Report of Activities of Building Services Section, Division of Building Research, National Research Council

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SUBJECT Report of Activities of Building Services Section, Division of Building Research, National Research Council.

A large range of building problems is associated directly with the maintenance of environmental conditions within buildings. These may occur in connection with: the performance of heating, air conditioning and ventilation systems and components; the effectiveness of the building enclosure in controlling heat and mass interchange between the building and outdoors; or the heat and moisture characteristics of the elements of the building enclosure under temperature, water vapour and air pressure gradients. The Building Services Section is concerned with studies in these and related areas such as ground thermal conditions adjacent to structures in or on the ground. Climate conditions, both inside and outside buildings, have an important bearing in most of the studies.

This report of the work of the Section has been prepared in the first instance for the information of the CIB Working Commission on Heating and Ventilation which is meeting in Copenhagen in June 1963. It covers essentially all of the current research activity related to heating and ventilation in the Division of Building Research.

Heating and Cooling Load Studies

The N.R.C. analogue computer facility has been used extensively to simulate the heat transfer processes that occur in and around buildings. One of the studies that was completed during 1962 was concerned with the heat gain through glass areas in the outside wall of a building. The computer was used to calculate the cooling required to maintain a constant air temperature inside a typical module of a large building taking the heat storage capacity of the structure into account. It was also used to determine the air temperature that would occur under the same ambient conditions if the cooling plant capacity was only half of the cooling load indicated in the earlier runs. This study indicated that comfort conditions (as opposed to constant conditions) can be achieved with cooling plants that are significantly smaller than normal design calculations would indicate. This work was reported in part in a paper to the ASHRAE Annual Meeting in 1962(1). The work is being continued.

As an adjunct to the computer study of cooling loads tables were prepared (2) for the transmission and absorption of radiant energy by various types of windows. The tables cover the following range of the independent variables.

Incident angle = 0 (10) 40(5) 70(2) 88 degress
KL = 0.05 to 2.00 with increasing increments
Index of refraction = 1.52 and 1.62
Single and double glazed windows

For a single sheet of glass the parallel and perpendicularly polarized beams are tabulated separately, as are the combined values for a non-polarized incident beam.

A review paper on the various methods of determining Non-Steady-State Heat Flow Through Wall and Roofs of Buildings was prepared and submitted for publication during 1960, but only appeared in the Journal of IHVE during 1962 (3).

Weather Data

A general purpose digital recording system has been developed which uses a standard multipoint self-balancing potentiometer as the basic measuring instrument. The system uses a commercially available digital encoder and tape punch, and is specially programmed to produce tape that can be processed directly by a Bendix G-15 digital computer. The essentials of the system and the tape format are described in Technical Note 351 (4). This system has been used in developing automatic punched paper tape weather recording equipment, which was put into service during the year, recording air temperature, humidity, wind speed and direction and the

solar radiation that is incident on a horizontal surface and vertical surfaces facing the cardinal directions.

Work was completed on the preparation of computer programs to condense these weather records to hourly average values of temperature, humidity and wind speed and hourly totals of the solar radiation fluxes. These condensed data will be used to prepare design information and to establish correlations between the radiation on vertical surfaces and the more commonly measured flux on a horizontal surface.

The information obtained so far indicates that the transmission factor for the atmosphere at Ottawa (45° north latitude) is considerably higher than is assumed as the basis of the design tables in the ASHRAE Guide.

House Air Leakage

Air leakage measurements were made during 1961-62 on two houses located in Ottawa. Both were one-storey five-room houses with full basement. House #1, which is the smaller of the two, had horizontal sliding sashless double windows; house #2 had double-hung wood sash windows. House #2 had twice as much crack length due to window and doors in proportion to volume as had house #1. Both houses were heated with a forced warm air heating system.

