# BUILDING RESEARCH NOTE

THE MARK XI ENERGY RESEARCH PROJECT
DESIGN AND CONSTRUCTION

by

R.L. Quirouette

Division of Building Research
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The Division of Building Research (DBR), in cooperation with the Housing and Urban Development Association of Canada, is undertaking a special energy conservation study involving four single detached houses built in Orleans, Ontario, 3 miles east of Ottawa. The objectives of the study are to determine the effectiveness of different measures to reduce energy requirements of single family houses and to validate a specially developed computer program for predicting the effectiveness of such measures for different housing types, variations in construction, location and operating conditions. An opportunity is provided to monitor the energy exchanges resulting from the equipment used by the occupants and to compare the operating characteristics of a conventional warm-air heating system with one having a supplementary solar collector and one incorporating an air-to-air heat pump. The four houses are of the same design, two storeys high, with three bedrooms and a finished floor area of 1248 sq ft (118 $m^2$). They are grouped on adjacent lots with identical orientation (Figure 1). The first house was built to meet current insulation requirements of the Ontario Building Code 1975, consistent with construction practices of the area. The other three houses were built to increase insulation levels and air tightness requirements for over-all comparison with the first house and to compare the performance of the three heating systems. A heat loss analysis is presented in Table 1.

## HOUSE No. 1 and No. 2 - STANDARD AND UPGRADED CONSTRUCTION

The first house has R-12 insulation in the walls, R-20 insulation in the ceilings and R-7 insulation on the basement walls. The insulation in the basement was installed in a conventional manner on the inside (Figure 2, Table 2). The insulation values used in the three upgraded houses are nominal R-20 for all exterior walls, R-32 for ceilings, and R-7.5 applied to the exterior side of the foundation wall down to the footing level (Figure 3, Table 3). The upgraded houses have triple-glazed windows and special measures were taken to improve the air tightness of their construction. A separate ventilation system will be provided in the three upgraded houses. The basic heating system of each house is a forced warm-air heating system using an electric furnace in houses No. 1 and No. 2, an air solar heating system in house No. 3 and a heat pump heating system in house No. 4.

## HOUSE NO. 3 - SOLAR SYSTEM

House No. 3 has an air solar heating system with 409 gross sq ft (39 $m^2$) of solar collector panels (Figure 4, Table 4). The roof surface faces 24° east of south and is sloped at an angle of 69°. A 200-cu ft (5.8 $m^3$) rock thermal storage unit is incorporated in the construction of the house to provide a short-term supply of heat energy. It is expected that the solar system will provide 50 per cent of the annual heating and as much for service hot water if compared to the energy requirement of house No. 2.

## HOUSE NO. 4 - HEAT PUMP SYSTEM

The heat pump system incorporated in the fourth house (Figure 5, Table 5) is also an air-to-air system but may eventually involve sources of heat other than the outside air. It will provide an opportunity for detailed evaluation of heat pump performance in cold weather conditions. It is expected that the heat pump will provide at least 30 per cent saving of the heat energy requirement when compared to the energy requirements for house No. 2.

## INSTRUMENTATION

The four houses are being instrumented by DBR so that continuous records will be obtained and analyses made of the energy exchanges within the house. Other records will be gathered of the climate conditions, the operation of equipment and appliances indoors, the opening and closing of doors and windows, and the operation of the heating systems.

All four houses are equipped with sensing devices (thermocouples) to measure and determine the heat flow through sections of each major wall. Each basement wall facing a unique direction has a thermocouple string. On both floors, the wood-frame walls are equipped with heat flow meters (also temperature sensors) for each orientation; the ceilings will also be equipped with heat flow meters. The exterior walls and ceilings of each house are also equipped with pressure taps (air pressure sensors) to observe the pressures due to wind and stack effect. These observations may lead to a realistic estimate of air leakage. The warm-air supply ducts of each house are equipped with orifice plates, devices that indicate air-flow rates within the duct. Thermocouples were also installed in the warm-air supply duct and return air duct of each room. The general humidity condition will also be measured within each house. The electrical energy to each room will be monitored on an individual kilowatt-hour meter and additional meters will record the electricity used by major appliances such as the hot water tank, the furnace and the dryer. Three separate water meters will measure the amount of hot and cold water used inside, and the amount of cold water going to the outside. There are devices that will check windows to determine whether they are open or closed. Sensors will be installed in the exterior door frames to monitor their use. There are moisture pins installed at strategic locations in the exterior walls to monitor wood moisture-content levels. There will also be instrumentation on the outside to record site climate conditions. The instrumentation is comprehensive and complex; the only sensible approach to collecting and analyzing the data is through the use of a computer. A small central computer has been installed in house No. 1.

## PROJECT CONSTRUCTION

The four houses were built by Talback Construction of Ottawa for the Housing and Urban Development Association of Canada as the HUDAC MARK XI PROJECT. The construction of the houses began 8 July 1977 and was essentially complete by the end of December of the same year. The projected construction schedule was 20 weeks. There were minor delays due to material shortages and also to inclement weather conditions. Nevertheless, the builder managed to maintain firm operational control even though many of the operations called for innovative changes in construction. Figure 6 illustrates the differences between the planned schedule and the actual construction schedule.

The construction of the four houses including the solar heating and heat pump heating systems was extensively documented through drawings, photographs and slides.

## BASEMENT INSULATION

In the upgraded houses, (Nos. 2, 3 and 4), the perimeter of the foundation wall is approximately 10 per cent longer on the outside due to the corners and garage-wing walls. A 1½ in. polystyrene insulation was applied to the exterior of the foundation wall starting from the footing and extending to the underside of the sill plate (see details 4 and 5, Figure 3). The sequence of construction was as follows; after dampproofing the basement wall (sprayed on), a 4 mil polyethelene sheet was draped over the wall, lapped 12 in. or more over at the joints and held in place with more dampproofing (brushed on). The polystyrene insulation was then spot-glued to the polyethelene and installed in rows, starting from the bottom. The last course was left open to be installed at a later time. The polyethelene was installed to act as an interface between the dampproofing and the polystyrene insulation to isolate the dampproofing and insulation adhesive, which are incompatible materials. The 2 ft by 8 ft polystyrene boards were installed such that the joints lapped and drained to the outside. Following installation of three rows of polystyrene boards, the foundation was carefully back-filled with the same material that had been taken out. With careful back-filling, little or no damage was done to the insulation. The last course of insulation was installed using concrete nails and galvanized metal washers. A galvanized metal lath was nailed over the insulation and two coats of cement parging were applied. For each house, approximately 54 man-hours of labour was required to install and finish 880 sq ft of insulated wall including wire mesh and parging. The materials represented approximately 70 per cent of the cost, the labour 30 per cent, and the unit cost was \$1.12 per square foot of insulated wall.

