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THE USE OF TEST BUILDINGS IN BUILDING RESEARCH

by

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THE USE OF TEST BUILDINGS IN BUILDING RESEARCH

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The use of test buildings is by no means a consistently good approach in research into building problems. Test buildings may be useful for certain phases of performance studies, but as in most experiments, the difficulties in arriving at sound and useful conclusions increase with the number of variables introduced. The kinds of building research studies for which test buildings are most useful are discussed, and examples given. Test buildings used in various projects of the Division of Building Research are described.

MANY PEOPLE conceive of a building research program as requiring full-scale test buildings, specially designed and instrumented for experimental purposes. In the housing field particularly, the concept of the "research house" appeals to the layman. He is likely to regard this as being at once the minimum and the maximum experiment required to prove a point. He is unlikely to differentiate between the use of an individual house, incorporating a variety of new materials and ideas, and the more realistic use of groups of houses incorporating certain specific variations. The common view appears to be that investigation of actual houses under actual conditions is a useful method of obtaining practical answers in a short period of time.

The scientist has never found this approach fully acceptable, preferring to conduct laboratory experiments under controlled conditions, followed by field application and observation. This apparent obsession of the scientist with controlled experiment is often difficult for the layman to understand, particularly in such a practical field as building. This paper suggests reasons for this attitude and discusses the philosophy of test buildings on the basis of experience gained in the building research field over the past ten years. Particular reference will be made to the Canadian use of test buildings and to the approach followed by the Division of Building Research of the National Research Council in the use of small test huts.

Tests on Full-Scale Houses

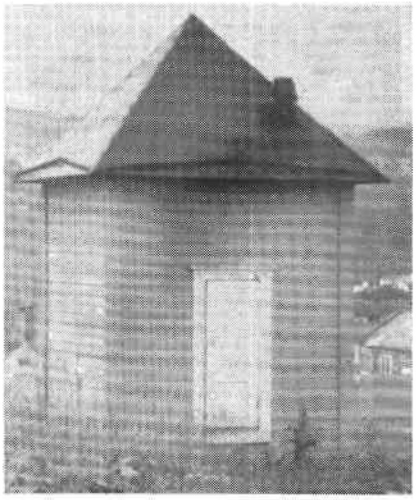
A full-scale house is, by itself, a complex arrangement of materials and components that can be described accurately only by means of a set of fairly detailed plans and specifications. The possible differences that may exist between houses, in materials, structural details, window arrangements, over-all shape and size, to name but a few variables, are almost without limit. Some of these differences may have little or no influence on the particular performance features to be investigated, but even if some facts can be established in this way, the number of features having possible influence on the result to be studied will still be large.

The variables inherent in house construction are only part of the problem; the complex effects of the exterior environment must also be considered. Wind, temperature, humidity, radiation, precipitation, and other factors that make up the weather, are all uncontrolled variables, acting sometimes separately and sometimes in combination. Some features of house performance may be related to one particular factor, but more often the combined effects of two or three factors are significant. Daily average values of outside temperature, for example, may represent a primary variable in one instance, but if freeze-thaw action is involved the related fluctuations of temperature and solar radiation become important. On the one hand the transient behaviour of weather factors may affect performance; in other cases the cyclical aspects over longer time intervals may be the important influence. Even annual weather cycles may change significantly at any one location, requiring a study to be continued over a period of several years. The weather thus not only increases the number of variables involved, but may introduce a time factor which requires that the duration of studies on actual buildings be extended to cover long periods, with corresponding increased cost.

There is yet another characteristic of full-scale house testing that complicates the situation, the question of occupancy. Occupants are normally necessary, both to simulate the actual case and for economic reasons. Although it is conceivable that the influence of the occupants on the interior environment could be duplicated artificially for certain studies, to do so in all other respects would be difficult and costly. Certainly from the economic point of view, the use of unoccupied houses in large numbers can seldom be justified. In any case, the variables introduced must still be contended with and in the majority of cases using real occupants, the differences between the various families involved must be recognized.

Two examples will serve to illustrate the marked influence which differences in the habits of occupants can have on studies in actual houses. An attempt to compare the summer comfort conditions in two occupied houses of widely different constructions failed because the differences attributable to the houses themselves were effectively masked by the uncontrolled opening and closing of windows. In another case two houses were fitted with aluminum windows and frames on an experimental basis

Fig. 1. One of the early test huts at Trondheim, Norway.