The helium tracer gas method was used to measure the house ventilation rate. The helium was circulated throughout the house by injecting it into the supply air duct of the forced warm air system. With the furnace blower operating continuously, a sample helium-air mixture was drawn from the return air duct to the katharometer and the subsequent helium decay characteristics were recorded, from which the over-all house ventilation rate was calculated.

The houses were instrumented to obtain pressure differences across the exterior walls, chimney draft, attic pressure and outside static pressure. Pressures were measured with a diaphragm strain gauge-type pressure transducer connected to the pressure taps by plastic tubing, through a 12-point pressure selector switch. Wind speed and direction were measured with an anemometer on site. The pressure and wind speed records were obtained with the multipoint digital recording system to which reference was made earlier. The tape record was processed with a digital computer in order to correlate pressure difference with temperature difference and wind.

During winter tests the ventilation rates varied from 0.25 to 0.40 air changes per hour for house #1, and 0.35 to 0.60 for house #2. During summer tests with windows closed the ventilation rates varied from 0.06 to 0.17 air changes per hour for house #1,

and 0.12 to 0.23 air changes per hour for house #2. During the second winter tests were made on house #2 with the cracks of the storm windows sealed with tape. The ventilation rates of house #2 were 0.33 to 0.57 air changes per hour. All ventilation rates given above are based on the total house volume, including basement.

Building Pressures

Through the co-operation of the Public Works Department and the Post Office Department, the Building Services Section has had the opportunity of measuring the pressure differences across the walls and the pressure distribution around the Sir Alexander Hamilton building, due to the wind and stack effect. The extent of pressurization of the building by the heating and the ventilation system is also being studied. The building is a nine-storey structure, with a penthouse, in rectangular shape and is the tallest building among a group of government buildings. All windows are located in the north and south walls with the exterior face of the east and west wall finished with solid masonry.

The building was instrumented for pressure measurements during the fall of 1962. Eight panels containing both inside and outside pressure taps were installed in the windows of the 8th, 5th and 2nd floors. Two outside pressure taps made of copper tubing were located at the 8th-floor level to measure the pressures on the east and west walls. An anemometer and a static pressure tap were erected on top of the penthouse roof. The plastic tubing connected to the pressure taps was brought to the 12-point pressure switch of the multipoint digital recording equipment. A record of the pressures, outside air temperature, wind speed and wind direction is being obtained on punched paper tape.

A computer program is being prepared to carry out a regression analysis of the wind and pressure data. With this program it is hoped to obtain a correlation of the pressure difference at various points of the building with wind speed and direction and also with inside to outside temperature difference.

Building Humidity

Continuing the study of relative humidity in buildings, which was formerly concentrated upon dwellings, several typical public and secondary schools in Ottawa, Saskatoon and Halifax have been instrumented with hygrothermographs to obtain representative values of classroom temperatures and relative humidities throughout the school year in these three climates. One-, two- and three-storey schools are involved; in some instances simultaneous measurements are being obtained in several classrooms, differing in location or use. Records for one year have been obtained at the three locations; in Ottawa the measurements are being continued for a second year.

Heating and Ventilation of Basement Fallout Shelters

Studies of air temperature, relative humidity and ventilation rate were continued in the family fallout shelter constructed in 1960 in the basement of an Ottawa house. Studies have been made of the operation of small fuel burning appliances suitable for cooking and heating in confined spaces such as shelters.

A multipoint carbon monoxide and carbon dioxide infrared gas analysis system has been assembled. The equipment is self-calibrating and can have its output recorded by a punched tape unit if required.