FRAME WALLS

It was decided that the design and construction of the wood-frame walls should satisfy two major requirements: 1) that the design and construction substantially reduce air leakage that occurs in conventional construction and 2) the walls be thermally upgraded to a value not less that a nominal R-20.

Since air leakage in small buildings has been identified as one of the major components of the energy balance, heat recovery from ventilating air for wood-frame construction was not only feasible but would likely prove cost effective. To incorporate a heat recovery ventilation system in a wood-frame house, it was judged that the building envelope such not leak more than 1/10 of the building volume per hour at design conditions. To achieve improved air tightness, construction details were reconsidered and new ones developed (Figure 3).

Three design configurations were analyzed: 1) 2 by 6 stud construction with an R-20 friction-fit batt, 2) 2 by 4 stud wall construction with a nominal 2 by 2 furring applied on the exterior side of the wall, and 3) standard 2 by 4 construction using a nominal 2 by 2 furring on the inside. It was decided to use the last, that is, to modify standard wall construction and adapt a nominal 2 by 2 furring strip on the inside to create the 6-in. wall cavity for a nominal R-20 value. To achieve the air tightness required, a 4 mil polyethelene sheet was installed between the furring and the 2 by 4 framing to create a cavity where all the electrical circuitry would be located thus removing some of the obvious sources of air leakage.

The polyethelene sheathing placed between two layers of insulation is susceptible to the accumulation of moisture but the heat exchanger ventilation system will assure that the indoor relative humidity not exceed acceptable limits. Calculations reveal that at design conditions of outdoor and indoor vapour pressures, no moisture should accumulate in the walls unless the indoor relative humidity exceeds 45 per cent. To verify this hypothesis, numerous moisture sensors were installed throughout the construction at suspect locations.

The final wall construction (see details 2 and 3, Figure 3) consists of an R-7 friction-fit batt placed horizontally between the 2 by 2 strapping, an R-12 glass fibre friction-fit batt placed vertically between the 2 by 4 studs, and an exterior one-inch fibreboard rated at a nominal R-3. A design analysis of the wall indicates that the nominal thermal resistance including gypsum board and exterior sheathing and air films is R-24.3. In the laboratory test, the actual R value was found to be significantly less than the nominal one, to be exact, it was 19.6.

The construction cost of the exterior walls of house No. 1 (standard construction) was \$0.99 per square foot. The cost of the upgraded walls of the other three houses was \$1.70 per square foot. This is a 72 per cent increase over the construction cost of the exterior walls in house No. 1.

CEILINGS

The ceilings of houses No. 2, 3, and 4 were upgraded to a nominal thermal resistance of R-32 by placing two layers of friction-fit insulation (see details 1 and 6, Figure 3). A 6-in. friction-fit glass fibre batt was placed horizontally over the lower cords of the trusses and a 4-in. R-12 friction-fit batt was placed between the cords of the trusses. This operation was done from the inside of the house before the ceiling gypsum was installed. This provided a total of 10 in. of glass fibre insulation for a nominal thermal value of R-32. An air vapour barrier consisting of 4 mil polyethelene sheathing was installed over the ceilings and lapped at the perimeter to form a continuous impermeable and air-tight barrier. The ceilings were strapped at 16 in. o.c. with nominal 1 by 3 furring and covered with ½ in. gypsum board. The cost of thermally upgrading the ceiling must also include this additional material and labour.

The cost for upgraded ceiling was \$0.97 per square foot. This is an increase of \$0.57 per square foot over the cost of the R-20 ceiling in house No. 1.

WINDOWS

While all the windows in house No. 1 are essentially sealed double-glazed units, the windows in the upgraded houses are casement sealed triple-glazed units. The casement window is more expensive than a wood slider, and the triple-glazing that was incorporated added a 10 per cent increase in cost over the same window type with a sealed double-glazed unit. The use of sealed triple-glazed windows raised the thermal value of the window glass from R-2 to R-3. The basement windows of all four houses are sashless double-glass sliders.

The cost of the windows in the upgraded houses was \$11.96 per square foot as compared to \$5.19 per square foot in house No. 1. This cost includes labour, materials and taxes but no overhead or profit.

HEATING SYSTEMS

The design heat loss calculations for house No. 1 and the upgraded houses (Nos. 2, 3, and 4) are presented in Table 1. The design heat loss for house No. 1 is 46 898 Btu/h (13 747 W) for an indoor temperature of 72°F (22.2°C) and an outdoor temperature of -13°F (-25°C). The annual energy consumption is estimated to be 20 236 kW·h for a winter severity factor of 8693 F degree-days (4673 C degree-days).

The design heat loss for houses No. 2, 3, and 4 is estimated to be 28 886 Btu/h (8 466 W) for the same design conditions stated above. The annual estimated heat loss from these houses, not considering the contribution that may be made by the solar or heat pump heating systems of houses No. 3 and 4, is estimated at 12 464 kW•h. This is a gross annual saving of 38 per cent over house No. 1.

Solar Heating

The solar heating system of house No. 3 consists of three arrays of solar collector panels installed on the south-facing portion of the roof (Figure 4). Two air plenums, consisting of insulated metal ducts, supply and collect the air circulated through the collector panels. The air handler unit, which houses a fan, circulates the air; motorized dampers direct the air in the appropriate direction in the house at the right time. A short-term thermal storage, utilizing a rock medium, was built at the basement level in a little room just under the concrete slab of the garage floor. It is an insulated box containing 200 cu ft (5.8 $m^3$) or approximately 10 tons of one-inch river gravel. This volume will provide one to two days of stored thermal energy at winter design conditions.

The installation of the solar collector panels required approximately two man-weeks of labour. This included the installation of all perimeter insulation, perimeter flashings, infill panels, all associated hardware, and all cap flashings. The collector panels were bolted through the roof following a careful alignment of the arrays using nominal 2 by 2 furring strips nailed over the roof shingles. One-foot square holes were cut at the top and bottom of each array to receive the inlet and outlet starting collars that connect the collector arrays to the indoor duct system. The perimeter of the collector arrays was insulated with 1½ in. medium density glass fibre insulation. The infill panel and the metal flashings were made of pre-finished metal of the same colour and texture as the trim material used elsewhere on the house.

The ductwork can be divided into two zones - inside the house and outside the building envelope. The main plenums are 10 in. by 16 in. air ducts insulated to a value not less than R-10 in the attic and to a value of R-8 inside the house. Glass fibre insulation with reinforced foil was used to insulate all ductwork. All ducts were sealed with silicone caulking and all joints formed by the insulation were taped.

The walls of the thermal storage room were insulated to an R-8 level on the inside with 2 in. of medium density glass fibre insulation and 3 in. of low density glass fibre at the ceiling. The floor of the thermal storage room was insulated with 3 in. of foam plastic insulation, not because of thermal requirements but to adjust the height of the finished floor and align the lower plenum space with the wall duct opening. The room measures 5 ft by 7 ft by 9 ft and is completely covered with type X gypsum board on the inside. There is an average depth of 4 ft 6 in. of one-inch river gravel over a wire mesh placed over an array of lintel blocks used to form the lower plenum space. Warm air is forced downwards over the face of the aggregate and is collected at the bottom. Heat transfer occurs within the rock medium in a thin layer of perhaps 4 to 6 in. and progresses downwards as the thermal storage is being charged. To recover heat from the thermal storage room, the air flow is reversed: cool air is injected at the bottom, collected at the top and circulated to the house.

