AN OUTDOOR CONSTRUCTION TEST FACILITY, SASKATOON, CANADA

C.P. Hedlin
Hedlin Consulting, Inc.
Saskatoon, Saskatchewan, Canada

When in service, building materials and systems are subjected to a complex set of conditions. These are imposed by the interior conditions of the building, the weather and, in the case of roofs, possible damage due to traffic and later construction. Performance is also affected by the design, construction and effectiveness of subsequent maintenance.

Many laboratory tests are done to evaluate the properties of materials and systems. These are valuable but are unlikely to include the mix of factors that affects performance in the field. No experimental system can fully replicate the conditions that occur in the field. However, some realism can be added by outdoor testing and by field observations on existing buildings.

This paper describes an outdoor test facility and, for illustration, lists some of the results of work there. The facility is located at Saskatoon, Saskatchewan, Canada. The weather is continental in nature and is characterized by summer and winter extremes. Instrumented experimental wall and roof panels are exposed and in situ measurements are made on them. Temperatures, heat flows and moisture contents are included in the tests. Data are recorded on digital equipment. Thermal resistances are calculated. Changes in moisture content are measured gravimetrically and related to design or other factors.

Tests can be run over long periods of time. This may be necessary in order to expose the specimens to seasonal variations and to allow natural processes of change to occur. At Saskatoon, some tests were run over a number of years.

Work has been done on roof systems, individual roofing materials and wall systems. Particular attention was given to the protected membrane roofing system, including the effect of design on thermal insulation performance. Performance of conventional roofing systems has been studied, including the effect of insulation joint widths on heat transmission. A number of roof membranes were exposed as part of a large study being carried out by the materials section of the Institute for Research in Construction, National Research Council of Canada (NRCC), Ottawa.

Wall panels have been studied for moisture gain, including in situ weighing of one such panel to determine the rate of gain.

This testing has provided information under conditions that approximate those of the field. It is acknowledged that field conditions include hazards that cannot be simulated at such a facility. Field observation can help to fill in some of the gaps.

INTRODUCTION

Building materials and building systems, or assemblies, are exposed to rigorous environments. Their successful performance depends on the quality of the materials, design, construction procedures and on maintenance. Practical estimates of performance can be derived from field observations and from specially constructed outdoor test facilities that expose test specimens in a real-world environment where their performance can be measured.

The main purpose of this paper is to discuss the outdoor testing of building materials and systems at a facility located at Saskatoon, Saskatchewan, Canada. The paper includes discussion of measurement and analytical procedures. A number of examples of work are cited to indicate the potential and the limitations of outdoor test methods based on that experience.

Only work at Saskatoon is cited here. Other, similar facilities exist elsewhere and have been active for many years.

Information about outdoor testing has been provided through symposia sponsored by ASTM and others. Nevertheless, the value of "field-type" studies at special outdoor test facilities and at field sites on real buildings is, perhaps, not yet fully understood, nor are the possibilities fully exploited. Outdoor testing, with the realism that it provides, can constitute a valuable complement to laboratory testing.

Outdoor test facilities operate under prevailing weather conditions. This should ensure that none of the environmental players in the process are missed. However, it also means that tests may be of long duration because of the time periods needed to achieve the required exposure.

Analytical procedures are complicated by uncertainty as to causes of observed phenomena and conclusions are likely to be less precise than those obtained in a laboratory test.

The Prairie Regional Station (PRS) was a part of the Division of Building Research (DBR), and later the Institute for Research in Construction (IRC) of the NRCC. The PRS has been closed, but some of the staff now comprise the Building Science Division of the Saskatchewan Research Council. The Outdoor Test Facility continues to be operated by that group. The opportunities for investigation have been enhanced by the access to laboratory facilities at the SRC.

The PRS had a history of outdoor test work spanning about 40 years. Two facilities were used. The first was built in 1949 and comprised a number of small test huts each about 1.2m (4 ft.) square and 2.4m (8 ft.) high, and a small building to house monitoring equipment. Early work on blown-in-place insulations, ground temperatures and moisture deposition in building walls was carried out there by Mr. G. O. Handegord and his colleagues. It was used until a second facility was built in 1966. The latter is the subject of this paper.

