NBSIR 85-3194

Opportunities for Full-Scale Testing of Residential Building Interactions in Environmental Chambers

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NATIONAL BUREAU OF STANDARDS, Ernest Ambler, *Director*

Abstract

Much building energy performance research has been concerned with individual components such as space conditioning equipment, controls, and building envelopes. Less work has been done on how these various components interact on the whole-building scale to determine energy use and other factors. As the understanding of component performance has increased through measurement and modelling, our lack of understanding of the interactions among these individual items has become more apparent. It is difficult to examine these interactions in real homes due to the physical complexity of homes, the uncontrollable nature of the weather, and effects of occupants. This report focuses on opportunities for full-scale testing of residential building interactions in environmental chambers, where one has control of weather conditions and occupant effects. Such research will increase our understanding of the physical nature of these interactions and their effects on energy use, comfort, cost, and other factors. In this report we review past and current research in the area of full-scale testing in environmental chambers and other related work. Based on this review, further research is proposed in several important areas of residential building performance.

Key words: building performance; energy conservation; environmental chambers; full-scale testing; residential buildings; whole building performance

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1. INTRODUCTION

The thermal performance of residential buildings is quite complex due to the interaction of building envelope components, mechanical equipment, controls, the environment, and occupant activities. While research has been conducted over the years concerning these individual elements, the study of their relation to whole-building performance is much more difficult. The interactions of the physical elements of a building, the variability of weather conditions, and occupant behavior make it difficult to isolate causes and effects when conducting full-scale field studies of residential buildings. These difficulties can be avoided by testing prototype buildings (undersized, simple structures) and actual buildings in environmental chambers where one can control, and accurately repeat, exterior weather conditions. This report discusses the potential for full-scale residential building research in environmental chambers. Several examples of past work are discussed to demonstrate the value of such research and to identify problems appropriate for chamber testing.

Many studies have been conducted in environmental chambers, benefitting from the ability to control weather conditions in these facilties. The use of prototype buildings offers the further advantage of concentrating on only those features of the building which are important to the study and avoiding complications arising from the existence of superfluous building features. Several prototype buildings have been studied in the large environmental chamber at the National Bureau of Standards (NBS) to validate the NBSLD computer model for predicting indoor temperature and space conditioning loads (Burch, Peavy and Powell 1974; Kusuda and Bean 1981). Because of the advantages inherent in this experimental approach, these studies revealed the potential for undesirable furnace oversizing when steady-state theory is used to predict heating loads as compared to calculations that consider dynamic thermal response. In addition, several energy conserving cooling strategies for use in hot climates were evaluated with a degree of detail and control not achievable in field studies of real homes.

This same chamber has also been extremely useful in infiltration studies because of the absence of wind effects and the ability to repeat tests under identical weather conditions. Although infiltration is a highly variable quantity, dependent on many factors, this research was able to establish a linear dependence of building infiltration rates on inside-outside temperature difference and quantify the contribution to whole-building leakage of various building components (Hunt and Burch 1975; Hunt, Treado, and Peavy; Silberstein 1980). The study of the contribution to leakage of specific building components, such as windows, requires infiltration measurements under identical weather conditions with and without the windows sealed. The repetitive establishment of identical conditions can be easily accomplished in a chamber but is impossible to achieve in the field. Similarly, environmental chamber testing enables evaluation of specific components on the whole-building scale through the testing of a reconfigured building under identical weather conditions. The value of environmental chamber testing has been demonstrated many times, as discussed in detail below, and great potential remains for studying additional aspects of building performance.

In addition to describing past demonstrations of the value of environmental chamber testing, other research suggestive of chamber testing is also discussed. These additional topics include full-scale testing of manufactured housing, studies of the effects of thermal mass on heating loads and thermal comfort, and research into cooling equipment performance in hot, humid climates. Based on this review of past research, several topics which merit consideration for environmental chamber testing are presented. For example, testing of prototype and actual buildings is proposed to study the interaction of building envelope characteristics, air conditioner performance, and indoor humidity control. Full-scale testing of manufactured housing is also proposed to study important issues including HVAC design, installation and control, and energy conserving construction options. The installed performance of heating equipment as it is affected by installation and building design characteristics is another area which would benefit greatly from environmental chamber testing. In addition, a reconfigurable test facility is proposed for use in chamber and full-scale testing.