In addition to space heating, the system is also equipped with a hot water pre-heat system. This system comprises a heat exchanger or hot water coil which is installed at the top of the air handling unit (fan housing). There is a pre-heat tank approximately 1½ times the volume of the regular service tank (40 imperial gallons) which is used to store the energy available for hot water pre-heating.

The solar system will operate all year. The operational priorities are space heating followed by hot water heating. During the summer months, when no space heating is required, manual dampers bypass the thermal storage room completely. During this mode of operation the system is used solely for hot water heating. A thermal performance analysis of the solar system estimates a 50 per cent reduction in annual heating cost and about the same or slightly less for serivce hot water heating.

The solar heating system, which includes all solar hardware, ductwork and insulation, controls and electrical wiring, thermal storage room, and the labour for construction and installation, cost $18 000 or $44 per square foot of collector.

Heat Pump Heating

The heat pump heating system of house No. 4 is a 2½ ton refrigeration unit consisting of two major components: an outdoor component comprising compressor, heat exchanger and fan, and an indoor component comprising another heat exchanger and fan. The indoor component is housed in a furnace casing which has a back-up electric heater. A heat pump heating system is essentially a refrigeration unit that cools the outdoor air and in the process rejects heat to the interior of the house. While the system is not new in principle it is difficult to design a heat pump that will operate efficiently and effectively at low temperatures. Specification for the system will be found in Table 5. The full cost of the heat pump system including ductwork, grills, labour to install, and warranty, amounted to $3893. The heat pump unit excluding the forced warm air heating system was approximately $1000 less.

EASTERN FOREST PRODUCTS LABORATORY

The Eastern Forest Products Laboratory (E.F.P.L.), another participant in this project, is conducting experiments within each of the houses, which may result in savings of structural material, in particular, floor joists and roof sheathings. Each of the four houses is the subject of a unique system of joists and sub-floor sheathing which involves continuous spans and glued sub-floors. Preliminary tests have indicated that the three experimental floors perform as well if not better than the reference minimum standard floor of house No.1. The roof sheathing of each house is a combination of waferboard panels of either spruce or poplar plywood. The roofs will be observed for a number of years to determine the serviceability of these materials in a roof application. A final report will be issued by the E.F.P.L. at a later date.

## SUMMARY

House No. 1 (Lot 405) and house No. 2 (Lot 406) are perhaps the most important within this project as they will be subject to detailed observations of energy use under actual occupied conditions. Through these observations actual energy savings will be determined and related to the costs of the individual thermal upgrading measures applied to house No. 2. Houses No. 3 and 4 will be used to study in detail the performance of the solar heating and heat pump heating systems. These houses were of the same construction as house No. 2 to compare equally the performance of the three heating systems.

The houses are unoccupied at the time of this writing and have been rented since January 1978 by the Division of Building Research to complete the instrumentation and to initiate calibration measurements which will determine the unoccupied performance characteristics. When these have been established, houses No. 1 and 2 will be rented to families; houses No. 3 and 4 will be rented by DBR for select experiments. The effect of family activities on energy use in the first two houses will be monitored and the results applied in a detailed energy audit. The four houses will be observed for a period of two to five years. Much data will be gathered and analyzed, and reporting will probably begin about one year after a full weather cycle has been obtained.

## TABLE 1 HEAT LOSS ANALYSIS

| | HOUSE No. 1 - STANDARD CONSTRUCTION | | | HOUSES No. 2, 3, and 4 - UPGRADED CONSTRUCTION | | |
|---|---|---|---|---|---|---|
| Design Data | Indoor Temperature 72°F (22.2°C)<br>Outdoor Temperature -13°F (-25°C)<br>Degree Days - 8 693 (F deg), 4 673 (C deg) | | | Indoor Temperature 72°F (22.2°C)<br>Outdoor Temperature -13°F (-25°C)<br>Degree Days - 8 693 (F deg), 4 673 (C deg) | | |
| | Ceilings R-20, Walls R-12<br>Basement R-7, 2 ft below grade<br>Windows, double glazed R-2<br>Doors, metal insulated ≈R-6 | | | Ceilings R-32, Walls R-20<br>Basement R-7.5, down to footing<br>Windows, triple glazed R-3<br>Doors, storm + metal insulated R-7.5 | | |
| | Heat Loss | | | Heat Loss | | |
| | watts | Btu/h | % | watts | Btu/h | % |
| Construction Data | | | | | | |
| Frame Walls | 2 971 | 10 137 | 21.6 | 1 855 | 6 330 | 21.8 |
| Ceilings | 837 | 2 856 | 6.1 | 544 | 1 856 | 6.4 |
| Exposed Floor Over Garage | 99 | 338 | 0.7 | 48 | 164 | 0.6 |
| Basement Wall Above Grade | 1 133 | 3 866 | 8.2 | 999 | 3 409 | 11.8 |
| Basement Wall Below Grade | 888 | 3 030 | 6.5 | 573 | 1 955 | 6.8 |
| Basement Floor | 394 | 1 345 | 2.9 | 394 | 1 345 | 4.7 |
| Windows | 2 687 | 9 169 | 19.5 | 1 582 | 5 398 | 18.7 |
| Doors | 323 | 1 102 | 2.3 | 263 | 897 | 3.1 |
| Infiltration | 4 415 | 15 065 | 32.1 | * 2 208 | 7 532 | 26.1 |
| | 13 747 | 46 898 | 100.0 | 8 466 | 28 886 | 100.0 |

**House No. 1:**
Design Heating Load
13 747 W, 46 898 Btu/h
Estimated Annual Heat Energy
Consumption - 20 236 kW·h

**Houses No. 2, 3, and 4:**
Design Heating Load
8 466 W, 28 886 Btu/h
Estimated Annual Heat Energy
Consumption - 12 464 kW·h

* Assumed to be 1/2 of House No. 1

TABLE 2

HOUSE No. 1 - STANDARD CONSTRUCTION

GENERAL CHARACTERISTICS

Property

- Lot No. 405, Registered plan M-171, Gloucester Township
- Lot size, 40.0 ft (12.3 m) wide by 125.0 ft (38.5 m) deep
- Easement on east property line
- Long axis oriented N-S
- Berm, 8 ft (2.5 m) high on rear lot line

