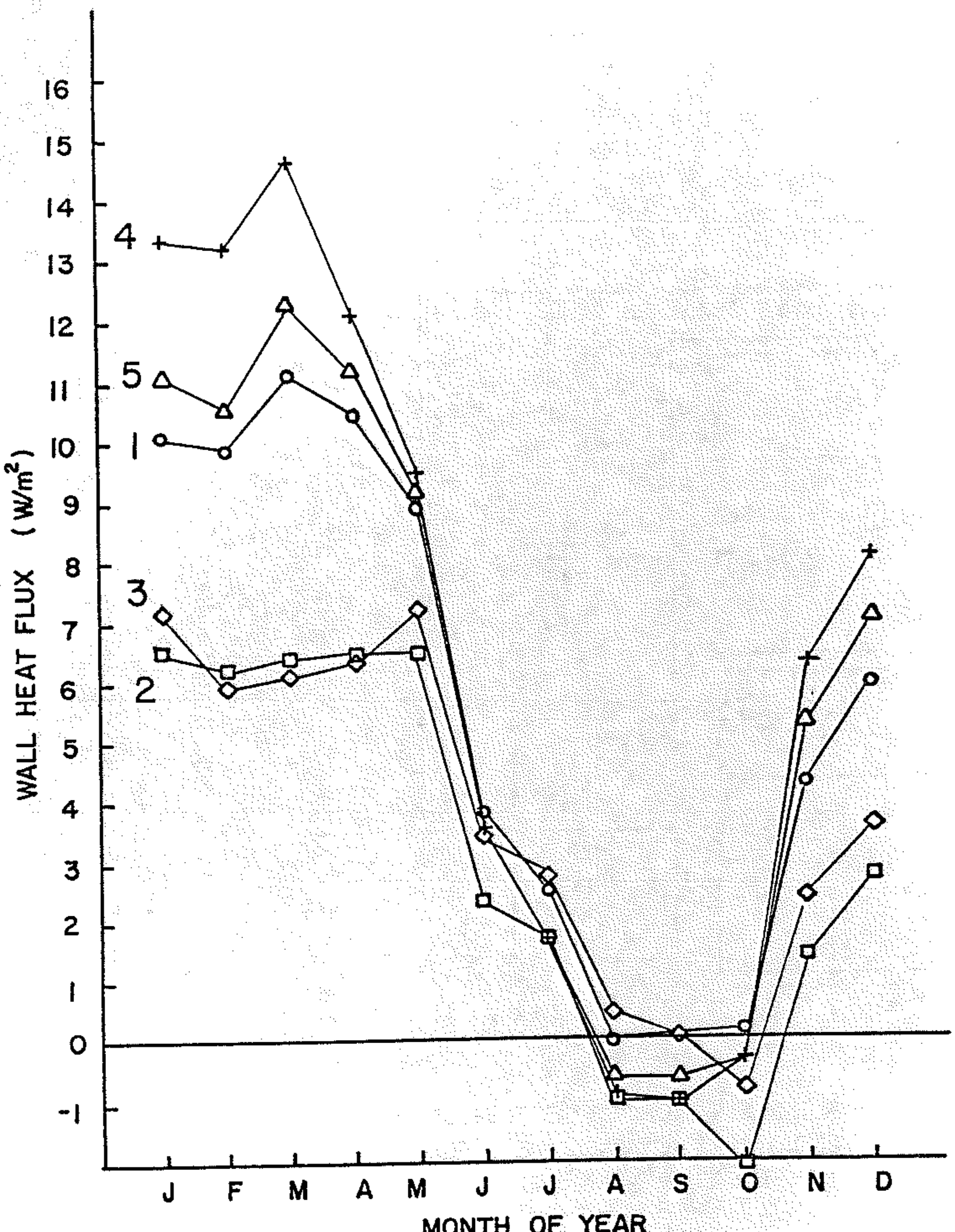

Figure 3: AVERAGE MONTHY WALL HEAT FLUX 2.54 m. BELOW ROOF OF WILLIAMSON HALL FOR THE FIVE PROBE GROUPS, 1978 (POSITIVE VALUES REPRESENT HEAT FLOW OUT OF THE BUILDING)