2. PAST AND CURRENT FULL-SCALE TESTING STUDIES

Several studies have been done involving full-scale testing of both prototype and actual buildings in environmental chambers and exposed to outside weather conditions. In this section we review several examples of this work to demonstrate the usefulness of chamber testing and to point out specific residential building interactions requiring additional study. The review is divided into four sections, i.e. prototype buildings in environmental chambers, prototype buildings outdoors, actual buildings in chambers and actual buildings outdoors. The latter section includes only those studies of actual buildings which are suggestive of the research projects proposed later in this report.

2.1 Testing of Prototype Buildings in Environmental Chambers

There have been several studies of prototype buildings in environmental chambers to investigate aspects of building performance such as heat transfer, wall thermal mass effects, HVAC controls, thermal comfort, and air movement within rooms. The prototype buildings are very simple structures with one or two rooms, located within larger environmental chambers with controllable temperature and humidity. In this section we briefly discuss some examples of prototype testing in environmental chambers.

The first examples are tests conducted in the large environmental chamber at NBS. One case involved a masonry structure consisting of a single cell with a 6 by 6 m base and a height of 3 m (Peavy, Powell and Burch 1973; Burch, Peavy and Powell 1974). Tests were made of its dynamic thermal performance with and without wall insulation, with the insulation located on the inside and outside of the walls, with and without interior thermal mass, and with various amounts of fenestration. The tests were made under various outside temperature cycles to simulate realistic exterior weather conditions. The experiments revealed that the addition of insulation decreased the variation in interior temperature over space and time, with exterior insulation resulting in the smallest variations. Tests made with a thermostat controlling the interior temperature showed that assumptions of steady state heat transfer lead to calculated maximum heating loads 30 to 70% higher than measured under simulated diurnal weather patterns or calculated with consideration of dynamic thermal response. This finding has important implications for the sizing of heating equipment. While the test conditions differed significantly from those of realistic buildings in the field, the fact that the structure was simple, alterable, and located in a chamber with controllable ambient conditions enabled the study and understanding of several important effects.

Another building, with a high level of thermal mass, was tested in the large environmental chamber at NBS to study energy conserving cooling strategies and to validate the NBSLD computer model for predicting interior temperatures and space conditioning loads (Gujral, Clark, and Burch 1980 and 1982; Kusuda and Bean 1981). The structure in this case was a single cell masonry building with external insulation, about 6.4 by 5.2 m and 4.7 m high. Two cooling strategies were evaluated in a simulated Saudi Arabian climate. One of the schemes was continuous nighttime cooling using a ceiling mounted cooling coil. Nighttime cooling has the advantages that utility loads are low and the cooling equipment is more efficient. During the daytime, when the cooling system was off, the thermal mass of the building envelope was able to prevent overheating of the interior. The other cooling strategy was nighttime cooling using natural ventilation. Both strategies were evaluated and resulted in considerable reductions in cooling energy requirements, compared to continuous cooling of light-weight buildings, while still maintaining comfortable interior conditions. Another small prototype building was tested in the large NBS chamber to study attic condensation (Burch et al. 1984c).

A two-room test house was used to study the effects of residential HVAC controls on energy use and thermal comfort in an environmental chamber at Portland State University (Spolek and Peterson 1984). Each room was 3 by 3 m and 2.4 m high, and the structure was of standard, lightweight wood-frame construction. In these tests the chamber was cooled and the test structure was heated with electric baseboards controlled by a standard thermostat. An alternative controller to regulate heater cycling was also studied and resulted in marginal energy savings and somewhat improved thermal comfort. The main thrust of this work was to demonstrate the use of the test facility. Future work is planned with other control strategies and forced-air heating systems.