Building Design

- Single detached house
- 2 storey, 3 bedroom, 1 1/2 bathroom, attached garage
- Orientation of rear elevation, 24° east of south
- Gross floor area, 1 249 sq ft (118 $m^2$)
- Gross wood frame enclosure area, 2 406 sq ft (227.8 $m^2$)
- Gross basement enclosure area, 1 437 sq ft (136 $m^2$)
- Gross window area, 164 sq ft (15.5 $m^2$)
- Gross exterior door area, 44 sq ft (4.2 $m^2$)
- Net wood frame wall area above grade, 1 525 sq ft (144.4 $m^2$)
- Net foundation wall area, 891 sq ft (84.4 $m^2$)
- Net ceiling area, 673 sq ft (63.7 $m^2$)
- Heating system, forced air electric furnance, 15 kW
- Design heating load, 46 898 Btu/h (13 747 W)
- Estimated annual heating, 20 236 kW·h

Building Construction

- Ontario Building Code, 1975
- Wood frame construction, 2 by 4 stud walls, 2 by 8 wood joist, wood trusses 24 in. o.c.
- Cast-in-place concrete foundations, 8-in. walls
- Wall insulation, glass fibre, paper backed, R-12
- Ceiling insulation, glass fibre, paper backed, R-20
- Basement insulation, glass fibre, paper backed, R-7, inside, 2 ft below grade
- Windows, double glazed, wood frame, sliding and double-hung
- Exterior doors, metal insulated, ≈R-6, no storm door
- Roof, asphalt shingles, 210 lb
- Siding, horizontal, aluminum 8 in., ivory white
- Brick, front of house only, one storey, garage
- Soffits, continuous vented, aluminum
- Fascia, aluminum

TABLE 3

HOUSE No. 2 - UPGRADED CONSTRUCTION

GENERAL CHARACTERISTICS

Property

- Lot No. 406, Registered plan M-171, Gloucester Township
- Lot size, 40.0 ft (12.3 m) wide by 125.0 ft (38.5 m) deep
- Easement on west property line
- Long axis oriented N-S
- Berm, 8 ft (2.5 m) high on rear lot line

Building Design

- Single detached house
- 2 storey, 3 bedroom, 1 1/2 bathroom, attached garage
- Orientation of rear elevation, 24° east of south
- Gross floor area, 1 249 sq ft (118 $m^2$)
- Gross wood frame enclosure area, 2 406 sq ft (227.8 $m^2$)
- Gross basement enclosure area, 1 437 sq ft (136 $m^2$)
- Gross window area, 164 sq ft (15.5 $m^2$)
- Gross exterior door area, 44 sq ft (4.2 $m^2$)
- Net wood frame wall area above grade, 1 525 sq ft (144.4 $m^2$)
- Net foundation wall area, 891 sq ft (84.4 $m^2$)
- Net ceiling area, 673 sq ft (63.7 $m^2$)
- Heating system, forced air electric furnace, 10 kW
- Design heating load, 28 886 Btu/h (8 466 W)
- Estimated annual heating, 12 464 kW·h (38 per cent saving over house No. 1)

Building Construction

- Wood frame construction, 6-in. walls, 2 by 4 studs + 2 by 2 horizontal strapping inside, wood trusses 24 in. o.c.
- Cast-in-place concrete foundations, 8-in. walls
- Wall insulation, glass fibre, friction fit, R-12 + R-7
- 4 mil polyethylene vapour barrier, throughout
- Ceiling insulation, glass fibre, friction fit, R-20 + R-12
- Exterior sheathing, 1-in. fibreboard, thermal value, R-3
- Basement insulation, closed cell polystyrene, 1 1/2 in. R-7.5, outside of wall, extending to footing
- Windows, triple glazed, wood frame, casement, awning
- Exterior doors, metal insulated, with storm door, ≈R-7.5
- Roof, asphalt shingles, 210 lb
- Siding, horizontal, aluminum 8 in., ivory white
- Brick, front of house only, one storey, garage
- Soffits, continuous vented, aluminum
- Fascia, aluminum

TABLE 4

HOUSE No. 3 - UPGRADED - SOLAR

GENERAL CHARACTERISTICS

Property

- Lot No. 407, Registered plan M-171, Gloucester Township
- Lot size, 40.0 ft (12.3 m) wide by 125.0 ft (38.5 m) deep
- Easement on east property line
- Long axis oriented N-S
- Berm, 8 ft (2.5 m) high on rear lot line

Building Design

- Single detached house
- 2 storey, 3 bedroom, 1 1/2 bathroom, attached garage
- Orientation of rear roof, 24° east of south
- Gross floor area, 1 249 sq ft (118 $m^2$)
- Gross wood frame enclosure area, 2 406 sq ft (227.8 $m^2$)
- Gross basement enclosure area, 1 437 sq ft (136 $m^2$)
- Gross window area, 164 sq ft (15.5 $m^2$)
- Gross exterior door area, 44 sq ft (4.2 $m^2$)
- Net wood frame wall area above grade, 1 525 sq ft (144.4 $m^2$)
- Net foundation wall area, 891 sq ft (84.4 $m^2$)
- Net ceiling area, 673 sq ft (63.7 $m^2$)
- Heating system, solar, air-to-air, with forced air distribution
    - 409 sq ft (39 $m^2$) collector area, 21 panels
    - 200 cu ft (6 $m^3$) rock thermal storage, 1-in. dia river gravel
    - Ductwork, sheetmetal, insulated, R-8 and R-10
    - Fan, 800 cfm
    - Hot water pre-heat system
    - Solid state control, winter/summer operation
- Supplementary heating, electric furnance, 10 kW
- Estimated annual heating, 6 232 kW·h (50 per cent saving over house No. 2)

Building Construction

- Wood frame construction
- 6-in. walls, 2 by 4 studs + 2 by 2 horizontal strapping on inside, 2 by 8 floor joists, wood trusses 24 in. o.c.
- Cast-in-place concrete foundations, 8-in. walls
- Wall insulation, glass fibre, friction fit, R-12 + R-7
- 4 mil polyethylene vapour barrier, throughout
- Ceiling insulation, glass fibre, friction fit, R-20 + R-12
- Exterior sheathing, 1-in. fibreboard, R-3
- Basement insulation, closed cell polystyrene, 1 1/2 in. R-7.5 outside wall, extends to footing
- Windows, triple glazed, wood frame, casement and awning
- Exterior doors, metal insulated, with storm door, ≈R-7.5
- Roof, asphalt shingles, 210 lb
- Siding, horizontal, aluminum 8 in., ivory white
- Brick, front of house only, one storey, garage
- Soffits, continuous vented, aluminum
- Fascia, aluminum

TABLE 5

HOUSE No. 4 - UPGRADED - HEAT PUMP

SPECIFICATIONS

Property
- Lot No. 404, Registered plan M-171, Gloucester Township
- Lot size, 38.1 ft (12.2 m) wide by 125.0 ft (38.5 m) deep
- Easement on west property line
- Long axis oriented N-S
- Berm, 8 ft (2.5 m) high on rear lot line