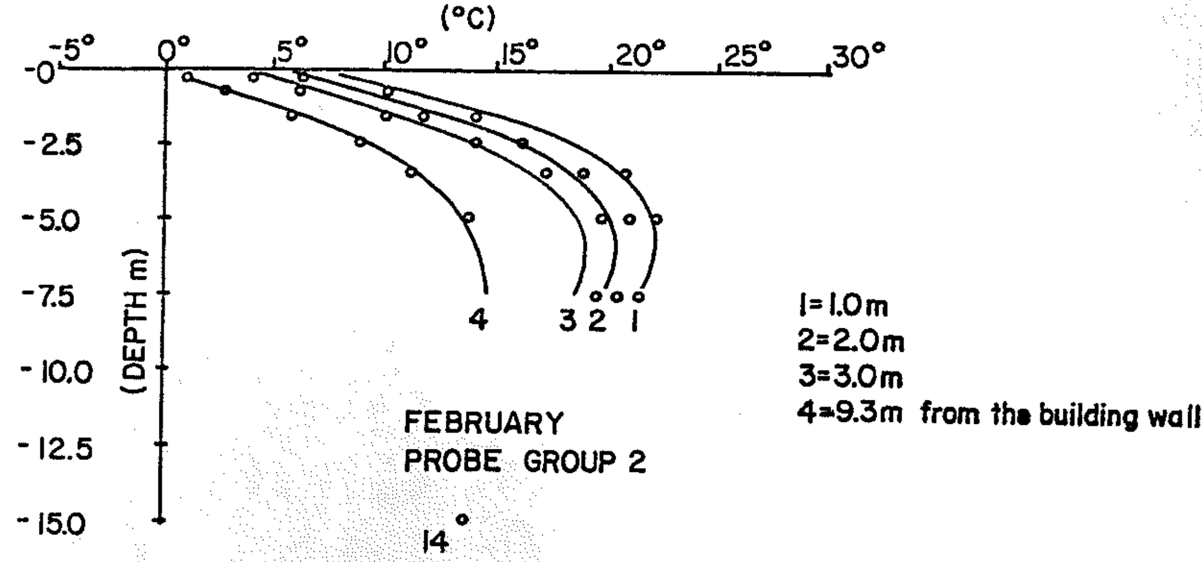

Figure 4: COMPARISON OF MEASURED MONTHLY SOIL TEMPERATURES WITH PREDICTED VALUES.

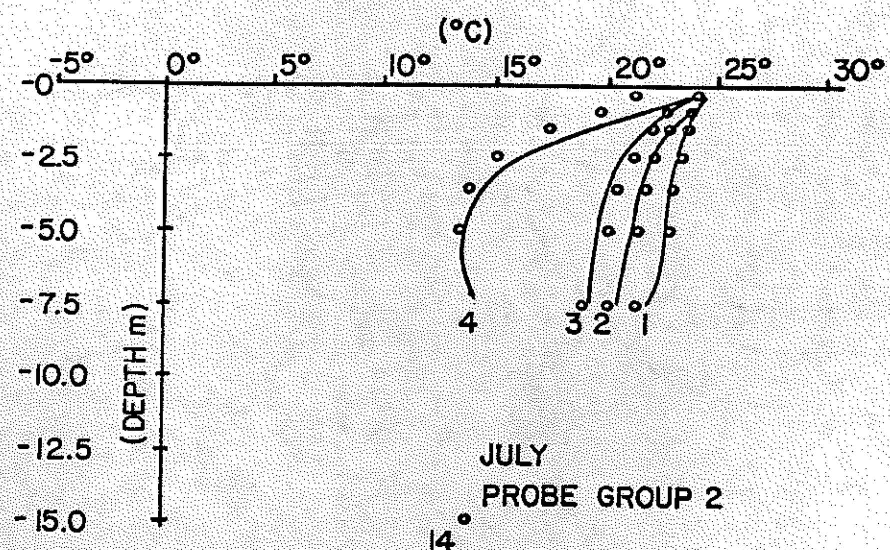

Figure 5: COMPARISON OF MEASURED MONTHLY SOIL TEMPERATURES WITH PREDICTED VALUES.