THE FACILITY

The facility includes the main test building, measuring equipment and temporary structures.

The facility is located in a fenced compound covering about 1 hectare (2 acres). Temporary structures include racks for the exposure of materials and structures for special studies.

The main test building is 24m (78 ft.) long by 4.5m (14 ft.) wide and 3.7m (12 ft.) high, above grade level. The long dimension lies in the east-west direction. It is set on a concrete slab, on grade. Extruded polystyrene insulation 50mm (2 in.) thick is located horizontally as perimeter insulation. It extends 0.6m (2 ft.) out from the edge of the building, at grade level. This insulation is covered with pavers to provide a walkway.

A portion of the building, approximately 9m (30 ft.) long, was built for experimental purposes. Wall and roof panels can be constructed and put in place for in situ testing. There is provision for 14 roof panels and 17 wall panels (7 facing north, 7 south and 3 facing east). Each of these panels is 1.2m by 2.4m (4 by 8 ft.), though wall panels of up to 2.4m by 3.7m (8 by 12 ft.) can be accommodated by minor structural changes.

The remainder of the building is used for service functions though its roof is used for exposure of roof insulations.

The building is heated electrically. No cooling is provided. The interior of the building is kept at about 21°C in cool weather, though it exceeds that in warm weather. Interior humidity can be controlled locally by the use of humidifiers and hoarding to separate humidified spaces from one another.

Experimental panels are exposed to the prevailing weather on the outside (see Figure 1). The building is somewhat protected from wind by low tree growth about 30m (100 ft.) to the north and 60m (200 ft.) to the west.

The climate at Saskatoon is continental in nature; temperatures can range from −40°C (−40°F) in the winter to +40°C (+104°F) in the summer. Exterior surfaces of south facing walls may experience daily fluctuations in temperature of more than 80°C. Typically the area receives 2400 hours of sunshine each year and 350mm of precipitation, including about 750mm of snow (75mm of moisture). Winters are prolonged; the area has about 6000°C (11000°F) heating degree days/year. Subfreezing temperatures can prevail almost continuously from November to March. Wind speeds rarely exceed 80 km/h (50 miles/hour).

At various times, test data have been recorded in several ways. Early work involved paper chart recorders. This was superseded by recording on magnetic tape with subsequent reading and analysis. Data were also transmitted directly to a minicomputer for processing.

Digital equipment records temperatures, heat flow rates etc. In the past data were recorded on magnetic tape or transferred directly into a minicomputer. Currently, they are recorded on flexible disks for subsequent processing and storage. The number of data points being recorded at any one time ranges from about 60 to 120. Scanning time for this number of points is from 5 to 10 seconds. Analytical procedures assume that the time lapse is negligible; conditions do not change significantly from the beginning to the end of the scan.

Temperatures are measured with thermocouples. The accuracy of the data gathering system at O°C, based on measurement of temperature in an ice bath, is within 0.1°C (0.2°F). Errors of this magnitude are not likely to be important in most building tests.

Further, errors in temperature measurement may not be important if they are systematic. For example, thermal resistance depends on the difference between the temperatures on either side of a specimen. Systematic errors in temperature measurement are negated in the calculation process.[1]

Other errors, caused by uncertainties about the thickness of the specimen and about the placement of thermocouples on the insulation surface, are likely to be more significant.

Heat flux meters, 50mm and 100mm (2 and 4 in.) in diameter, are used for measurement of heat flow rates. A larger meter, 500mm by 500mm (20 by 20 in.), is also available. The heat flux meters were calibrated at the DBR in Ottawa.

Calibrations of heat flux meters are checked periodically against a specimen of rigid glass fiber whose thermal resistance was earlier checked in a guarded hot plate apparatus. In that case, the heat flux meters are mounted in the roof against the bottom surface of the calibrated glass fiber specimen. The rate of heat flow and the temperature difference across the glass fiber are measured for up to a week. The data are processed using analytical procedures described below. The results are used to calculate the coefficient for the heat flux transducer and determine whether it has changed.

The work at Saskatoon sometimes requires quantitative measurement of moisture content, while at other times simple detection of moisture is sufficient.