Building Design
- Single detached house
- 2 storey, 3 bedroom, 1 1/2 bathroom, attached garage
- Orientation of rear elevation, 24° east of south
- Gross floor area, 1 249 sq ft (118 $m^2$)
- Gross wood frame enclosure area, 2 406 sq ft (227.8 $m^2$)
- Gross basement enclosure area, 1 437 sq ft (136 $m^2$)
- Gross window area, 164 sq ft (15.5 $m^2$)
- Gross exterior door area, 44 sq ft (4.2 $m^2$)
- Net wood frame wall area above grade, 1 525 sq ft (144.4 $m^2$)
- Net foundation wall area, 891 sq ft (84.4 $m^2$)
- Net ceiling area, 673 sq ft (63.7 $m^2$)
- Heating system, heat pump, air-to-air, with forced air distribution
- Cooling capacity, 30 800 Btu/h
- Heating capacity, 30 800 Btu/h, high temperature, coefficient of performance (COP) 2.7, @ 47° Fdb, 43° Fwb
- Heating capacity, 17 500 Btu/h, low temperature, COP 1.8, @ 17° Fdb, 15° Fwb
- Supplementary heating, electric furnace, 10 kW
- Estimated annual heating, 8 725 kW·h, (30 per cent saving over house No. 2)

Building Construction
- Wood frame construction
- 6-in. walls, 2 by 4 studs + 2 by 2 horizontal strapping, on inside, 2 by 8 floor joists, wood trusses 24 in. o.c.
- Cast-in-place concrete foundations, 8-in. walls
- Wall insulation, glass fibre, friction fit, R-12 + R-7
- 4 mil polyethylene vapour barrier, throughout
- Ceiling insulation, glass fibre, friction fit, R-20 + R-12
- Exterior sheathing, 1 in. fibreboard, R-3
- Basement insulation, closed cell polystyrene 1 1/2 in., R-7.5, outside wall, extends to footing
- Windows, triple glazed, wood frame, casement and awning
- Exterior doors, metal insulated, with storm door, *R-7.5
- Roof, asphalt shingles, 210 lb
- Siding, horizontal, aluminum 8 in., ivory white
- Brick, front of house only, one storey, garage
- Soffits, continuous vented, aluminum
- Fascia, aluminum

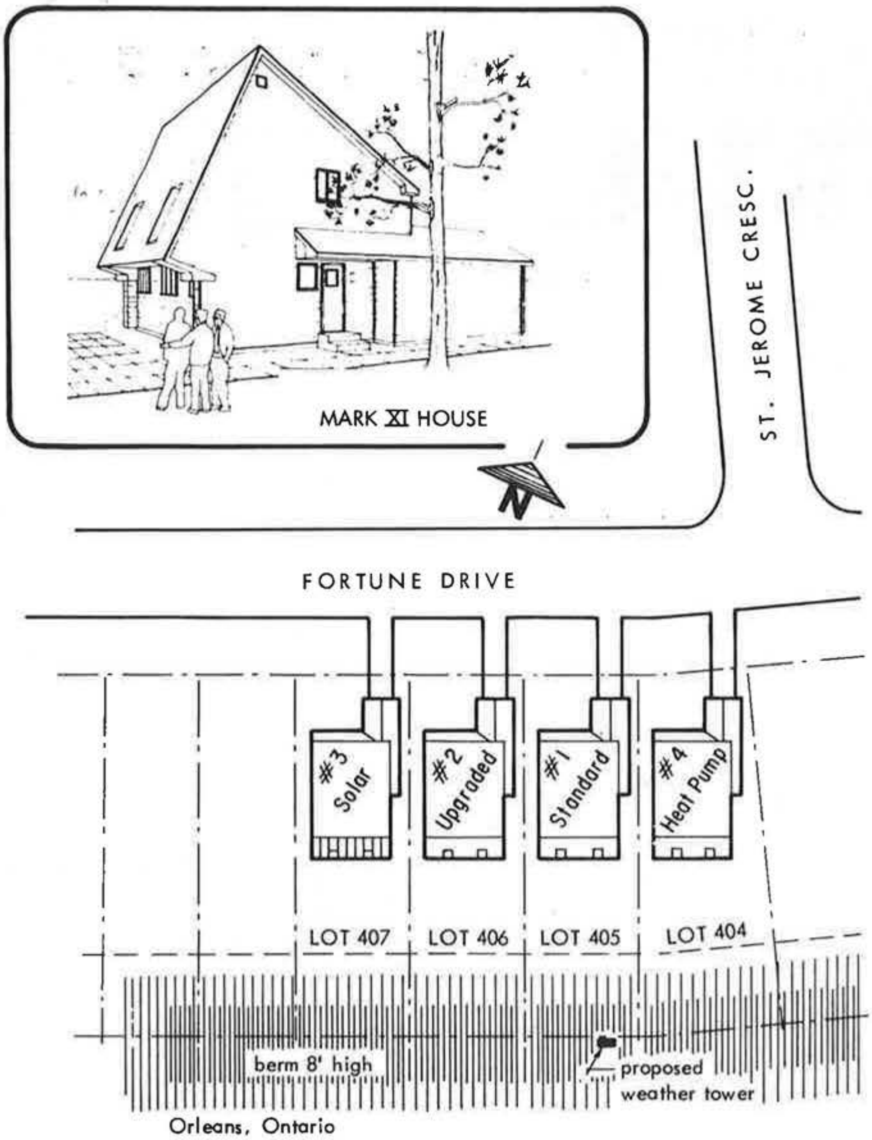
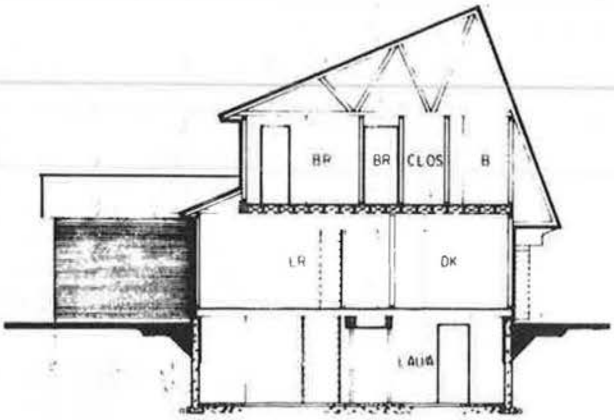