(°) MEASURED TEMPERATURES

(-) CALCULATED TEMPERATURES

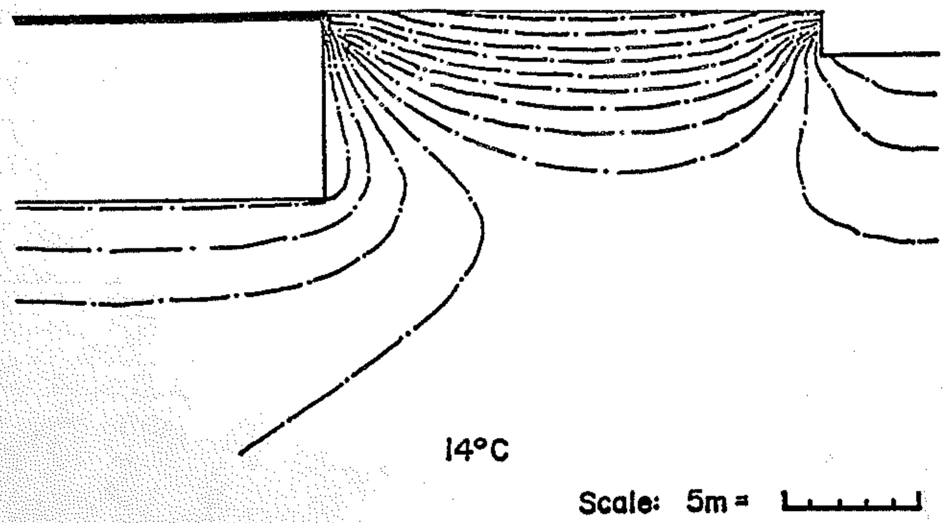

Figure 6: FEBRUARY SOIL ISOTHERMS ABOUT WILLIAMSON HALL
T_{air} = −11.2° C , 2°C / CONTOUR LINE

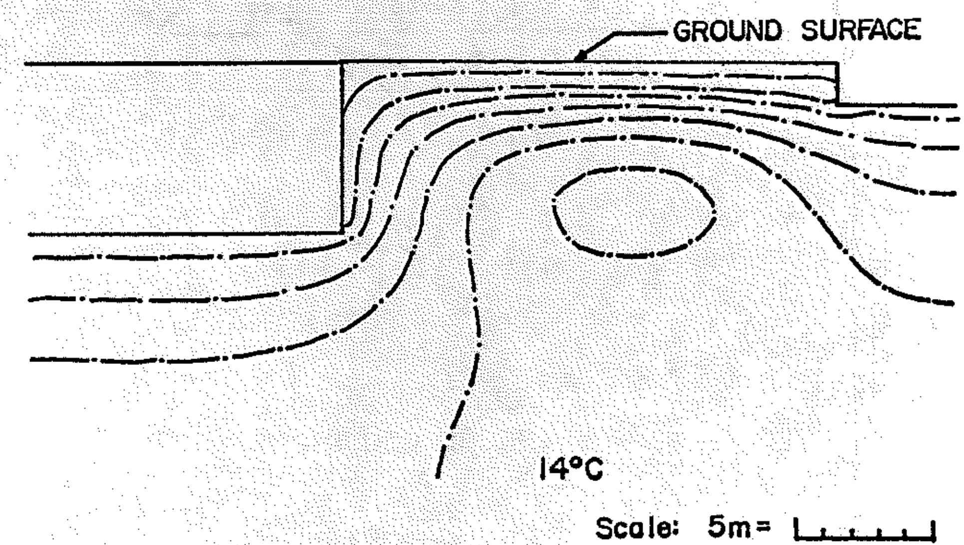

Figure 7: JUNE SOIL ISOTHERMS ABOUT WILLIAMSON HALL
T_{air} = 22.1° C, 2°C/CONTOUR LINE

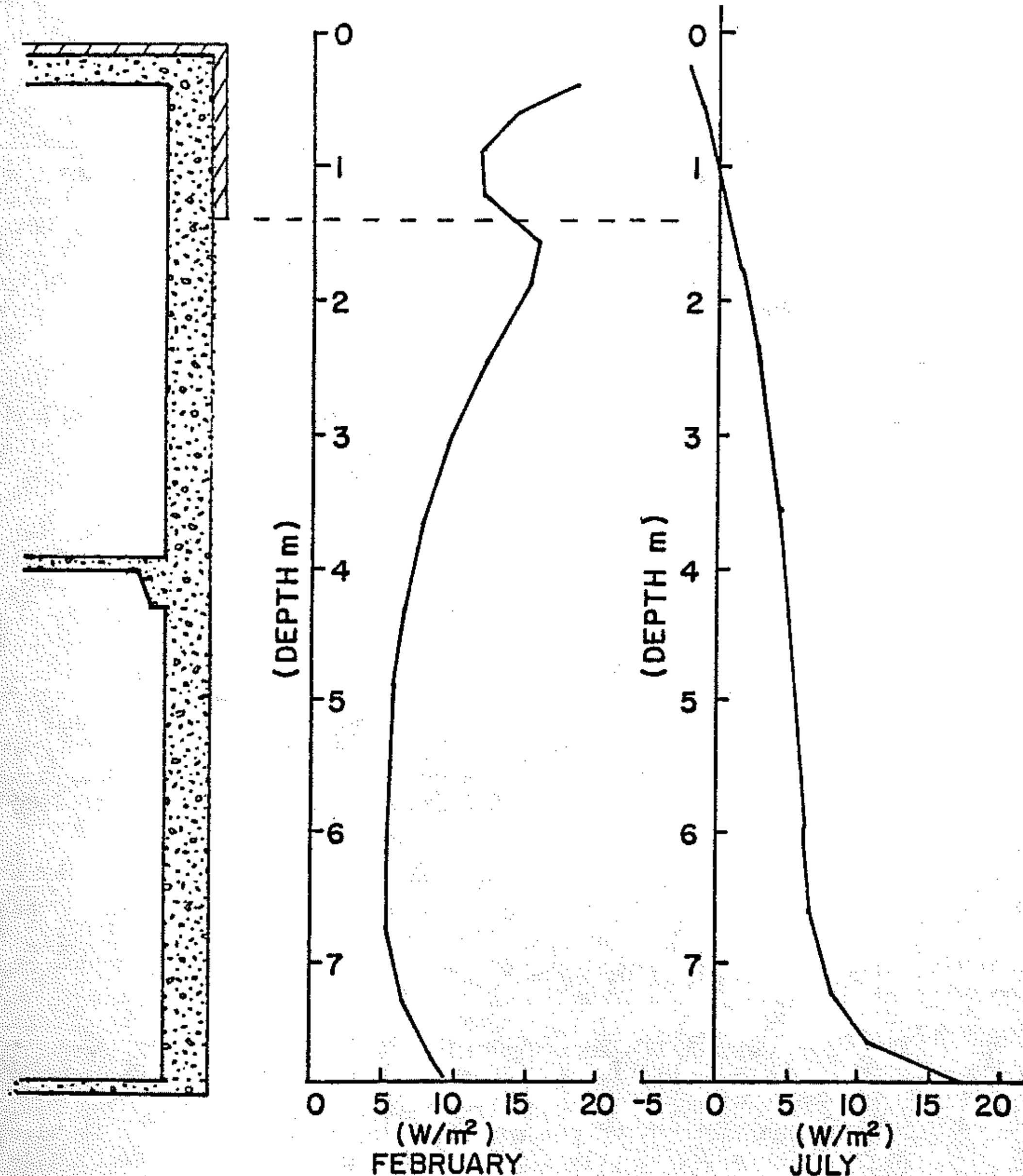

Figure 8: INSIDE HORIZONTAL HEAT FLUX THROUGH THE WALL AT WILLIAMSON HALL (W/m^2)

SESSION VII QUESTION AND/OR COMMENT

Roseme, Berk, Boegel, Hollowell, Rosenfeld, Turiel

a. W.H. Snyder, Johns-Manville Corporation

Q: I question the table showing fiber glass as a pollutent. OSHA has officially classified fiber glass as a nuisance dust. Therefore, unless the table is greatly expanded to include the other nuisance dusts which can occur inside residences, fiber glass should be deleted.

A: Fiberglass is included as a pollutant because of reported health effects associated with occupational exposure to glass fibers. Primary effects associated with glass fibers include transient irritation of the skin, eyes, and upper respiratory tract. One should note that the table also includes other irritants such as formaldehyde and odors. It is important to note, however, that several epidemiologic studies on glass fiber workers indicate that glass fiber exposure results in neither chronic health hazards nor carcinogenic effects.

b. David T. Harrje, Princeton University

Q: The EPA has suggested a U.S. working level for radon that is one-half the Canadian Standard. Can you comment on the energy implications with the air-to-air heat exchanger with this more rigid standard?

A: Reducing the concentration by a factor of two of a pollutant with a constant source strength implies a doubling of the ventilation rate. A given heat exchanger is less effective in recovering heat at higher flow rates and also requires more energy to run the fans that supply the air flow. However, the ventilation rates that we are talking about are fairly small. We have performed radon concentration measurements versus ventilation rate at a research house that we believe has an above average radon source. We were able to lower the radon concentration in this house to levels of about one-half Canadian Standard of 0.02WL with a ventilation rate of approximately 0.8 ach. The energy economics discussed in my paper are based on supplying 0.5 and 0.75 ach with an air-to-air heat exchanger.

c. P.R. Achenbach, NBS

Q: Were all of your data collected with continuous operation of the heat recovery system. Have you experimented with controlling the ventilation system by a device which senses concentration of a selected indoor air contaminant?