When observing conditions that produce condensation, e.g., in walls, it may not be necessary to measure the actual moisture content of the building specimens. In such cases, detectors are used which provide an output which signals moisture deposition. These include commercial "dew detectors" which react to the deposition of free moisture, and in some cases, to high humidities. Simple devices such as wood blocks with pairs of terminals, set up to measure changes in electrical resistance, are also used.

Only simple measurements of moisture content are made. To date, tests have not been done which require accurate, detailed in situ measurements of moisture content. Gravimetric measurements involving removal of the specimen for weighing, or core testing, have proved to be adequate for most purposes.

MEASUREMENT AND ANALYTICAL PROCEDURES

In collecting digital data, the sensors are scanned and their outputs are recorded regularly (e.g., every five minutes). This is a higher frequency than is needed to represent most phenomena. However, if high speed variations, such as those due to wind, were to be studied, special apparatus would be used to record at much higher frequencies.

In cold weather thermal resistances can be calculated by averaging heat flows and temperature differences. In this case the thermal resistance

$$R = \text{delta } T/Q$$

where delta T, Q are, respectively, the average temperature difference and the average heat flow rate across the specimen for the period of test.

Warm weather produces daily reversals of heat flow direction. In that case, simple averaging may be unreliable. Then, the heat flow rate is represented by transfer functions

$$Q0 = A0*TT0 + A1*TT1 + \text{—} B0*TB0 + B1*TB1 + \text{—} C1*Q1 + \text{—}$$

where Q0 and Q1 are, respectively, the current heat flow rate and the heat flow rate at one time step (e.g., 1 hour earlier).

TT0, TT1, TB0, TB1 are temperatures at the top and bottom surfaces of the specimen currently, and one time step earlier.

A0, A1, B0, B1, C0, C1 are the empirical coefficients corresponding to the top and bottom surface temperatures and to heat flows.

Thermal conductance is given by:

$$C = ((A_0 + A_1 + — + A_n) - (B_0 + B_1 + — + B_n))/(2*(1 - (C_1 + — + C_n))).$$

These calculation methods have proven to be accurate to within 5 percent based on comparisons with insulation specimens calibrated in guarded hot plate apparatus.[2]

Exposure racks allow any orientation for the specimens. Typically they face south and are positioned at 45 degrees from the vertical to maximize the solar radiation effect. Plastic building materials, siding, roofing membranes and thermal insulations have been exposed.

The performances of roof components can be observed within systems. This includes their individual performances and interactions between building components.

Examples are:

- Performance of surface coatings of thermal insulations.
- Interaction between roofing membranes and thermal insulations.
- Behavior of moisture in thermal insulation in conventional and protected membrane roof (PMR) systems.
- Thermal performance of insulations in conventional and PMR systems.
- Slippage of roof membranes on sloped decks.

Some of these are discussed in more detail in "Examples of Test Work."

DATA STORAGE

Raw data are stored to keep a permanent record of the tests. It allows future analyses that circumstances may require. Data have been successfully stored on nine-track magnetic tape, at 1600 b.p.i. for nearly 20 years. At the present time, plans call for storage on magnetic disks.

When required for further use, the data are transferred to a minicomputer or to flexible disks for processing with microcomputers.

EXAMPLES OF TEST WORK

Following are examples of work done. These illustrate the nature of such studies in this area, the approach that was taken, and the kind of information benefits that derive from them. Some of them illustrate types of information that are unlikely to be obtained in laboratory studies.

Moisture Balance In Thermal Insulation

Sometimes information is found by chance.[3] Critics might claim that the results should have been obvious. Perhaps they would be right. Nevertheless, serendipity plays a part in "field-type" studies because of the interaction of many factors whose combined effects are difficult to comprehend.

In one such case, information was found by chance inspection of a part of the building that was not intended for experiments. Extruded polystyrene placed beneath a paving stone walkway demonstrated dramatic differences in the rates of gain of moisture depending on whether:

- It was on the north or south side of the building.
- The upper surface was ventilated or covered with a paver.

The large gains in moisture on the south side, were exceeding 15 percent by volume. North side moisture contents were about 3 percent. It was apparent that direct solar heat, plus solar heat reflected from the adjacent wall, increased the vapor pressure of the available moisture driving it into the insulation on the south side.There was no comparable heat source to cause a similar effect on the north side.