Chimneys

Studies of the safety aspects of various masonry chimney arrangements have continued. For this purpose test specimens 6 ft (2 m.) long are being observed when subjected to inlet flue gas temperatures of 500, 750 and 1000°F (380, 420, 560°C) to steady state and to inlet temperatures of 1400 and 1800°F (780 and 1000°C) for consecutive 1/2-hour periods to represent chimney fire conditions. Records are taken of chimney temperatures, dimensional changes and cracking. To date several clay brick test chimneys and chimneys constructed of solid concrete blocks of expanded shale, expanded slag, gravel and pumice aggregates have been tested. Most of these have had separate clay tile or pumice concrete liners. Differences in the performance of the various arrangements have not been great. Several test chimneys constructed of concrete blocks with corner air spaces and integrally cast liners were also tested. These are of the type used for venting gas burning appliances in one region in Canada. Tests were conducted with and without natural ventilation through the corner air spaces.

Subway Ventilation

A study of temperature and ventilation in the Toronto Subway has been completed. The investigation consisted of velocity measurements in openings leading to stations and tunnel, and temperature records in station areas. With the assistance of simple theory it was possible to relate the subway temperatures to:

1) the outside air temperature
2) the heat load due to trains and passengers
and 3) the ventilation induced by train motion.

Window Air Leakage

A study of the air leakage characteristics of typical house windows used in Canada has been completed. This study was carried out coincident with the development, by the Canadian Government

Specifications Board, of specifications for aluminum windows, both horizontal and vertical sliding, and horizontal sliding sashless windows. These specifications require a maximum air leakage rate for residential type windows of 0.75 cfm per lineal foot of sash crack (0.069 cubic meters per meter) at a pressure difference across the prime sash of 0.30 inches of water (0.76 cm) corresponding to the velocity head of wind at 25 mph, based on tests on a specimen of standard size. Windows tested included horizontal sliding, vertical sliding and hinged types, both with and without weather-stripping. Special attention was given to measurements on horizontal sliding windows of the sashless variety, in which the glass slides in grooves, either milled directly in the wood frame or fabricated from plastic. This type of window has come into wide use for residential construction in recent years. The specimens tested were without weatherstripping and air leakage values obtained were generally several times greater than permitted by the specifications. The laboratory studies demonstrated techniques for increasing the air tightness to the extent required. Tests on each of the other types of windows showed a great range of performance, with air leakage values both well above and well below the specifications limit.

Thermal Performance of Windows

Studies have continued in the cold room on the effectivenesss of thermal breaks or barriers used in the construction of metal frames and sash for double windows. Without such thermal barriers the inside surface temperature of the frame is much lower than that of the glass under winter conditions. Since one of the objectives in using double glazing is to permit the maintenance of building humidities to the point where condensation occurs on inside glass surfaces it is desirable to have an arrangement in which temperatures on inside surfaces of sash and frame components are not lower than on the glass surfaces. The CGSB window specifications referred to above include such a requirement. Measurements have been made on a number of window specimens to determine if this requirement is met.

The inside surface temperatures for given air temperatures on either side of a window are a function of window geometry, the test configuration and the surface heat transfer coefficients. Studies are being carried out to determine the influence of these factors in order to assist in standardization of window thermal test procedures. Extensive measurements have been made of the inside surface temperature distribution and thermal conductance of an idealized double window arrangement consisting of two sheets of glass installed in a panel of rigid insulation. The influence of air space geometry, warm side configuration, air space venting and air infiltration has been determined.

In connection with the program a study has been made of the errors that can occur in the measurement of surface temperatures when thermocouple junctions are attached to the surface. A small wind tunnel was built which allows the radiation and convection heat

transfer at a test surface to be varied independently. The true surface temperature is inferred from subsurface temperature measurements.

Sealed Double Glazing Units

Development of methods of evaluating sealing methods used in the construction of factory-sealed double glazing units has continued. Tests for seal leakage and initial dew point of the air in the space followed by thermal stressing of the units in the laboratory weathering apparatus (5) are being conducted for manufacturers to check for compliance with Central Mortgage and Housing Corporation requirements. The results of the first series of tests on most of the units marketed in Canada have been summarized and reported (6).