The last example of prototype testing in environmental chambers is the use of test rooms to study the effectiveness of air distribution, or ventilation efficiency, in several Scandanavian laboratories (Malmström and Ahlgren 1982; Sandberg 1984; Skåret and Mathisen 1982). The test facilities used in this work consisted of one or two small rooms with controllable ventilation rates, supply and exhaust vent locations, interior and supply air temperatures, and internal loads. These controllable conditions allowed the evaluation of mechanical ventilation strategies in terms of thermal comfort and effectiveness in replacing room air with supply air. This research has revealed the existence of significant stratification of air within spaces ventilated using techniques common in modern office buildings. Under such conditions, the breathing zones in these spaces have effective ventilation rates that are significantly lower than both the design rates and the ventilation rates required for the health and safety of the occupants. This research has provided, and continues to provide, other valuable findings which could only be obtained in these simple and controllable test facilities.

In summary, full-scale testing of prototype buildings in environmental chambers has proven to be a useful test method. The use of simple structures allows the study of specific aspects of building performance without the confounding effects of irrelevant building features. Conducting the tests in environmental chambers, where one can control climatic conditions, enables the detailed study of the effects of ambient conditions and the comparison of a structure's performance in different physical configurations.

2.2 Testing of Prototype Buildings in the Outdoors

While the testing of prototype structures in environmental chambers has the advantages discussed above, such experimental work lacks the realistic conditions of the outdoor environment such as wind, rain, and radiation effects. In order to study these effects, there have been several cases of full-scale testing of prototype buildings in the outdoors. Three examples of such research are discussed in this section. The first involves six, one-room test buildings at NBS, the so-called "thermal mass" buildings. These buildings are 6 by 6 m with 2.3 m ceilings, and are of identical floor plan and orientation. The only difference is in their wall construction, with variation in the types of materials used and in the amount of insulation and thermal mass. The structures have been used to study the effects of wall mass on heating loads and thermal comfort (Burch, Krintz and Spain 1984b). These experiments found a significant thermal mass effect on heating loads during the intermediate heating season when solar and other internal heat gains caused the indoor temperature to rise above the thermostat setpoint. The more massive buildings were better able to store this heat and use it later in the day than were the less massive structures. Also, the wall mass reduced overheating during the day, leading to improved thermal comfort. The fact that the buildings were identical except for wall construction made this study and the quantification of the results possible. Four of these structures were also used to study the effects of thermal mass on the energy savings due to night temperature setback (Burch et al 1984a). While computer simulations predicted greater savings in the less massive buildings, these measurement results exhibited too much variability to determine whether or not differences in thermal mass caused significant differences in the setback savings.

Another prototype structure exposed to the outdoors was used to study envelope heat transfer, air infiltration, and the effectiveness of an air-to-air heat exchanger (Persily 1982a and 1982b). This structure, located at Princeton University, was a single cell about 2.4 by 2.4 m and 5.5 m high. It was extremely airtight and of lightweight wood-frame construction with reconfigurable window systems. It was used to study the effects of night sky radiation on envelope heat loss and the relation of fan pressurization test results to natural infiltration rates induced by weather. The Princeton chamber was also used to determine the heat recovery effectiveness of an air-to-air heat exchanger. Because the heat loss characteristics of the chamber were so well understood, the tests enabled precise measurements of the device's heat recovery efficiency including effects of heat conduction through the device. This full-scale testing approach was more realistic than a laboratory testing approach in which the heat exchanger is installed in a system of ductwork, and provided more accuracy than would be achievable in a house with its uncontrolled air leakage and complex heat loss characteristics.

The last example of outdoor testing of a prototype structure involves the Mobile Infiltration Test Unit (MITU), constructed at the Lawrence Berkeley Laboratory (LBL), to study the predictive ability of the LBL infiltration model and to examine the physical assumptions on which the model is based (Modera, Sherman and Levin 1983). MITU is an airtight, wood-frame structure 4.9 by 2.4 m and 2.4 m high with sixteen locations available for the installation of calibrated leakage panels. The fact that the experimenters know the location and characteristics of the leaks enabled studies of infiltration that would not have been possible in an actual home, in which leakage sites are not at all well characterized in terms of location and magnitude.

