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As part of the program of the National Research Council (NRC) to evaluate passive solar heating techniques, a test facility was constructed at the Division of Building Research (DBR) to obtain data on the thermal performance of passively heated structures and to develop simple calculation procedures and guidelines for designing houses with passive features. This Note gives the construction features and instrumentation details of the passive solar test facility and describes the studies being undertaken at DBR related to passive solar heating.

1. INTRODUCTION

Information on the thermal performance of passive solar heating can be obtained by monitoring either full-size occupied houses or experimental test cells. There is a considerable degree of uncertainty in data from occupied houses due to variations in occupant behaviour. On the other hand, test cell data cannot cover the range of conditions that occur in larger structures, especially the interaction between solar-heated zones and the remainder of the building. The test buildings described in this Note represent a full-scale section of a house, combining the advantages of a controlled experiment with the ability to examine the interaction between south and north zones.

The experimental facility will provide data to aid in determining the dynamic thermal characteristics of houses with different amounts of thermal mass. The data will also be used to verify the thermal performance predicted by hour-by-hour computer simulation programs. These programs, in turn, will be used to assess the performance of passive systems and to compare passive solar techniques with other energy conservation measures under Canadian climatic conditions. The simulation programs will also be used to develop passive design guidelines and a simplified procedure to calculate the space heating requirement of houses taking into account solar gain, thermal storage and allowable temperature swing.

The following sections describe the DBR test facility as well as other projects aimed at understanding and quantifying the performance of passive solar-heating methods.

2. DBR PASSIVE SOLAR FACILITY

2.1 Description of Test Facility

The test facility shown in Figures 1 and 2, is located on the NRC campus in Ottawa (elevation 114 m, latitude 45°19' North, longitude 75°40' West).

It consists of three huts divided into four 2-zone test units (numbered Unit 1 to Unit 4) and four single-room units (R1 to R4). Each hut consists of a one-storey insulated wood-frame superstructure over a basement. The exterior walls and the roof of the above-grade construction have thermal resistance values of 2.1 and 3.5 $m^2 \cdot °C/W$, respectively. Since the basements are being used for the study of basement heat loss, the floors of the solar units were insulated to a resistance value of 7 $m^2 \cdot °C/W$. All units and rooms were made as airtight as possible.

Each of the two-zone units consists of a south and a north room with a connecting door. The north room opens onto the corridor through an insulated steel door (thermal resistance of 1.25 $m^2 \cdot °C/W$) fitted with magnetic edge seals. Each south room has a south-facing window of 2.6 m^2 net glass area; each north room has a 1 m^2 window facing north. All the windows are of the casement type containing sealed double-glazing with an air-space thickness of 6.35 mm (thermal resistance of 0.35 $m^2 \cdot °C/W$). The interior surfaces of all the walls and ceilings (other than mass walls) are finished with an off-white paint and the floors are carpeted.

The three "direct-gain" test units (Units 1, 2 and 3) differ only in the type and amount of mass located inside the insulation layer, as shown in Figure 3. The interior finish of Unit 1, which represents a conventional insulated wood-frame construction, consists of a single layer of 12.7 mm gypsum board. In Unit 2, all the interior wall surfaces have a lining of four layers of 12.7 mm gypsum board while the ceiling has a two-layer lining of the same material. In Unit 3, all the walls are lined with a 100 mm course of solid cement bricks except for the wall between the south and north room which is made of a single course of the same brick. The amount of thermal storage contained in the units is given in Table 1.

The mass-wall unit (Unit 4) has the same interior finish as Unit 1 but has, in addition, a mass wall located just inside the window. This wall, which is made of solid cement bricks, is 0.305 m deep and has two 406 mm by 76 mm vent holes at both the top and bottom. A plastic sheet is suspended over the inner surface of both top vents to act as a back-draft damper. The outer surface of the mass wall is covered with a flat black paint.

The thermal interaction between a sunlit south room and the remainder of a passively heated house can be examined in the facility by monitoring each test unit in either of two modes. In the first mode the unit is monitored as two separate rooms; in the second mode the connecting door is opened and air is circulated between the two rooms using a small fan (2.8 m^3/min) located above the door.

The four single-room test units (Units R1 to R4) have the same interior finish as Unit 1. Each room has a window of 2.6 m^2 net glass area facing one of the four cardinal directions (see Figure 2).

Each of the rooms in the test facility is heated individually with an electric baseboard heater driven by a precision controller to avoid the temperature variations caused by conventional room thermostats. In addition, the south room of the two-zone units and three of the single-room units (R1, R2 and R3) are equipped with an exhaust fan which cools the room with outdoor air whenever the room temperature reaches a preset maximum. The exhaust fan is controlled by the space-heater controller.