The laboratory weathering apparatus has been modified mechanically and a second apparatus is under construction to increase the testing capacity. Tests have been carried out on a prototype of a simpler temperature cycling apparatus. This consists of a chamber in which units are exposed to air temperatures cycling from about 70°F to 130°F (21° to 54°C) with relative humidities approaching 100 per cent. The performance of most units in this apparatus appears to parallel that in the present weathering apparatus. In addition to detecting poor or weak seals the high humidity cycle appears to produce failure in those units with seals having a high water vapour diffusion coefficient, which are not readily detected in the present weathering apparatus. The design of a chamber with capacity for about fifty 14- by 20-inch (36 x 51 cm) units is now underway. Observations have been continued on units mounted on vertical outside exposure racks.

Rain Leakage

An apparatus for examining the rain leakage characteristics of wall and window combinations is under development. Plans have been completed and construction is proceeding. The test specimen will be mounted in an 8- by 8-ft (2 1/2 m x 2 1/2 m) opening on the side of a 10- by 10- by 4-ft deep (3m x 3m x 1.3m) box. Water droplets will be sprayed on the test specimen with control of direction and quantity. Wind pressures as occur on walls in practice will be simulated by pressurizing the box.

Wall Heat Transmission

An experimental study has been completed of the performance characteristics of the wall panel test unit (7), used to determine over-all heat transmission coefficients of building sections up to 8 ft (2 1/2 m) square. The apparatus allows control over both

radiation and convection conditions to which the test section is exposed and separate correlations were made of these two types of heat exchanges. The total warm surface conductances recommended by the ASHRAE Guide, similar to those occurring in practice with natural convection, were duplicated.

Edge heat leakage, inherently low in the apparatus because heat loss is supplied by an extended guard panel, was further reduced by adjusting the thermal resistance of the edge insulation to give a nearly constant temperature gradient over the edge area. Although the arrangement still gives slight distortion of the isotherms near the edge, analysis indicates that the influence of this on the measured conductance value of the test section is negligible. Based on the favourable results obtained with this edge arrangement, alterations were carried out on the guarded hot box (8) to incorporate a larger edge contact surface in the form of an aluminum guard panel from which the edge heat loss can be supplied.

An investigation has been started to determine the effects on heat transmission of air infiltration due to natural convection through mineral wool insulation. Tests will be carried out on various arrangements and types of insulations in a typical 8-ft (2 1/2 m) square wood-frame wall installed in the wall panel test unit. Mineral wool batt and blanket insulation without facing materials is now available in Canada for installation in walls. This insulation is being sold in thicknesses that do not completely fill the stud space, so that there is a possibility of an air space occurring on one or both sides of the insulation over the height of the wall. In addition, very low density insulation is manufactured. These factors raise questions about the possibility of convection effects, which it is hoped will be resolved by these studies.

Test Huts

The construction of the two SCR brick test huts insulated with 2-inch wool batts has been modified to simulate brick veneer constructions. The walls now consist of 6-inch (16 cm) SCR brick 3/4-inch (2 cm) air space, sheathing paper, 7/16-inch (1 cm) exterior fibreboard sheathing on 2- by 2-inch (5 x 5 cm) studs, polyethylene vapour barrier and hardboard interior finish. In one case the air space is vented to outside and in the other it is unvented. The objective is to determine if the presence of the sheathing affects the extent of condensation in the insulation and the moisture content of studding during the summer.

Four new insulated masonry test huts have been constructed. Two are of brick cavity wall filled in one case with loose fill mineral wool and in the other with "water-repellant" vermiculite loose fill. The other two are 8-inch (20 cm) 2-core concrete blocks, one of sand and gravel aggregate and the other of expanded slag aggregate. The cores of both are filled with "water-repellant" vermiculite. Initially no interior or exterior finish has been applied to the walls. The objective is to obtain some

records of the moisture conditions in the insulation or its effects. Small wooden blocks containing resistance moisture meter pins have been installed at various locations in the insulation to provide an indication of moisture conditions. In addition, the insulation is sampled periodically. Heat and moisture required to maintain 70°F (21°C) and 40 per cent relative humidity are measured during the heating season.