2.3 Testing of Residential Buildings in Environmental Chambers

There have been a small number of full-scale tests of actual buildings in environmental chambers that have combined controlled weather with real buildings. Examples of this type of full-scale testing are described in this section.

There have been several tests of manufactured housing in the large environmental chamber at NBS (Hunt, Treado and Peavy 1976; Tietsma and Peavy 1978; Silberstein 1980). The first study considered several aspects of the thermal performance of a two-bedroom modular house with a floor area of 56 m^2. This work included studies of the part-load efficiency of the heating plant and the effect of furnace sizing on net efficiency. The latter aspect of the study required testing with three different furnaces under identical exterior temperature conditions, which could only be achieved in such a chamber. The temperature difference dependence of the infiltration rate of this modular structure was also studied and a clear linear dependence was found. Another modular house was tested in the NBS chamber in an earlier study of air leakage (Hunt, Treado and Peavy 1976). The testing included an examination of the dependence of infiltration on temperature difference and the effects of storm windows, door openings, and furnace fan operation on the infiltration rate. The fact that the tests were made in the chamber under controlled and repeatable temperature conditions enabled the demonstration of the linear dependence of infiltration on temperature difference and the unexpectedly small effects on infiltration of storm windows and the opening of doors.

A dramatic example of full-scale testing in an environmental chamber involved a full-sized, four-bedroom townhouse installed in the large chamber at NBS (Peavy et al 1975). This building was a factory produced structure of modular design with a floor area of 110 m^2. These thermal performance tests were made under simulated daily temperature cycles for two cities and with simulated occupancy patterns. The testing was designed in part to evaluate the capability of the NBSLD model for predicting maximum heating and cooling loads, interior conditions, and daily energy requirements. There were also infiltration experiments in the house that demonstrated the linear dependence of infiltration on temperature difference and revealed that leaks associated with doors and door openings had a small effect on the total infiltration rate (Hunt and Burch 1975).

Such testing of residential buildings in environmental chambers allows the detailed study of the performance of realistic structures. The fact that the tests are made in a temperature controlled chamber allows direct comparisons of different furnaces and different envelope airtightness configurations. Infiltration studies are particularly well suited to chambers where temperature effects can be examined without the confounding factors of wind speed and direction encountered in the field.

2.4 Other Relevant Research in Residential Building Interactions

In this section we discuss past and current examples of full-scale field testing of residential building interactions. This discussion is limited to that research relevant to the projects proposed later in this report, and is not intended as a complete review of full-scale testing of resiential buildings. The first example is ASHRAE SP43, "Dynamic and Seasonal Performance of Central Forced-Warm-Air Heating Systems" (Fischer et al 1984). This ongoing study, being conducted by Battelle-Columbus Laboratories, involves the testing of two unoccupied, conventional wood-frame houses typical of Midwest homes built in the nineteen-fifties and sixties. The basic goal of the research is to develop and verify a model to simulate dynamic interactions of the key components of a gas-fired, forced-air heating system and the building structure in response to weather. These components include the house structure, building envelope, furnace, air distribution system, venting system, air infiltration, and controls. Some of the equipment factors which are being varied include furnace location, combustion air source, furnace efficiency rating, furnace sizing, venting arrangement, ignition type, and control modes. As these and other factors are varied, the dynamic response of temperatures, heat flows, and gas usage are studied in order to understand the interactive processes occurring in homes. This large and long-term effort suggests similar work with other types of heating and distribution systems, with more consideration of envelope features, and involving the use of prototype buildings, along with chamber testing as a means of achieving additional experimental control.

Another important example of full-scale testing of residential building interactions is a study of duct leakage and its effects (Orlando and Gamze 1980). This study in several U.S. homes involved the development of a technique to measure the airflows involved and the effects of duct leakage on heat load. The investigators studied the magnitude of duct leakage, where the associated heat goes (i.e. how much ends up as useful heat in the living space), how the distribution system impacts furnace efficiency and operation, and the effect of the furnace fan on infiltration rates. While the research did not provide a complete characterization and explanation of the phenomena involved, it revealed some interesting results and raised many important questions. For example, this work identified increases in infiltration due to an imbalance between the supply and return flows of the distribution system and effects on furnace efficiency of lower return air temperatures due to duct leakage. As in the previous research project, this work suggests the need for additional whole building research as discussed later in the report.