2.2 Measurement and Data Acquisition

The average indoor air temperature of each room and the average temperature of the inside and outside surfaces of the mass wall are measured with 12-point and 9-point copper-constantan thermopiles, respectively. Copper-constantan thermocouples are used to determine the attic air temperature, the corridor air temperature, the ventilation fan inlet air temperature and the temperature of the air flowing through the vent holes of the mass wall.

Three Eppley pyranometers are used to measure the incident solar radiation on the horizontal surface, the south-facing vertical surface and the north-facing vertical surface. The direct normal component of solar radiation is measured with an Eppley pyrheliometer.

The electrical space-heating energy consumption in each room is determined by means of a kW·h meter modified to generate a pulse output. Modified kW·h meters are also used to record the energy consumption of the cross-room circulation fans and the room-cooling fans. Wind speed and direction are measured on a 12 m high weather tower at the site.

An 80-channel Monitor Lab data logger is used to scan and record the data on 9-track magnetic tape which is later processed on an IBM 370 computer. Wind data, radiation data and temperatures are scanned every minute, then averaged every 15 minutes and recorded. Pulse signals from the modified kW·h meters are accumulated on a pulse-to-analogue interface after which their totals are scanned and recorded every 15 minutes.

The test facility building was completed in March 1980 and equipped six months later with full instrumentation and a data acquisition system. Data on the performance of the eight test units were collected during the 1980/81 heating season. During the following summer an exterior layer of insulation was added to the walls and ceilings of all the test units to bring their thermal resistance to 4.2 and 5.6 $m^2 \cdot °C/W$, respectively. In December 1981, a night insulating curtain was installed on the window in front of the mass wall in Unit 4. Data have also been gathered for the 1981/82 heating season.

3. PASSIVE SOLAR STUDIES

The results obtained in the passive solar test facility form part of several projects which are described briefly in the following sections.

3.1 Evaluation of Passive Solar Heating Techniques

The data collected on the test units during 1980/81 are being analyzed to determine the energy-saving potential of different passive solar-heating techniques. Data gathered for the three direct-gain units are being used to study the effect of mass on solar gain utilization and energy savings, and on indoor temperature variation (overheating). The data for the 1981/82 heating season will be used to assess the savings and overheating potential in very well insulated passive houses.

The data on the mass-wall unit (Unit 4) will be used to examine the performance of a "Trombe-Wall" type passive system under Canadian climatic conditions. The effect on performance of the insulating curtain installed in December 1981 will also be evaluated.

Future plans for the 1982/83 season include modifications to the facility to assess the performance of attached sunspaces.

3.2 Study of the Dynamic Thermal Response of Houses

Since the thermal response factors available in the existing literature[1] and used in energy calculation programs were derived for commercial buildings with large amounts of thermal mass, the need remains to determine the response factor for lighter constructions, particularly light-frame houses, in order to simulate their thermal performance.

Experiments are being performed in the three direct-gain passive test units to determine dynamic thermal response factors that could be appropriate for houses with three different levels of thermal storage mass; namely, light, medium and heavy. One experiment consists of shading the south window for a long period, then removing the shade for one hour to generate a solar energy pulse input. By measuring the decay in the space-heating requirement, the transfer function (and hence, the response factors) of the room can be calculated.

The results of this study will be used to check the response factors predicted by the room response-factor calculation program. Appropriate response factors will then be used in the "ENCORE-CANADA" program[2] and other available energy calculation methods to simulate the thermal performance of the three direct-gain units. Finally, the simulated and measured performances will be compared to assess the ability of these calculation methods to simulate envelope losses, building dynamics and solar gain.

3.3 Study of Solar Gain through Windows

In a well-insulated passive solar house, the solar gain through the windows can contribute a large fraction of the heating requirement of the house. The solar contribution can be enhanced through the use of "improved" windows such as multiple-glazed windows, windows with reflective films, and glazed units with convection suppression (honeycomb windows). However, in order to assess the potential of these techniques for improving the net heat gain through windows, the methods to calculate the solar heat gain must be updated and modified for greater accuracy.

Determining the solar gain through windows consists of two calculations: first, that of the solar radiation incident on the outside surface of the window and, second, that of the amount of incident solar energy transmitted through the window and absorbed by the room. A brief description of the work being done to improve these calculations follows.

In recent years, a number of models have been developed to calculate the solar radiation incident on tilted surfaces from data measured on the horizontal. This has given rise to the need to determine how well these models predict the solar energy incident on vertical surfaces. The solar radiation values measured on the horizontal surface at the passive solar test facility will be used to calculate, with the help of the models, the solar radiation incident on vertical-south and vertical-north surfaces. The accuracy of each model will be determined by comparing the calculated values with the measured values. The best model will subsequently be incorporated into various energy calculation programs.