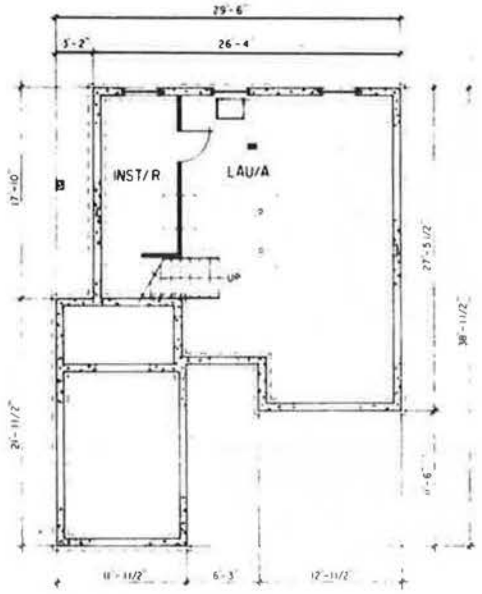

FIGURE 1

SITE PLAN - MARK XI PROJECT

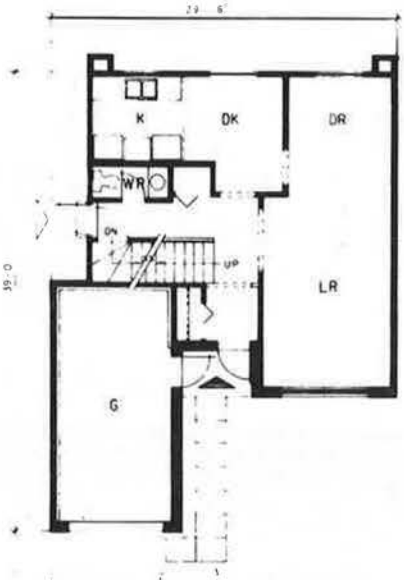
FRONT ELEVATION
SCALE




SECTION
SCALE




BASEMENT PLAN
SCALE

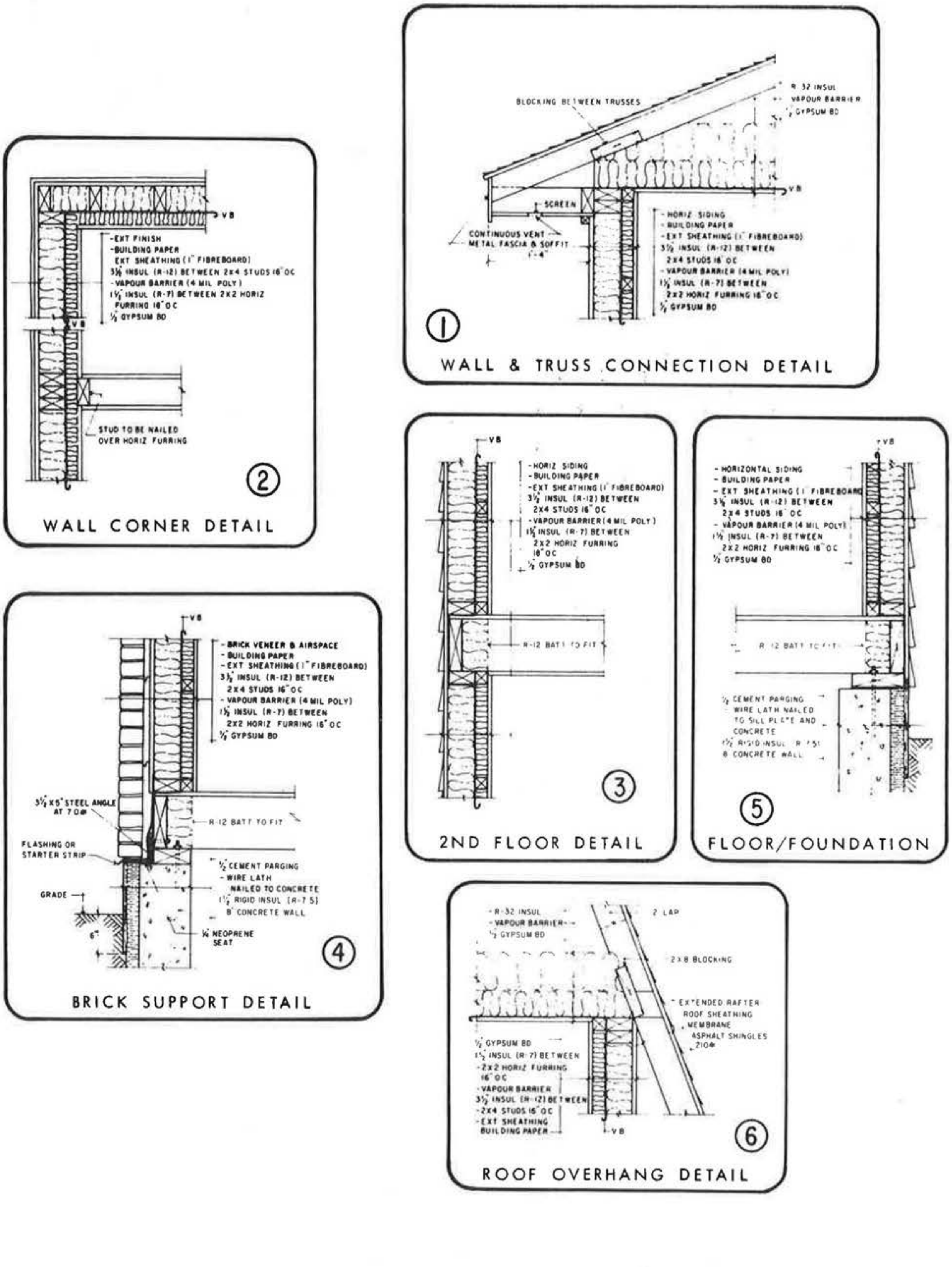



GROUND FLOOR PLAN
SCALE


SECOND FLOOR PLAN
SCALE

FIGURE 2

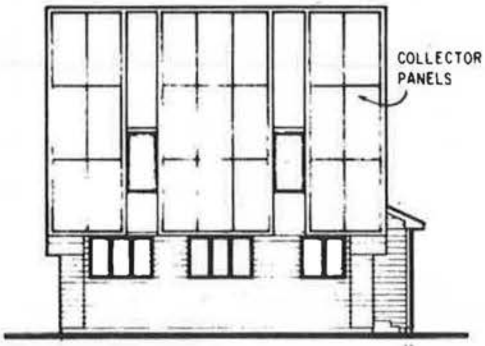
HOUSE NO. 1 - STANDARD CONSTRUCTION
(TYPICAL ARCHITECTURAL DESIGN OF ALL 4 HOUSES)