There have also been several studies of manufacturer housing that have revealed important issues in this area of significant construction activity. A study at the Florida Solar Energy Center (1982) involved the side-by-side testing of two unoccupied modular structures, one constructed with standard insulation levels and the other with higher insulation levels and other improvements. This research revealed a 10% difference in energy use between the two structures and a six-year payback period for the energy conserving improvements. The addition of an air barrier in the low-energy house was found to have no effect on infiltration. Such side-by-side testing of similar modular structures has potential for use in evaluating alternative constructions and equipment selection and installation, especially when conducted in environmental chambers. Additional testing of modular structures, done by Science Applications, Inc. (1980), involved the extensive study of two buildings and included the installation of several different heating systems. This research considered several important issues in modular housing energy use including equipment type, sizing, and distribution. Several of the study's findings identified areas for additional research. These findings include rates of interior temperature change in excess of existing comfort standards, significant duct leakage, wide variation in heat delivery to registers, awkward and illogical register locations, excessive furnace noise, and inappropriate thermostat locations. Additional research into these and other issues is required, and the use of environmental chambers is an appropriate means for understanding these important questions.

There have also been studies of residential building interactions involving modelling but little or no field testing. Instances where modelling has suggested important effects of interactions between building features, or where some controversy exists as to the net results of these interactions, are candidates for full-scale experimental work in environmental chambers. One important example involves the interaction of envelope thermal characteristics, building thermal mass, and heat pump performance as they determine thermostat setback savings. The question of setback savings with heat pumps has been discussed for many years, with references being made to the importance of envelope heat loss and thermal mass. Some modelling studies have demonstrated energy savings using night setback with heat pumps (Ellison 1977; Schade 1978), while others have shown increased energy use with setback (Zabinski and Parlange 1977; Air Conditioning Heating and Refrigeration News 1977; Bullock 1978; Bartlett 1979). In all cases, the research has referred to the importance of the envelope and thermal mass, but the effects of these factors have not been studied. The whole question of setback with heat pumps has been subject to little full-scale testing. More recently, alternative control techniques were proposed to avoid large amounts of electric resistance heating during the warm-up after the setback period (Backus 1982; Benton 1983). The latter study included experiments in five homes. The experiments did show energy savings with the new controls, but did not study interactive effects associated with the building envelope and thermal mass. These building envelope issues are important to understanding this problem, and full-scale testing in chambers is an appropriate and useful experimental approach.

Another example of a problem which lends itself to full-scale testing in environmental chambers has been studied at the Florida Solar Energy Center (FSEC) and concerns cooling in hot, humid climates. The research has concentrated primarily on modelling with limited field testing in occupied and unoccupied homes. One issue concerns the interaction of cooling load (sensible and latent), air-conditioner efficiency, envelope heat transfer, and indoor humidity control (Khattar 1984; Khattar and Swami 1984). As air conditioner efficiencies increase, the ratio of sensible to total cooling of the device (SHR) also increases, and thus the control of indoor humidity may suffer. The problem arises from the fact that both more efficient equipment and improved thermal integrity of building envelopes lead to shorter air conditioner on-times. Modelling done by FSEC has shown that undesirably high indoor humidity levels can occur if the air conditioner is controlled by a thermostat alone and is improperly sized regarding its SHR. Researchers at FSEC have also done modelling and field testing of the importance of moisture storage in interior furnishings and building materials. This work has important implications for indoor humidity control and air conditioner energy use, especially when considering the use of nighttime ventilation to decrease cooling energy requirements. Humidity brought in during the night is absorbed within the house and affects daytime humidity levels, cooling requirements, and net energy use. Full-scale testing in environmental chambers would assist in the development of a more complete understanding of this issue.

3. Exisiting Environmental Chambers

In this section, several existing environmental chambers are described briefly, including some details regarding size and range of ambient conditions.