A computer program has also been developed to calculate the net solar heat gain through single-, double-, and triple-glazed windows for 13 Canadian locations[3,4]. The program will be updated to include calculations for the solar gain through other glazing types (quadruple-glazing, windows with reflective films and honeycomb windows), as well as the effect of shading from overhangs and window frames. Ways to account for the short-wave radiation reflected out of rooms through windows will also be studied.

3.4 Development of Passive Solar Design Guidelines and Calculation Procedure

A simple method to estimate the heating energy requirements is needed to compare the energy consequences of a variety of house designs as well as to evaluate the compliance of these designs with energy standards.

An important component in an energy calculation method of this nature, particularly for passive solar houses, is the amount of solar energy gained through the windows and utilized to offset the heat losses. Only a fraction of the solar energy gained can be utilized. The magnitude of this fraction depends on a number of factors including geographical location, size and type of glass, over-all building heat loss, thermal storage properties of the house, and the allowable rise in indoor temperature.

The object of this study is to develop a simple method for estimating the utilization of solar gain through windows in all types of houses in all climatic regions of Canada. This method has been derived from a large number of detailed computer simulation runs and is being checked using the measured data from the test facility.[5] It will ultimately be used to develop guidelines for the design of passive solar buildings.

4. SUMMARY

The ultimate aim of the DBR passive solar program is to assist building designers in producing more energy-efficient homes that do not sacrifice indoor thermal comfort. This will be achieved by developing design guidelines and a simple calculation procedure for the various phases of the design process. An important element of this effort is the generation of reliable, pertinent data to verify these design methods and, in general, to aid in the evaluation of passive solar-heating techniques.

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Table 1

THERMAL STORAGE CAPACITY OF THE TWO-ZONE UNITS

Test Unit	Type	Storage Mass (Kg)*		Heat Capacity (MJ/K)	
		South Room	Total Unit	South Room	Total Unit
1	DG, Light	645***	1308	0.75	1.53
2	DG, Medium	1810	3704	2.03	4.13
3	DG, Heavy	7435	13565	6.33	11.55
4	Mass Wall**	4200	4866	3.70	4.48

* includes all wall and ceiling finishes inside insulation layer as well as carpet and floor

** mass includes "mass" wall

***all four single-room units have the same thermal characteristics

(a) NORTH FAÇADE

(b) SOUTH FAÇADE

Figure 1 Over-all view of test facility

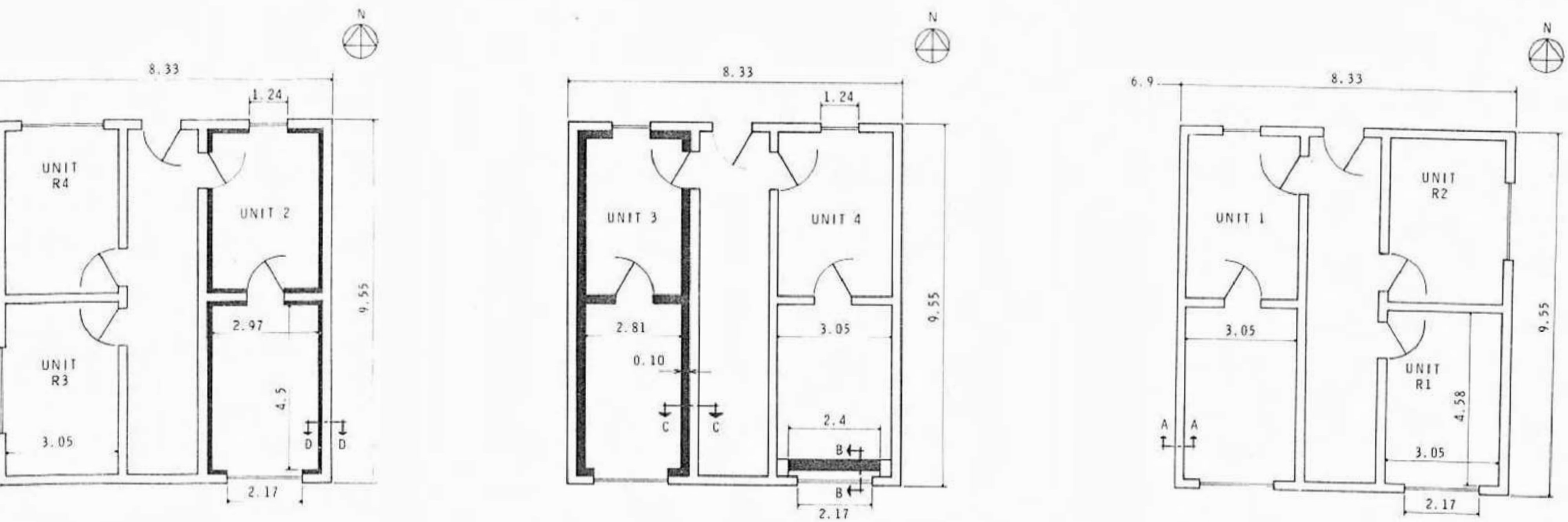

Figure 2 Details of test units
(All dimensions in metres)