A: All of our data was collected with continuous operation of the heat recovery system. We have not experimented with controlling the ventilation system with an indoor air quality sensor in residential buildings, but a variable ventilation control system based on a CO_2 detector is being developed by Honeywell, Inc., under subcontract to LBL. We do plan to run some tests using a dehumidistat to control the operation of the heat exchanger in residences.

Sodergren & Dahl

a. Alfred Guntermann, The Austin Company

Q: Does the concrete storage/window collector system lend itself to mechanical cooling systems. In particular, will the concrete temperature ever fall felow the room air dewpoint temperature, resulting in condensation occuring on the concrete and/or windows?

A: It would be possible to install a cooling coil in the air conditioning unit to cool the recirculation air. Normally the lowest temperature will occur in the cooling coil and there will be no condensation on the concrete surfaces or in the windows.

Theoretically it is possible to cool the concrete to a temperature below the dewpoint of the outside air and then shunt off the cooling unit and let the concrete, thus having some condensation. If that happens, the concrete surface will soon be heated above the dewpoint and the condensation will stop. As soon as the mechanical cooling is switched on again the wet channels will drv. In practice, I do not think it will happen.

The system can be used to cool the building with the cool night air and then a comfortable temperature can be kept during the day without the use of a cooling unit. The system has been used in this way in Sweden a couple of years with good results.

Waite and Snyder

a. Morton Sherman, Jim Walter Research Corporation

Q: Using a 4-inch thick glass fiber blanket insulation at 75°F mean temperature, what is the maximum R value capability measured by the guarded Hot Box Test Method for the standing seam/concealed fasteners/ thermal spacer system?

A: No response

b. D. Simes, Votcax, LASL

Q: Butler Building System was used in the presentation. Do other systems plan similar roof systems?

A: No response

c. C.T. Miller, Fiberglas Canada, Ltd.

Q: Blkt thickness of 1" and 4" were discussed. Does author(s) consider suggested fastening clip system and thermal spacer suitable for use with blkts of greater insulation thickness, i.e., 6"? What effect on roof structural integrity does clip system present as compared with securing roof panels directly to purlins?

A: No response

Larson

a. Bud Coutu, Atlas Industries

Q: Can you please comment or send information on 1) accumulated moisture build up and 3) reduced air changes on urethane panelized housing (these panels are used on both wall and roof applications together).

A: In our tests no such moisture was formed in tested sandwich panels. Further tests investigating the influence at very high moisture contents in the surrounding air are going on.

Some tests have been performed on quite recently constructed 2-story family houses based on a concrete slab cast directly on the ground and outer walls and roof construction of sandwich panels with foamed polyurethane insulation. In the Swedish Building Code SBN75 the highest number of air changes recommended is 3 air changes per hour at an air pressure of 50 Pa. The measured air changes for these houses were only 0.9 air changes per hour at 50 Pa. At the time of measurement the fan of the house was disengaged and ventilation openings covered.

Larrson

a. F. Heller, Toronto Board of Education

Q: Where are mechanical services located such as wiring and plumbing?

A: In quite recently constructed two story family houses based on a concrete slab cast directly on the ground, plastic conduits for electrical wiring for illumination were foamed into the sandwich panels. Cables for electrical heating panels were installed in plastic conduits, on the one hand cast into the concrete slab and on the other hand in the attic, in non-bearing gypsum partition walls and concealed by lists close to the floors.

Plumbing for bathrooms was installed from the first floor through coring-outs foamed into the floor and further down through the partition walls to sewer conduits cast into the concrete slab.

Johnson

a. J.H. Klems, LBL

Q: How much of the heating demand difference (kwh) between EER and CCH houses was attributable to efficiency difference between the heat pump and resistance heating systems, and how much due to greater themal integrity?

A: No response

Wilkes

a. R. Weil, Stevens Institute of Technology

Q: Is your data gathering limited to thermal properties or are you also gathering data about such properties as corrosiveness?

A: The data gathering was intended to be supportive to our extensive experimental and analytical programs dealing with heat transfer in buildings. Thus the project was limited to thermal properties.

b. R.R. Gilpin, University of Alberta

Q: Have you any data on the effect of temperature difference on thermal conductivity of Fiberglas insulation:

A: We have not collected any specific data that shows an effect of temperature difference on the thermal conductivity. While the effects of T may become important under extreme conditions, it is felt that at the T's and mean temperatures encountered in normal building applications the effect is insignificant.