NBS Environmental Chambers

There are seven environmental chambers at NBS, ranging in floor area from about 8 to 180 m^2. The temperature within the chambers can be varied from -45 to 65 ^oC and the dewpoint from -15 to 32 ^oC. These interior conditions can be varied according to predetermined cycles to simulate diurnal patterns. Two sets of two chambers have a common insulated wall so that indoor and outdoor environments can be created to impose a differential thermal load on components such as windows or heat pumps. The large chamber has a 9.4 m ceiling and a volume of 2,000 m^3, and is capable of holding an entire house.

Portland State University Chamber

This chamber (Spolek and Peterson 1984) has a floor area of about 65 m^2 and a height of 4.9 m for a volume of about 320 m^3. It presently contains a two room test house (each room 3 x 3 x 2.5 m), and is being used to study residential HVAC controls.

Owens-Corning Thermal Research Facility

This is a large environmental chamber with dimensions of 11 x 21 x 7.6 m for a floor area of about 230 m^2 and a volume of about 1,700 m^3 (Mumaw 1980). It contains a metering pit (4 x 6 m) for testing horizontal building elements such as floors, ceiling and roofs, or more complex elements such as attics (Wilkes 1981 and 1983). The temperature within the chamber can be controlled within -45 and 65 ^oC.

4. PROPOSED FULL-SCALE TESTING RESEARCH

In this section several specific research topics are proposed for full-scale testing in environmental chambers. Some of the research is related to past and current experimental work described earlier, while other topics are based on questions posed by past modelling studies. Some of the research is proposed to address whole building interactions important to today's most pressing building research issues such as cooling in hot/humid climates, manufactured housing, and indoor air quality. The full-scale testing research includes both prototype structures and real buildings to be tested in environmental chambers, with the possibility of additional testing in the outdoors. Based on the potential associated with prototype building experiments, the design and construction of a reconfigurable test structure is proposed for use in both chamber and outdoor testing. While many of the questions discussed below have been raised previously, the determination of their quantitative significance requires additional study.

4.1 Effects of Building Design and Equipment Installtion on the Performance of Space Conditioning Equipment

This research topic is similar to ASHRAE SP43, but is meant to include other types of heating equipment and distribution systems, to give more consideration to envelope and building mass effects, and to employ controlled testing in environmental chambers. The basic thrust of the project is to understand the various ways in which the building structure, thermal envelope, heating equipment, and distribution system interact to determine the in situ performance of the space conditioning system in terms of energy use and comfort. More emphasis could be given to envelope and mass effects by using a reconfigurable, prototype building in an environmental chamber, rather than structures with constant envelope characteristics, such as those involved in the ASHRAE study. Also, the use of environmental chamber testing will enable more detailed and controlled experiments than have been possible in SP43. While ASHRAE SP43 has concentrated on gas-fired, forced-air heat, this research could include oil, electric resistance, heat pump, wood and other systems and distribution by hot water, steam, radiant panels and other means. Gas-fired steam, hot water heating, and individual room heating also merit consideration, as well as cooling equipment.

In addition to equipment questions such as sizing, design, location, venting, and combustion air source, this research would consider the interaction of the equipment with the rest of the building envelope and distribution system. These interactions include the effects of equipment, duct and register location on heat delivery and heat flow within the house, the effect of control strategies on equipment performance, and the effect of infiltration rates and internal air flows on heating performance and vice versa. The experimental design of SP43 can serve as a useful model for the development of this proposed research. The proposed project includes the study of a number of smaller issues, several of which are described below.

4.1.1 Envelope Infiltration and Combustion Appliances

The central questions of this topic are how combustion appliances affect building infiltration and how the tightness of the building envelope affects the performance of combustion appliances. The first part of the issue includes the increase in building infiltration rates due to combustion air requirements, off-cycle flows up the flue, and furnace fan operation. A small amount of data on these questions exists as part of previous infiltration studies (Shaw and Brown 1982), and some relevant modelling work has also been done (Warren and Webb 1978). Full-scale, controlled experiments are necessary to quantify and understand the issues involved. The other side of this topic is the effect of envelope tightness on combustion appliance performance due to inadequate combustion air supply under certain situations. The combinations of weather conditions, envelope tightness, and internal air flows which can cause problems need to be investigated and understood. The use of dedicated outside air supplies (i.e. sealed combustion) or other strategies for alleviating these problems also calls for full-scale testing of their effectiveness and impact.