Further investigation and modifications to the system provided confirmation of conclusions obtained in tests on flat roofs. It also extended the understanding of factors affecting gains of moisture by thermal insulation.

Effect Of Moisture On Heat Flow[4]

Formal tests were carried out to evaluate the effects of moisture on heat flow in insulation.

Tests included measurements with:

- A wide range of moisture contents—dry to 25 percent by volume.
- Insulation of differing porosities—extruded polystyrene to mineral fiber.

In warm weather the vapor pressure gradients reversed daily. In open-celled insulation, this caused a large component of heat transmission due to evaporation/condensation cycles; moisture evaporated on the warm side of the roof (top in the daytime and bottom at night) and some of it apparently moved toward the cold side where it condensed and deposited heat.

In summer, even small amounts of moisture had a large effect.[5] One percent by volume caused approximately a doubling of heat transfer rate. The thermal lag increased with the moisture content. The practical effects will depend on:

- The temperature control required in the building.
- The mass of the deck.

The results demonstrated the magnitude of the effect. Practical consequences would have to be estimated for individual cases, or could be checked with appropriate tests.

This behavior was not detected in closed-cell insulations.

In cold weather, the moisture was immobilized; it was diffusely distributed in the upper part of the porous insulation as frost, not as a thin layer of ice. This produced a relatively large effect; the increase in heat flow was about 3-5 percent for each percent mc by volume.[4] An ice layer would be expected to have a rather small effect; it would affect only a layer of insulation approximately equal to the volume of moisture, while the rest of the insulation would remain dry and function normally.

Tests were continued through winter seasons. The thermal resistance remained approximately unchanged through several months of subfreezing temperatures suggesting that the moisture continued to be distributed through the insulation; it did not tend to concentrate at the cold surface. The continuous monitoring provided information about moisture migration in the insulation through the fall season, as the weather became cold.

The results were, perhaps, of more academic than practical value, but added to an overall understanding of moisture effects. They reaffirm the importance of keeping insulation dry.

Effect Of Roof Application Deficiencies

Insulation joints constitute a thermal bridge.[6] The amount of heat that will be transferred through a joint depends on its width, the nature of the roof deck, and the design of the roof (i.e., conventional or protected membrane). Tests demonstrated the effect of several joints, and clearly showed the importance of design and application. Rates of transfer of heat increased by about 8 percent for a 6mm (0.25 in.) butt joint and 17 percent for a 13mm (0.5 in.) butt joint. For a shiplap joint the increase was only 1-2 percent.

In the case of protected membrane roofs, wind, snow and rain will enter the joint and affect the result. The "field-type" study allows some evaluation of wind effects by correlating measured heat flows with meteorological information about contemporary wind speed and direction.

SYSTEM EVALUATION

An entire system can be evaluated. For example, foamed-in-place urethane panels were exposed on the roof for more than 10 years. During that time the performance of the coatings was observed and the thermal performance of the insulation was evaluated by periodic measurements of heat flow coupled with the measurement of temperature difference across the insulation. Based on these data it was found that the thermal resistance fell by about 1 percent per year.

A variety of coatings were used. All of the liquid-applied coatings required regular attention, usually including reapplication after four to five years. Perforations in the coatings resulted in immediate solar attack and demanded prompt repair to protect the insulation. The only coverings that did not require repair were poured-in-place concrete and gravel. The thermal performances of specimens covered by concrete and gravel were not distinguishably different from those with liquid applied coverings.

Field observations of such systems indicate that good performance demands careful maintenance. A system in Winnipeg was observed over a period of about 10 years. It was given the necessary attention and continued to perform well. On the other hand, examples of failure were observed when the coatings were not maintained, when conditions produced moisture gain in the insulation, or when the substrate on which the foamed-in-place urethane was unstable.

The following two items are mentioned to illustrate the type of work that can be done. Tests are incomplete so detail cannot be given.