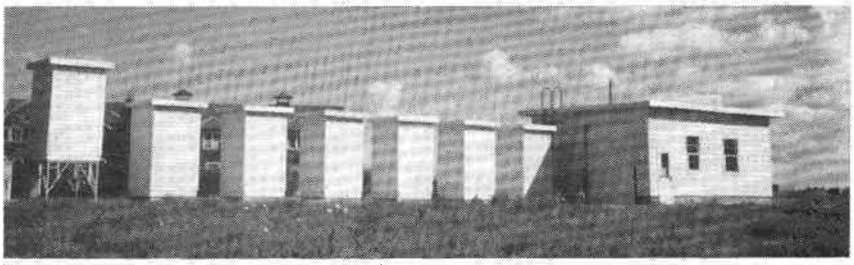


and were to be observed over one winter. The tenants in one house reported no difficulties with the windows. They did, however, ventilate the house extensively by opening windows, and dried all washing outdoors, so that the indoor humidity in winter was so low as to cause no condensation on the aluminum frames. The tenants in the second house said the windows were satisfactory but on examination after a period of cold weather a coating of as much as one inch of ice had accumulated on the warm side of the window sills, a condition that would have been quite unacceptable to many tenants. These tenants never opened windows in winter and dried washing indoors, thus maintaining a high moisture condition in the house.

Very few planned, large-scale house performance studies have been carried out in Canada. There have been, and probably will continue to be, studies on groups of a few "experimental" houses designed to demonstrate or evaluate some specific characteristics, but the results from such experiments are often of limited value. This approach was tried initially by the Division of Building Research in its early formative years, before its laboratory and other research facilities were available.

Two similar houses were built in 1947 at the Montreal Road site, as part of a staff rental housing program. These houses incorporated a variety of new materials and equipment, as well as involving one or two departures from conventional structural features. The observations made and the reports of the tenants were interesting and informative, but any conclusions that could be drawn had very limited application. Many of the features could have been studied to greater advantage in the laboratory had such facilities been available at the time. Perhaps the most significant results were to be found in the experience gained by the research workers involved.

On rare occasions an opportunity is provided in which the number of variables within a group of buildings may be reduced so as to make possible a designed experiment with a small number of samples. When such situations are recognized by interested people, useful results may be obtained with a minimum of expense. A notable example in Canada was the work of F. L. Lawton at Arvida, Quebec, in 1930 to 1935.[1, 2] The main study conducted by Lawton involved eight houses of identical plan and construction in which different insulation arrangements were employed. The houses were electrically heated, with the energy input metered accurately; the householders were co-operative to the extent of maintaining records of interior conditions. The nature of the experiment permitted the author to draw some fairly definite conclusions regarding the comparative thermal performance of the houses and to relate these to previous, less complete, investigations in a roughly quantitative manner. Even with close similarities within a group of houses, however, there were still a great many variable factors to complicate the analysis.



(Photo: National Film Board of Canada).

Fig. 2. Outdoor test station at Saskatoon showing the service building, six wood-frame test huts constructed over a service tunnel, and a standard hut on the left.

The need for statistically sound evidence from a large number of houses, under the wide range of climatic conditions and with the large number of variables to be contended with, is normally recognized by manufacturers of building products. Development departments in such organizations are continually producing new materials that must be tested to determine their suitability for use in houses across Canada. These products are tried out on a field basis in as many cases as the manufacturer can afford. When their performance has been tentatively established, they are released for sale. They therefore come to be used in a large number of houses across the country with their expected performance being confirmed or questioned through the medium of reports to the supplier. The manufacturer inevitably experiments to some degree with his customers in this way, using the information he gains to improve the performance of his product in future production.

This is the only economic method that he can utilize for no matter how much money is available for testing, it is not enough to enable him to cover all conditions to which his product will be exposed. The manufacturer's problem is really the same as the research worker's problem — he must do what it is possible to do, having in mind the requirements of the situation. The manufacturer, like the researcher, utilizes the scientific method. Observations of the performance of the product, isolation of the factors causing the effect, the development of hypothesis explaining the effect, and subsequent testing to confirm the hypothesis, summarises the procedure followed. The objective is the accurate prediction of performance, achieved through synthesis of the available information and experience.