Shipp, Meixel, Ramsey, Eckert

a. Ed Burgin, Tect Associates, Ltd.

Q: Details of Construction Features: Moisture Barrior (exterior water) Wall Structural Characteristics; insulation; vapor barrier (Internal condensation.

A: The roof and upper 1.2 M (4 Ft) of Williamson Hall were coated with a latex waterproofing membrane. Drain tile was placed around the building parameter at the foot of this membrane and an asphalt damp-proofing layer was applied to the remainder of the walls below 1.2M depth. This system of waterproofing was found to be inadequate and several serious leaks resulted in the structure, particularly in areas where joints exist between two separately poured sections. The design and construction of the poured concrete walls and roof followed conventional engineering practice for load bearing struct.

b. R.R. Gilpin, University of Alberta

Q: You have not mentioned anything about the permiability or water movement in the soil? Where was the water table in our location? Was the temperature at that level near the building measured and compared to your conductivity calculation?

A: The water table at the Williamson Hall site was monitored by means of a well point and was found to remain consistently at the depth of 12 M (39.5 ft) throughout the measurement period. The temperature measurements recorded 15 M below the surface therefore extend into the water table but the building does not contact the water table.

While convection effects due to ground water movement were found to be neglible in this case, moisture transport between the surface and the water table was found to effect the soil moisture content and, consequently, the thermal properties of the soil. The summertime conditions exhibited soil thermal conductivities which were typically 20 percent greater than the drier winter conditions. By including this information in the computer simulations, predicted and measured values of heat flux and soil temperature at the building walls ranged within 1.5 W/M^2 and 0.5 ^oC of each other, respectively.

c. Charles E. Sherman, ERG, Incorporated

Q1: Have you made any energy consumption measurements? If so, a) what is the consumption in $Btu/ft^2/yr$? b) how does this compare with other buildings on your campus?

A1: Due to problems with the measurement transducers used in the university steam distribution system, no hard values are presently available for the total energy consumption of Williamson Hall or other campus buildings.

Q2: Have you developed any guidelines for the effect of buildings (underground or above ground) or ground temperature? This is particularly of interest in the simulation of energy use in buildings.

A2: Please refer to the discussion in the text regarding the measured soil temperature profiles.

Q3: From both structural and energy aspects, does the use of soil for roof cover provide any real benefit?

A3: Structurally, the additional strength required to support the weight of the soil cover must be taken into consideration. In addition, sufficient depth must be provided to allow for adequate drainage of the vegetation cover. A minimum of 30 CM (12 in) is needed to satisfy this latter criteria while the maximum allowable coverage will be a function of the supporting structure's specific design limitations.

Q4: Do you have any recommendation for insulating underground structure?

A4: Please refer to the response to Mr. French's question.

d. Dale French, The Upjohn Company

Q: As a result of your study, is a residential builder better off to use an earth cover of say 12" on a house or to bury the sides and use a R20 to R30 insulation system and conventional construction?

A: As a result of the analyses carried out on Williamson Hall and in conjunction with research performed at the underground Space Center at the University of Minnesota it has been concluded that the preferred roof construction is to place 30-46 CM (12-18 in) of soil over R20 or greater insulation. This is derived from the fact that though soil serves as an excellent thermal moderator it is a relatively poor thermal insulation. By virtue of the thickness of the surrounding soil cover, the majority of an earth sheltered structure is well insulated but within the upper 2.5M (8 ft) of depth supplemental insulation must be added in order to adequately insulate the structure. Elimination of the soil cover on the roof is not desirable for three reasons. One, a soil cover of 30 CM or more effectively damps out the diurnal variations in outdoor temperature and has been shown by computer simulation to reduce the peak load demands as well as the total energy consumption during temperature excursions of one to five days. This would be representative of the passing of a storm front, for example. Secondly, soil cover has been shown to be an effective means of reducing solar loads and can produce marked reductions in summer cooling loads when compared with conventional roof coverings. Lastly, the elimination of earth cover over the top of the building effectively reduces the depth of coverage on the walls thus increasing the wall insulation requirements proportionally.

e. David B. Goldstein, LBL

Q: How well did the temperature and heat flux measurements agree with the diffusion equation or with another theoretical model. Were significant changes in soil moisture content or thermal properties observed as a function of time? Was there an effect observed from ground water movement or rainfall migration into the soil?

A: Please refer to the response to Professor Gilpin's inquiry in which these points have been discussed.