4.1.2 Forced-Air Duct Leakage and Thermal Load Effects

This project is intended to build on the previous work by Orlando and Gamze (1980) which studied the magnitude of duct leakage in several homes. Testing of prototype structures is needed to determine the connection between the leakage location and magnitude, and the associated increase in heating or cooling loads. In addition, the effect of changes in return air temperature on space conditioning equipment efficiencies needs to be studied. The existence and effect of imbalances between the supply and return air flows is another important area where full-scale research is needed. These problems also relate to the heat flows, by conduction and convection, between the living space, the furnace location, and any other spaces where ducts are located.

4.1.3 The Relation of High R-Value Envelopes and Space Conditioning Equipment

As more homes are built with extremely high R-value envelopes, questions are arising as to the most appropriate ways to heat these structures. In such "superinsulated" buildings, the heating loads are so small that the capital cost, sizing, and efficiency of the equipment must be examined from a new perspective. High efficiency equipment may not make economic sense due to the low heating loads. It may be difficult to find properly sized equipment, and operating efficiencies may be affected by the low demand. Research is needed to study the performance of various heating systems in superinsulated homes, and to determine if and when critical points occur where particular types of equipment are no longer appropriate for specific combinations of insulation level and climate. Full-scale testing is also needed to study the creation and alleviation of previously nonexistent cooling loads in these buildings.

4.1.4 Thermal Loads Associated with Infiltration and Ventilation

The thermal loads associated with the rate of infiltration or ventilation have never been studied on the whole building scale, except for some limited tests in a prototype building (Persily 1982a). These loads are generally assumed to be directly proportional to the infiltration rate and the inside-outside temperature difference. This assumption has not been studied in the detail appropriate to its importance, especially in the area of coolings loads where latent heat is so significant. Unexpected relations between infiltration and heat loss may occur due to mixing effects of the interior air or heat transfer effects on the airstream as it flows through the building envelope. This question needs study for both uncontrolled infiltration through the envelope and mechanical ventilation.

4.2 Full-Scale Testing of Interactions in Manufactured Housing

Because of the large amount of construction activity in the area of modular manufactured housing, questions regarding the full-scale thermal performance of these structures is taking on increasing importance. Past research and experience raise many important issues for which experimental evaluation in environmental chambers would be quite useful. These include the location of ductwork, registers, HVAC equipment and thermostats, duct leakage, equipment sizing, influence of transportation on airtightness and heat loss, airtightness and insulation integrity of the connection between the two halves of double-wide units, comfort, noise, and energy conserving construction options. Side-by-side chamber testing of units with specific differences between them is one appropriate experimental strategy. Another strategy is the systematic variation of a reconfigurable modular house.

4.3 Building Envelope Characteristics, Air Conditioner Performance and Indoor Humidity Control

This project is intended to provide full-scale testing of the questions raised in the FSEC work described earlier. FSEC researchers have made calculations showing that energy efficient air conditioners, especially when installed in buildings with low thermal load envelopes, may not remove sufficient moisture to control the indoor humidity. A complete understanding of this issue would benefit from full-scale testing of prototype structures in chambers. FSEC has also done calculations, and some limited measurements, on the absorption and desorption of moisture in interior furnishings and building materials and the importance of such moisture storage in determining indoor humidity levels. This storage question is also appropriate to full-scale testing as another factor to study in this project. FSEC has done some testing in a small number of townhouses, but these studies did not include infiltration measurements that are so crucial to the study of latent cooling loads and indoor humidity. This research project should include testing of a prototype structure in an environmental chamber under different conditions of cooling equipment, control schemes, infiltration rates, envelope heat loss, and intentional ventilation strategies. Later chamber work can include interior furnishings for their contribution to moisture storage effects.