The Use of Small Test Huts

Apart from the broad, all-inclusive field observation approach used by the manufacturer and the costly, planned statistical study of groups of experimental houses, there is another research technique that has been used with considerable success. This method involves the use of small, simple test buildings exposed to actual weather conditions. It has been used occasionally in studies of the thermal and moisture performance of building sections in North America and in the Scandinavian countries.

The first use of small test buildings for thermal studies on walls occurred in Canada in the period from 1920 to 1925, and in Norway at about the same time. Professor A. R. Greig, at the University of Saskatchewan in Saskatoon[3] compared the heating requirements of several huts of identical size, constructed of different materials. Initial measurements of electrical heat input were made, with interior conditions under manual control, but the following year automatic control was utilized. Because of the simplicity of the hut construction, not only were relative thermal values obtained but reasonable estimates of thermal coefficients of walls were possible.

Dr. Andreas Bugge[4] utilized the same basic approach at Trondheim, Norway (Fig. 1), with over 27 test huts of different construction. He later employed a technique similar in principle to the guarded hot box, which permitted the evaluation of the thermal properties of individual walls or roofs in these test structures.

Small test huts have the obvious advantage over full-scale test buildings of low cost, permitting a much larger number of units to be considered in an experiment. They need not conform to any particular shape or configuration, and may be as simple in construction as is possible while still in keeping with the design of the experiment. The variables associated with occupancy are eliminated and the restrictions imposed by the safety and health requirements of building codes are not applicable. Changes in construction features are more readily made to suit the changing demands of the experiment. Simpler structures permit simpler instrumentation. Measurement of mass and energy flow are more readily obtained and can be more easily analyzed than in complex, occupied buildings. Simpler, standardized shapes may considerably reduce the complications associated with wind and other weather phenomena.

Studies involving variations in construction, where the behaviour of individual panels under predictable exposure conditions alone is of interest, may be adequately handled in multi-panel test buildings. The test building in this case can be a simple single structure with exterior walls, roof, or floor, made up of different components or combinations of materials. The various panels are subjected to the same indoor and outdoor environment when similarly orientated and direct comparison becomes possible. Certain advantages of the "separate hut" approach in the heat and moisture flow aspect are lost, but a great deal is gained by the ease of panel removal for observation and measurement. The multiple panel test building has been used very successfully in the United States, notably at Pennsylvania State College and at the National Bureau of Standards. The method has particular advantages in the moisture performance field, representing a materials exposure approach, the test building serving only as an enclosure in which representative conditions may be maintained.

The smaller test huts are not without their disadvantages and limitations. Important characteristics of the simulated full-scale buildings are lost in size reduction. Aerodynamic simulation is impossible under actual conditions and over-all thermal and moisture storage capacity cannot be duplicated. In many fields the small test building is entirely unsuitable, such as in heating system performance studies, structural testing, foundation performance, and architectural planning, to name a few. In the materials field, however, particularly in the performance of building enclosures, the test hut has great potential, the basic problems with the method being in the selection of exposure conditions, internal and external, and in the instrumentation and processing of results.

The Use of Test Huts by the Division of Building Research

Test huts for studies in the field of thermal performance of walls were first erected by the Division of Building Research in 1950 in Ottawa and Saskatoon. At that time the Division had no laboratory facilities for thermal testing of walls and there was need for some information on the performance of newly developed materials and wall designs. In Ontario, insulated masonry construction was being proposed, and in the Prairie Provinces various new types of insulation and insulation arrangement for wood-frame construction were being introduced.

Preliminary planning for a test hut installation had been underway at Saskatoon by the University of Saskatchewan. This work led to the establishment of the Prairie Regional Station of the Division in Saskatoon, and the design and construction of an Outdoor Test Station on the campus of the university there (Fig. 2). This outdoor test facility provided an underground tunnel to permit access to six individual test huts from below (Fig. 3).

The thinking of the Saskatoon group influenced the design of the huts in Ottawa in so far as instrumentation and basic design were concerned. The huts were heated electrically to maintain constant interior air temperatures, with air circulation maintained using a fan. Initially, control of temperature only was employed, but in subsequent studies controlled humidification was added. In all cases the total energy input was measured on a daily basis and became the primary parameter of performance.