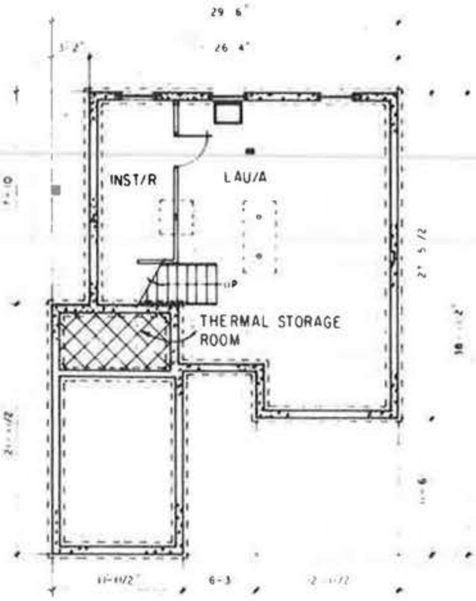

# FIGURE 3

## HOUSE NO. 2 - UPGRADED CONSTRUCTION

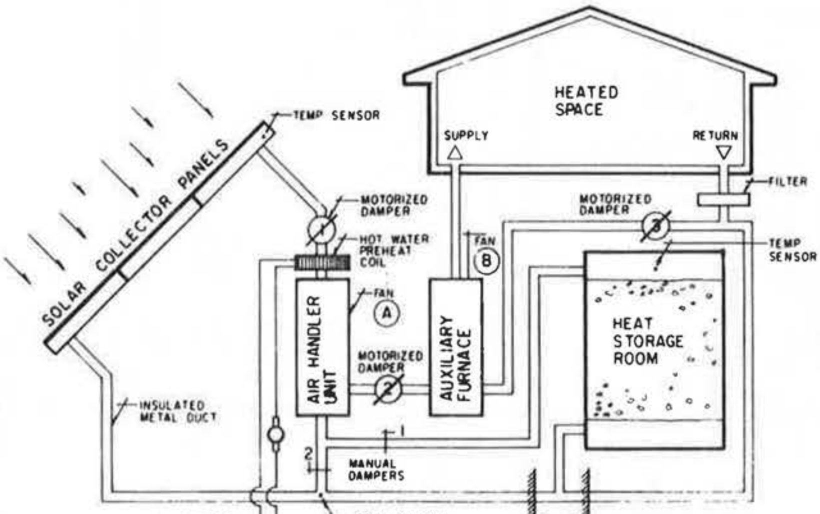
(CONSTRUCTION DETAILS FOR HOUSES 2, 3 & 4)