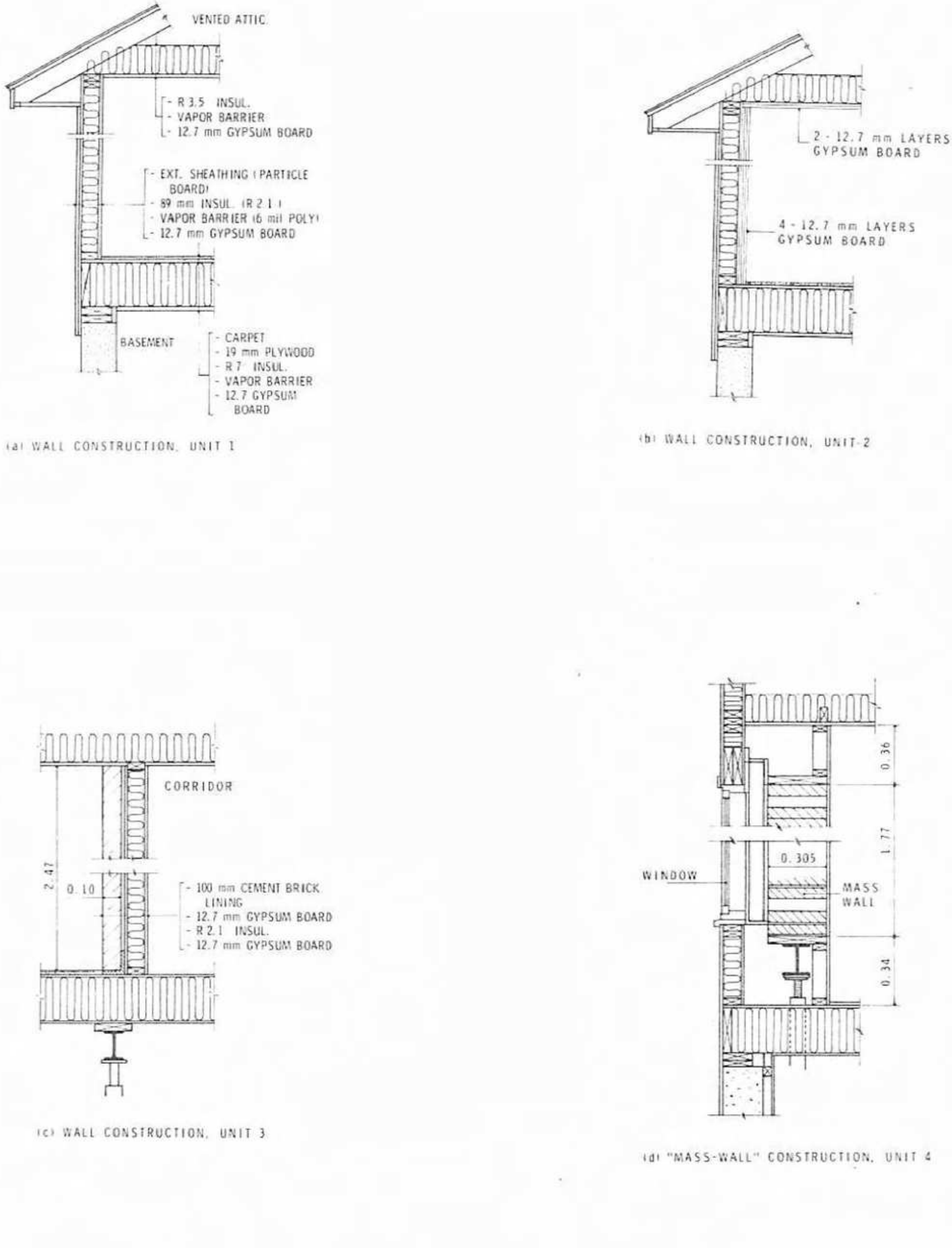

Figure 3 Construction details of test facility
(Thermal Resistance values in $m^2 \cdot {}^\circ C/W$)