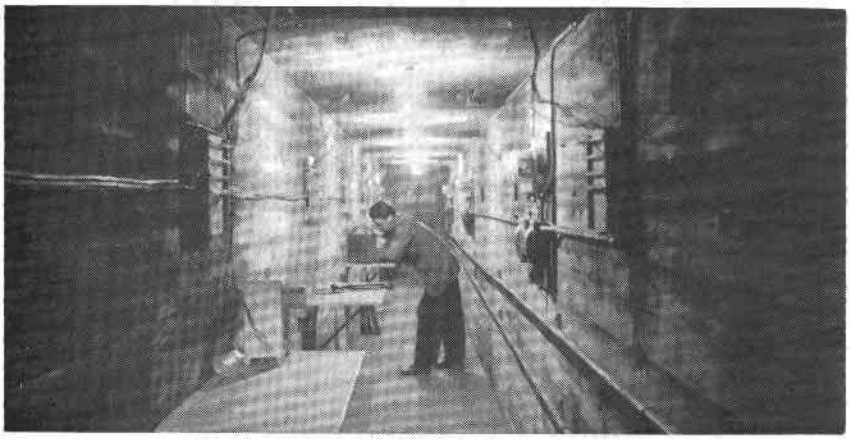
The Ottawa huts, involving unit masonry walls and incorporating variations having more significance from the moisture point of view, came to be regarded with somewhat different emphasis than those in Saskatoon. The influence of rain water absorption by masonry, coupled with the temperature-induced migration of moisture, led to studies which overshadowed the original relative thermal performance concept. The Ottawa huts came to be regarded, quite naturally, as providing a means for exposure of walls to the climatic conditions of Central Canada.

The Saskatoon installation had been specifically designed for thermal performance studies of variously insulated wood-frame walls. It had been anticipated that, in addition to overall thermal comparison between huts, correlations between heating requirements per unit temperature difference and wind velocity, as well as solar radiation, would be attempted. The north and south walls of each hut were also well instrumented for temperature and moisture content measurement in preparation for studies of transient conditions and solar radiation effects.

Enthusiasm for the test hut approach within the Division led to another development, that of using a "standard hut" as a type of calorimeter to be used in establishing climatic differences between various regions (Fig. 4). The thought was that the heat input to the test hut would be a measure of the combined effects of wind, outside temperature and solar gain on a small structure and, as such, would be indicative of the heating requirements for a particular area. Four such standard huts were erected, one at Saskatoon, Fort Churchill, Manitoba, Ottawa and State College, Pennsylvania. These huts were of insulated frame construction raised above grade level on a light metal stand, and heated electrically to maintain a constant inside air temperature (Figs. 2 and 4).

A useful comparison of the huts at Fort Churchill and Saskatoon was made during the first year of operation in 1951, and interest was stimulated by the correlation found of heat input with wind velocity. A similar

Fig. 3. View of the tunnel at Saskatoon providing access and services to the test huts above. Readings of thermocouples, power inputs and other instrumentation can be taken in the tunnel without disturbing the hut conditions. *(Photo: National Film Board of Canada).*



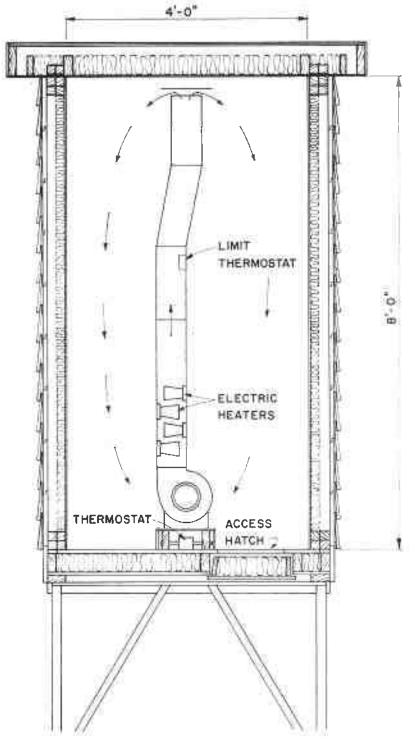


Fig. 4. Cross-section of the standard hut of the type exposed at Saskatoon, Churchill, Pennsylvania State College, and Ottawa.

analysis of records from the six Saskatoon huts was undertaken but yielded rather disturbing results. It became apparent that the Saskatoon-Churchill hut agreement was largely fortuitous, and that the effects of variable air leakage between huts made useful comparison quite difficult. Correlation of daily heating requirements with wind velocity showed not only discrepancies between huts, but for the same hut from season to season. Disturbing though this was, the magnitude of the effect on average seasonal values for the individual huts was small.