- A sandwich wall system is being tested. Heat flow through the panel, deposition of moisture in the system, and the effects of joints on heat flow are measured. The measuring system allows weighing of the entire panel in situ.
- Frame wall systems 300mm (12 in.) thick, insulated with mineral fiber to give RSI7 (R40) are being tested for moisture gain. Holes were intentionally left in the vapor retarder to allow measured air leakage into the wall. The interior humidity is controlled at the specified level. Moisture pins are used to detect changes in the moisture content of structural components in the wall.

CONCLUSION

Following are comments about outdoor testing philosophy and practice based on experience at Saskatoon.

Outdoor test facilities provide unique opportunities to evaluate the performance of roof materials and components in conditions that closely approximate those of service.

Laboratory tests often concentrate on the effects of selected variables; field tests provide a way of studying combined effects of all of the factors that normally come into play under field conditions. However, outdoor tests do not obviate the need for standard laboratory tests; they complement those tests by subjecting the specimens to conditions that are not practical, and often not possible, to simulate in the laboratory.

"Field-type" studies have a variety of uses. They may:

- Produce technical data on the performance of individual components for design use.
- Produce performance information about a prototype wall or roof system to help confirm or deny the adequacy of the system.
- Demonstrate phenomena for educational purposes.

Interpretation methods must be able to handle the conditions of the test (e.g., variability of the external conditions, possible long-term measurements, interaction of several variables).

Conditions are dictated by the prevailing weather and results may appear to be confusing. Unexpected results should not be rejected out of hand. By keeping an open mind, the observer may detect unexpected and useful conclusions that the mix of natural circumstances has produced. Serendipity plays an important role in the use of an outdoor facility.

If the test requires a wide range of weather conditions, it is necessary to wait for them to occur. For example, if seasonal effects are to be monitored, the test may go on for a year or more.

Long time periods are not always required (e.g., a thermal performance test in winter or in summer may be completed with a few days of observations).

Exterior conditions are dictated by the weather, however the ranges of test conditions can be increased in several ways:

- Local conditions can be modified (e.g., by shading from the sun or wind, by using heat traps to accentuate the heating effect of the sun).
- In some cases, tests can be repeated in a different location, with different climatic conditions. This may provide independent support for the conclusions, or may indicate the need for rethinking them.

The value of data obtained in one geographical location may be applicable in other, different climatic conditions. For example, measurements on heat flow in summer may apply in other locations in summer since both experience daily swings in temperature. The extent of the swings may not affect basic conclusions about the results.

However, if other environmental or inside conditions are widely different (e.g., if the second location is subject to high humidities which cause deposition of moisture in the building fabric), results for the two locations may not be interchangeable.

Tests of this type do not model the real world perfectly.

- Many problems in roofing are caused by improper design or poor application. Specific conditions can be copied, but the random, unpredictable variations that can occur in the field produce a level of interactive effects that cannot be simulated.
- The test facility discussed here does not have a large expanse of roof. The effects of dimension must be avoided or corrected. In some cases, the process is one-dimensional (e.g., the heat flow through a piece of insulation measured at a sufficient distance from its edge). Modeling would be a possibility, though that has not been done at this facility.

Data should be stored for future reference. Subsequent events may reveal new and unexpected uses for the data, in addition to the initial purpose.

REFERENCES

[1] Hedlin, C.P., "Calculation of thermal conductance based on measurements of heat flow rates in a flat roof using heat flux transducers," ASTM STP 885, pp. 184-202, December 1985.

[2] Hedlin, C.P., Orr, H.W. and Tao, S.S., "A method for determining the thermal resistances of experimental flat roof systems using heat flow meters," ASTM STP 718, pp. 307-321, December 1980.

[3] Hedlin, C.P. and Cole, D.G., "Effect of solar heat on moisture gains in building perimeter insulation beneath a paving-stone walkway," DBR, NRCC Building Research Note 193, 1982.

[4] Hedlin, C.P., "Effect of moisture on thermal resistance of some insulations in a flat roof under field-type conditions," ASTM STP 789, "Thermal insulation, materials and systems for energy conservation in the 80's," pp. 602-625, January 1983.

[5] Hedlin, C.P., "Heat flow through a roof insulation having moisture contents between 0 and 1% by volume, in summer," ASHRAE Trans., pp. 1579-1594, 1988.