SOUTH ELEVATION
SCALE 0 1 3 7

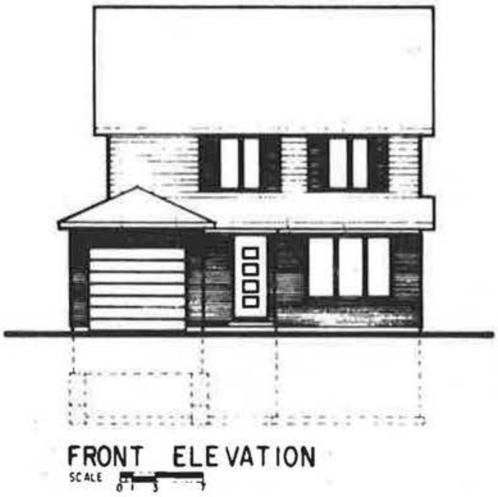


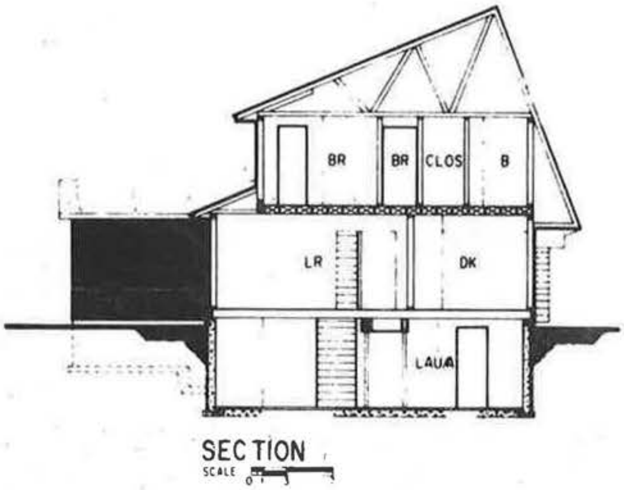

BASEMENT PLAN
SCALE 0 1 3 7




# FIGURE 4

# HOUSE NO. 3 - UPGRADED + SOLAR



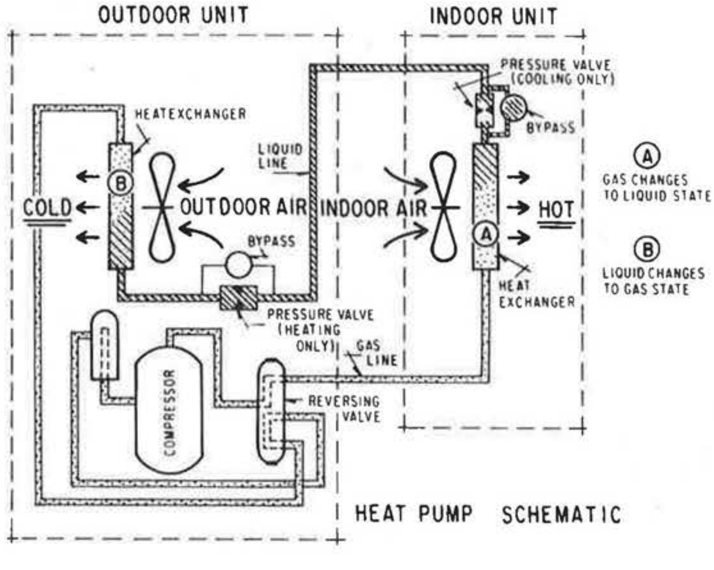




FIGURE 5

HOUSE NO. 4 - UPGRADED + HEAT PUMP

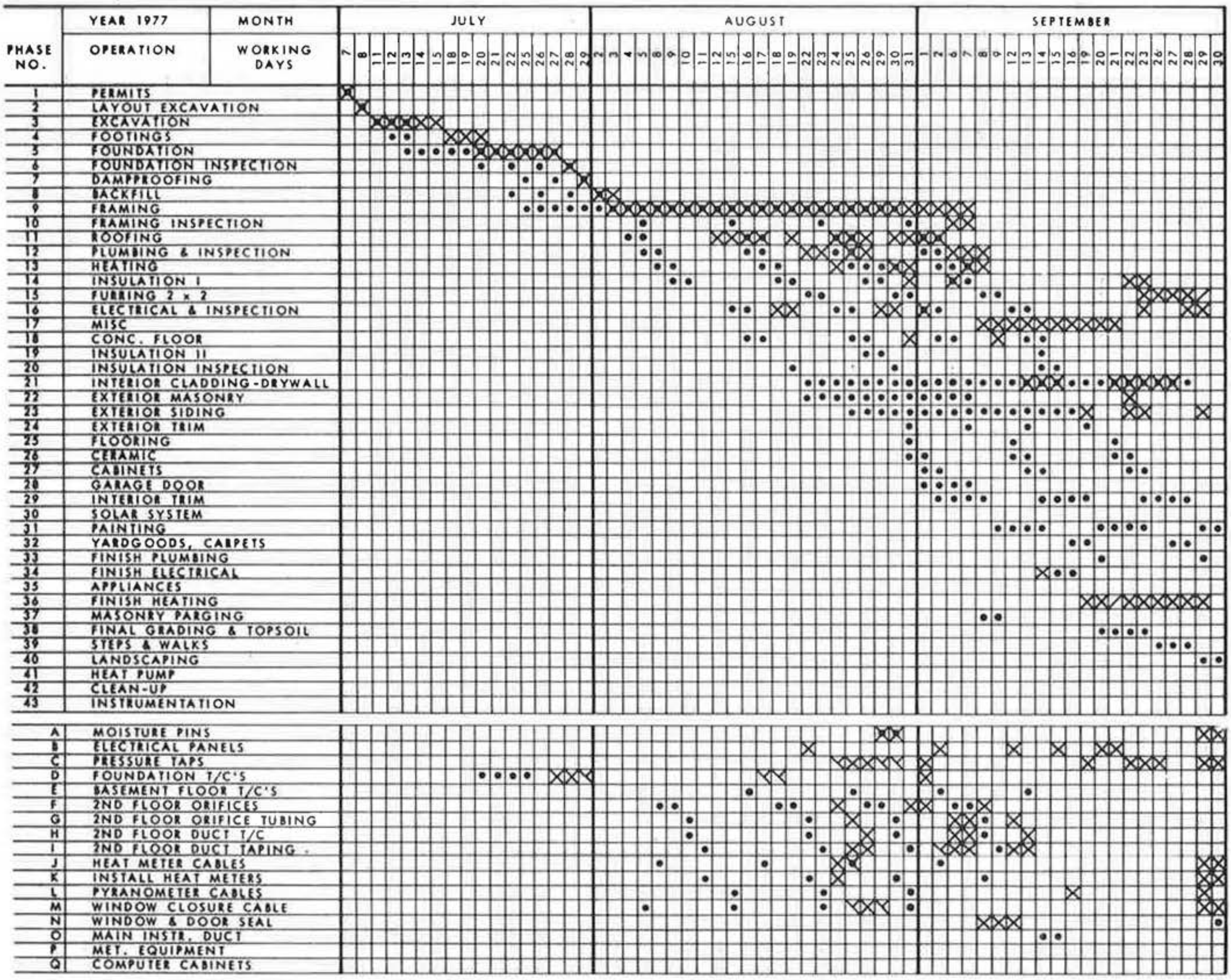



FIGURE 6

MARK XI PROJECT CONSTRUCTION SCHEDULE

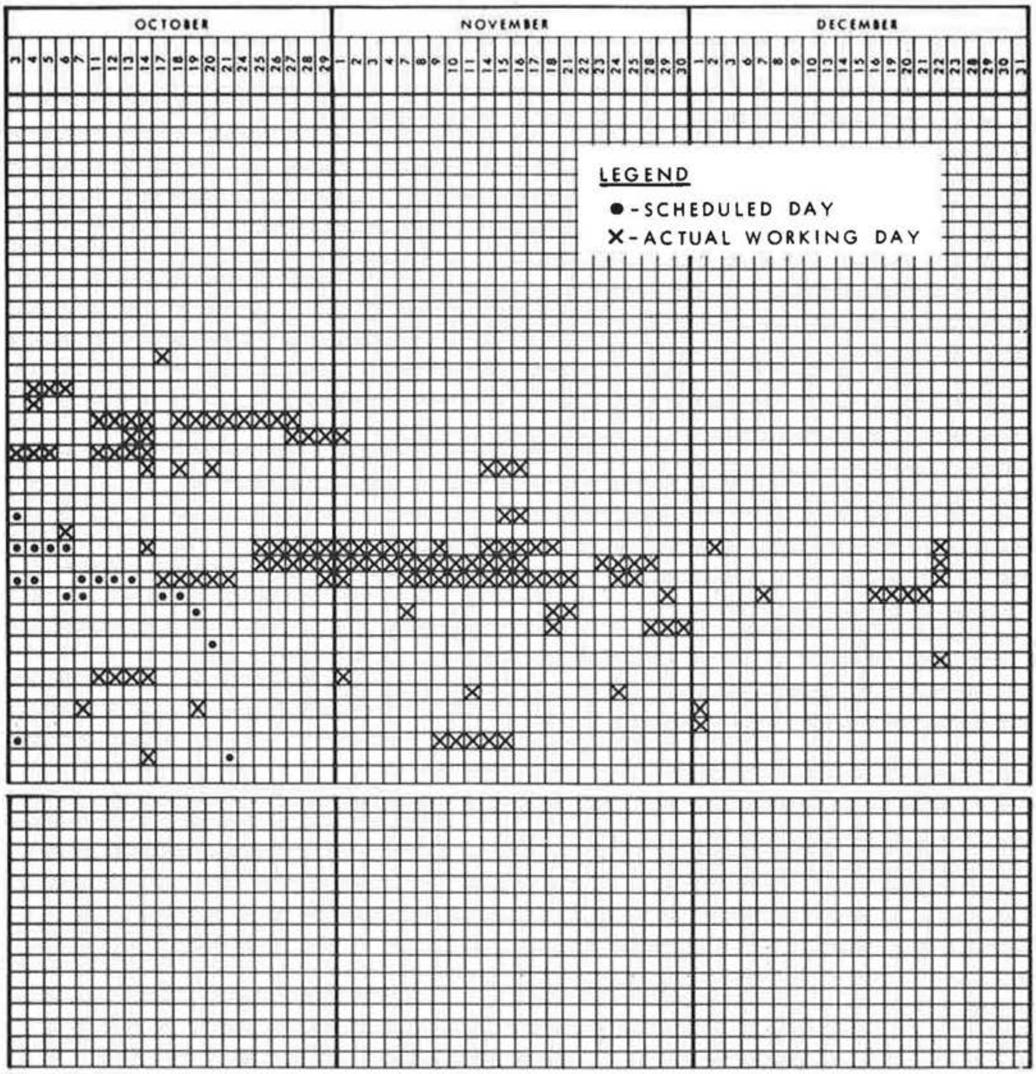



FIGURE 6 CONTD

NATIONAL RESEARCH COUNCIL OF CANADA

DIVISION OF BUILDING RESEARCH

THE MARK XI ENERGY RESEARCH PROJECT

DESIGN AND CONSTRUCTION

(BUILDING RESEARCH NOTE 131)

by

R.L. Quirouette

ERRATA

The following changes are made in Tables 2, 3, 4, and 5 under the heading Building Design.

| | |
|---|---|
| TABLE 2 | The design heating load should read 46 898 Btu/h (13 747 W). The estimated annual heating is 20 236 kW·h. |
| TABLE 3 | The design heating load should read 28 886 Btu/h (8466 W). The estimated annual heating is 12 464 kW·h. (38 per cent saving over house No. 1). |
| TABLE 4 | The estimated annual heating should read 6232 kW·h. |
| TABLE 5 | The estimated annual heating should read 8725 kW·h. |