At the DBR Prairie Regional Station in Saskatoon three light-weight concrete block huts have been constructed for similar measurements. One is uninsulated; in the others the cores are filled with vermiculite and expanded slag respectively.

Thermal Conductivity

Measurement of thermal conductivity at room temperature of materials submitted for test by manufactures has continued, using the guarded hot plate facilities of the Section. A new 18-inch (46 cm) heater plate was constructed, following the design used in the existing 8-inch and 12-inch (20 and 30 cm) guarded hot plates. This is to replace the 18-inch (46 cm) plate that has been in use at the National Research Council for approximately 30 years. The old plate has an unusual guard and test area heater winding arrangement that leads to errors when mean temperatures of test are significantly different from ambient air temperature.

A periodic heat flow apparatus intended to measure thermal conduticitivy and diffusivity of moist materials has been described((9) p.19). Development work has been done on the data processing procedures and in evaluating the reproducibility and accuracy of the system. Errors in initial test results were found to be larger than those predicted. The apparatus has been refined during 1962, improving the periodicity of the boundary conditions. A second set of evaluation tests has been started and will be incorporated in a report on the apparatus. Theoretical studies have been extended to include the effects of non-constant properties on periodic heat flow. The choice of a suitable standard material has been found to depend mainly on the nature of the variation of its properties with temperature. Tables of the complex hyperbolic functions used in reducing the test results have been prepared (10) in both Cartesian and Polar form.

Water Vapour Transmission

Measurement under standard conditions of water vapour permeability of films, papers and other building materials submitted by manufacturers has continued. Further co-operative work has been carried out in connection with the standardization of ASTM standard methods of water vapour transfer measurement. The Section is participating in a program intended to develop a suitable permeance reference specimen. One of the major sources of error in routine measurements of water vapour transfer by the cup or dish method is in defining an

appropriate average vapour pressure in the test space. If a specimen of known, constant properties were available it would be possible to calculate with precision the average vapour pressure for any desired period of several days from weight change measurements with the specimen in a wet or dry cup assembly. Plastic film known by the trade name, Mylar, is being investigated for this purpose. The material is thought to be stable and of uniform composition. Three rolls of 1-mil material have been donated by the manufacturer and put in the custody of the National Bureau of Standards in Washington. Five laboratories are undertaking round-robin wet and dry cup permeance tests to evaluate the practical value of the concept. Preliminary tests on all specimens used in the round-robin were carried out in the Section's laboratory. Differences between wet and dry cup test results were small. The spread in permeability test results among fourteen specimens tested by the wet cup method was about 0.5 per cent.

Laboratory studies of moisture build-up in insulation materials under conditions in which vapour flow is prevented on the low temperature side of the specimens ((11), p. 17) were temporarily discontinued. It is planned to reactivate this program in the immediate future.

Relative Humidity Measurement

Studies in the field of humidity measurement were continued at the DBR Prairie Regional Station using the controlled atmosphere producer. Measurements under static conditions were made of vapour pressures over saturated salt solutions below 32°F (0 °C). Some measurements of the dynamic performance of such solutions were also obtained. Studies of the characteristics of Dunmore-type lithium chloride cells were continued and several field calibration techniques were investigated involving a simple two-pressure system and a modified dew cell. Studies of the characteristics of the dew cell device were undertaken.

Ground Heat Exchange

Reports and papers have been prepared dealing with temperatures in the ground under and near heated or cooled areas on the ground surface. A theoretical paper (12) gives the steady-state temperature under the corner of a plate and shows how graphical superposition may be used to determine the temperature under polygonal areas. A paper describing the use of graphical methods and summarizing equations for most cases of both steady and transient temperatures under flat areas on the ground surface has also been published (13). To aid the field engineer in determining ground temperatures a report has been prepared which utilizes only graphical methods. This report which will be available in the near future, is intended for the person lacking a mathematical background in conduction heat transfer. Computer programs have been devised which allow rapid calculation of the temperature regime under flat areas of any shape. This method was used to calculate

the steady temperature under a northern lake for comparison with measurements.