[6] Hedlin, C.P., "Effect of insulation joints on heat loss through flat roofs," ASHRAE Trans., pp. 608-622, 1985.

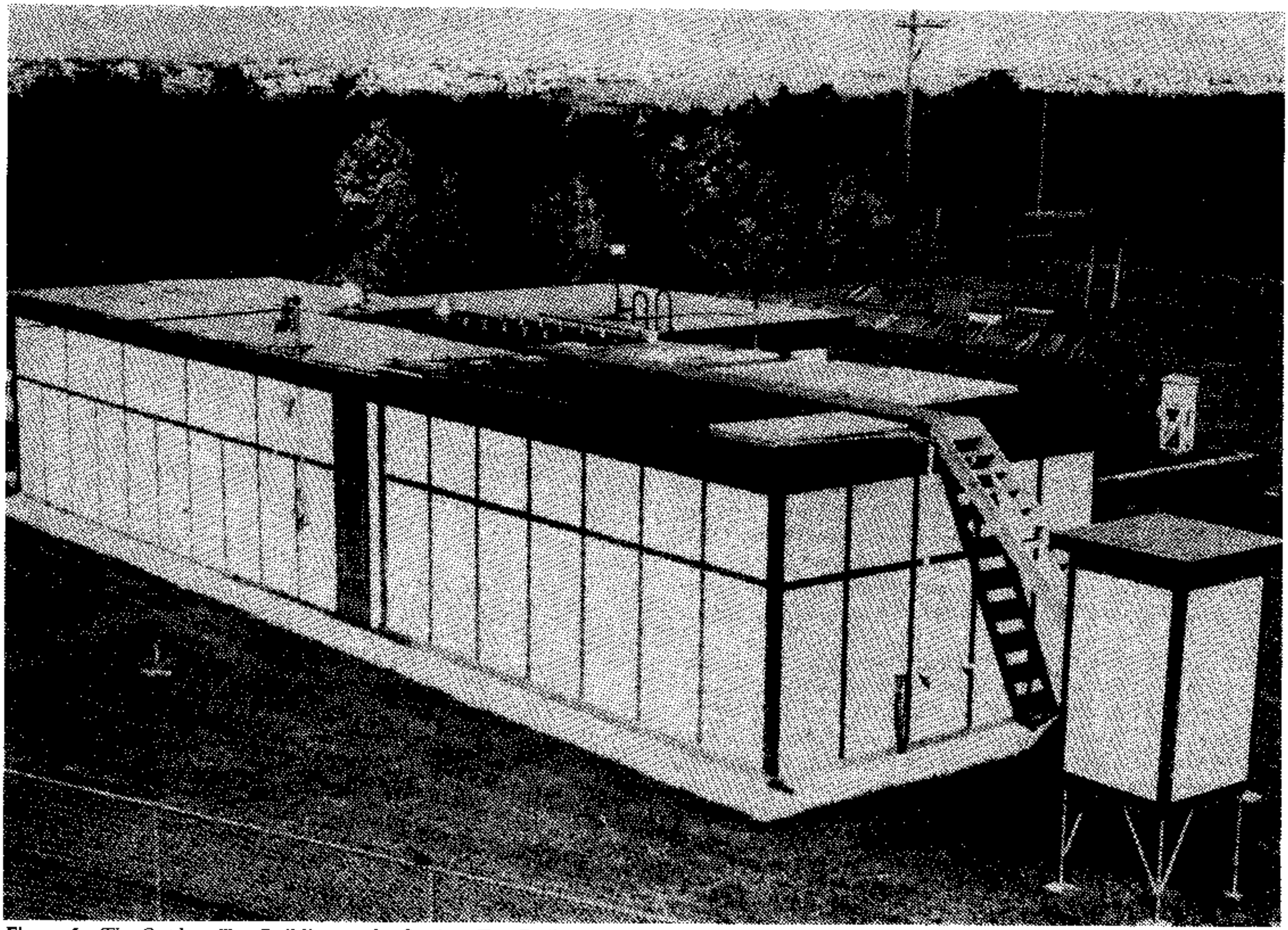

Figure 1 *The Outdoor Test Building at the Outdoor Test Facility, Saskatoon, Saskatchewan, Canada.*