Attempts were made to determine the air leakage characteristics of the huts directly, using a pressurization technique, and later employing tracer gas methods. These tests, admittedly incomplete, failed to establish any definite relation between measured leakage and heat input versus wind characteristics. It could be concluded only that the leakage of the individual huts changed with time and resulted in a thermal loss dependent on wind direction, velocity, and temperature difference.

The gradual development of laboratory facilities for steady-state thermal studies on built-up wall sections, both in Saskatoon and Ottawa, brought the test hut approach into new perspective. At best, it appeared that the hut technique offered only relative evaluation of wall thermal properties, and this only after a considerable time. A proper average value was obtained only after one year's operation; verification might require one to two more years of operation. It thus became clear to those concerned that the huts were of value in two particular fields:

(1) Studies of the performance of components under weather conditions that could not be easily reproduced or defined in the laboratory; and

(2) Performance studies involving periodic effects, dependent as to source and cycle on natural weather conditions and seasonal frequency.

These principles guided subsequent work at the two test locations. Studies at Saskatoon concentrated on the thermal effects produced by natural ventilation of the wall cavity. The investigations in Ottawa, concerned with cyclical effects, were concentrated on the summer-winter moisture migration reversal in insulated masonry construction.

Discussion

Test buildings for use in building research may range from existing structures, built for the usual purposes without thought for research, to small simple enclosures designed for the exposure to the weather, of building materials or components. Between these two extremes there may be individual houses of unique design, groups of buildings having certain similarities, intentional or unintentional, full-scale houses differing in some singular predetermined respect, or unoccupied huts designed to obtain information on one particular aspect of performance. The main difference in each case lies in the number of variables that must be taken into consideration in evaluating the results obtained.

The vast number of existing houses that have been built in recent years provide a statistical "population" which can be "sampled" to obtain information describing the conditions of exposure of building materials and components. Records of temperature and humidity conditions indoors, fuel consumption, and foundation measurements can usually be accumulated with simple instrumentation and with the co-operation of the homeowner. In some cases, more detailed observations can be made. This information, obtained on an organized basis, can be used to define the conditions or to determine procedures for studies with small test buildings so that they may simulate the actual cases. Significant results can then be obtained with only a limited number of samples.

The utilization of these two types of "test" buildings, complementing each other, relegates the use of full-scale experimental houses to a few special cases only. It is indeed fortunate that this possibility exists, for the limited-number, full-scale experimental-house approach exhibits the disadvantages of both extremes. Almost as many of the primary variables as are involved in actual houses must be accounted for with only a token number of samples. The instrumentation and analytical techniques must be far more complex than with small-scale huts. Much more careful and extensive experimental design procedures must be followed, with little chance of subsequent changes being made except at considerable cost.

The concept of using actual buildings in conjunction with small test buildings and laboratory studies is not new, since the three progressive steps — from laboratory to pilot scale to full scale—have long been recognized as desirable in the development of industrial processes. The application to buildings is not, however, always so straightforward as in industry because of the number and complexity of the variables that enter into the full-scale building situation, thus complicating greatly the full-scale experiment.

Information relating to actual exposure conditions and to the performance of materials may be discovered either by design or by accident, in both actual buildings and in test structures. In the latter case, certain unexpected factors come to light more frequently because of concentrated and repeated observation, but information obtained through reports of problems from the field are still of great value.

Contrary to popular view, an experimental building is not always particularly useful in building research. For some purposes a building may represent but a single case from which little can be learned. In certain other cases a complete building may be the most suitable means for establishing realistically the conditions desired for study, but will seldom provide by itself an entirely satisfactory basis for experiment. Most problems can at some stage be handled best in the laboratory. There is a continuing challenge in building research to learn how best to combine laboratory and full-scale experiments in the solution of particular kinds of building problems.

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