A paper on "The Calculation of Surface Temperature and Heat Flux from Subsurface Temperature Measurements" was presented to a Canadian Heat Symposium in June 1962 (14).

REFERENCES

(1) Stephenson, D.G. and G.P. Mitalas.
An Analog Evaluation of Methods for Controlling Solar Heat Gain Through Windows. American Society of Heating, Refrigerating and Air Conditioning Engineers Journal, Vol. 4, No. 2, Feb. 1962, pp. 41-46. (NRC 6560)

(2) Mitalas, G.P. and D.G. Stephenson.
Absorption and Transmission of Thermal Radiation by Single and Double Glazed Windows. National Research Council, Division of Building Research, Ottawa, December 1962. (NRC 7104)

(3) Stephenson, D.G.
Methods of Determining Non-Steady-State Heat Flow Through Walls and Roof of Buildings. Journal, Institution of Heating and Ventilating Engineers, Vol. 30, May 1963, pp. 64-73 (NRC 6726).

(4) Stephenson, D.G.
D.B.R. Digital Recording System. National Research Council, Division of Building Research, Ottawa, Nov. 1961. DBR Technical Note 351.

(5) Wilson, A.G., K.R. Solvason and E.S. Nowak.
Evaluation of Factory-Sealed Double-Glazed Window Units. American Society for Testing Materials. Symposium on Testing Window Assemblies, Special Technical Publication No. 251, 1959, pp.3-16 (NRC 5270).

(6) Wilson, A.G. and K.R. Solvason.
Performance of Sealed Double-Glazing Units. Journal, Canadian Ceramic Society, Vol. 31, October 1962, pp.68-82. (NRC 7042)

(7) Solvason, K.R.
Large-Scale Wall Heat-Flow Measuring Apparatus. American Society of Heating, Refrigerating and Air-Conditioning Engineers, Transactions Vol. 65, 1959, pp.541-550 (NRC 5421).

(8) Brown, W.P., K.R. Solvason and A.G. Wilson.
A Unique Hot-Box Cold Room Facility, American Society of Heating, Refrigerating and Air-Conditioning Engineers Transactions, Vol. 67, 1961, pp. 561-577 (NRC 6887).

(9) Building Research 1958 and 1959.
National Research Council, Division of Building Researchm Ottawa, June 1960, 96 pp. (NRC 5743).

(10) Shirtliffe, C.J. and D.G. Stephenson.
Tabulator Values of Special Hyperbolic Functions, Cosh (i + i) X; Sinh (i + i)X ÷ (i + i) X; (i + i) X Sinh (i + i) X. National Research Council, Division of Building Research, Ottawa. January 1961, 71 pp. (NRC 6159)

(11) Building Research 1960.
National Research Council, Division of Building Research, Ottawa, September 1961. 89 pp. (NRC 6463).

(12) Brown, W.G.
Steady Temperature Under the Corner of a Plate and Under Polygonal Areas on the Surface of a Semi-Infinite Solid. Quarterly Journal of Mechanics and Applied Mathematics, Vol. XV, Part 4, November 1962, pp. 393-399. (NRC 6891)

(13) Brown, W.G.
The Temperature Under Heated or Cooled Areas on the Ground Surface. Transactions, Engineering Institute of Canada. Paper EIC -63- MECH 3, 1963.

(14) Stephenson, D.G. and G.P. Mitalas.
The Calculation of Surface Temperature and Heat Flux From Subsurface Temperature Measurements. Transactions, Engineering Institute of Canada, Paper EIC-63-MECH 4, 1963.