4.4 Effects of Thermal Mass, Envelope Heat Loss and Equipment Type on Temperature Setback Savings

This work follows from two research issues described earlier, the experimental work on the effects of building mass on setback savings (Burch et al 1984a) and the issue of setback savings with heat pump systems. The first project investigated the existence of differences in night setback energy savings due to thermal mass in four one-room prototype buildings which were identical except for wall construction, including insulation and thermal mass levels. Due to excessive variability in the data, it was not possible to determine whether or not a mass effect existed, although computer simulations predicted an effect on setback savings. It is possible that research in an environmental chamber could discern such an effect, and further work could be done on the effects of internal mass (interior walls, furniture). The effects of air infiltration, which is an instantaneous heat loss as opposed to conduction through a wall, must also be considered. The heat pump issue has been the subject of disagreement and characterized by a lack of consideration of the important factors of envelope heat loss and thermal mass. Again, prototype testing in environmental chambers will assist the study of this complicated issue. For example, the heat pump equipment performance is affected by sizing, controls, amount and staging of auxillary strip heat, equipment balance point, and cycling and defrosting effects, in addition to envelope interactions. Since there are so many variables that must be considered, the use of simple structures in an environmental chamber will eliminate some of the complexity and assist in achieving some understanding of the problem. Thus, we are proposing a general study of the savings possible from temperature setback with consideration of the effects of the building envelope and heating equipment, particularly thermal mass and heat pump systems.

4.5 Whole Building Performance of Mechanical Ventilation Systems

Mechanical ventilation is becoming a more popular option for ventilating homes as indoor air quality concerns increase. While the equipment is fairly well understood, the whole building performance of mechanical ventilation systems on the residential scale has not been well studied. Important questions exist concerning system design and sizing, vent location, balancing, weather effects, control strategies, heat recovery, and integration with forced-air distribution systems. Mechanical ventilation systems are being designed, installed and operated with insufficient understanding of these issues and their performance, and research is needed to provide design and operation guidelines.

4.6 Interactive Effects of Insulation Quality

The quality of the installation of insulation in a building envelope has implications for more than just the space conditioning load of the structure. The insulation quality affects interior surface temperatures, and therefore thermal comfort, which are both important considerations in thermostat settings and energy use. Also, defects in the insulation can lead to condensation problems that can cause material failures and other deleterious results. Distibution losses are also affected when ducts or pipes are installed in envelope cavities that are intended to be well-insulated. The net effects of all these factors should be studied on the whole building scale in both prototype buildings and actual homes.

5. PROPOSED RECONFIGURABLE TEST FACILITY

Many of the above projects could be studied in a proposed reconfigurable, prototype building which would provide great flexibility in testing. The structure would be roughly 6 x 6 x 3 m with replaceable wall and ceiling panels in order to enable alteration of the envelope thermal properties. In addition, the structure would have controllable infiltration and mechanical ventilation, and several different modes of heating and cooling. Such a structure, installed in an environmental chamber, would be extremely useful in all of the proposed studies of residential building interactions.

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FORM NBS-114A (REV.11-84)

U.S. DEPT. OF COMM. BIBLIOGRAPHIC DATA SHEET (See instructions)	1. PUBLICATION OR REPORT NO. 85-3194	2. Performing Organ. Report No.	3. Publication Date

4. TITLE AND SUBTITLE

Opportunities for Full-Scale Testing of Residential Building Interactions in Environmental Chambers

5. AUTHOR(S)

Andrew K. Persily

6. PERFORMING ORGANIZATION (If joint or other than NBS, see instructions)	7. Contract/Grant No.
NATIONAL BUREAU OF STANDARDS U.S. DEPARTMENT OF COMMERCE GAITHERSBURG, MD 20899	8. Type of Report & Period Covered

9. SPONSORING ORGANIZATION NAME AND COMPLETE ADDRESS (Street, City, State, ZIP)

Architectural and Engineering Systems Branch
U.S. Department of Energy
Washington, DC 20585

10. SUPPLEMENTARY NOTES

☐ Document describes a computer program; SF-185, FIPS Software Summary, is attached.

11. ABSTRACT (A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here)

Much building energy performance research has been concerned with individual components such as space conditioning equipment, controls, and building envelopes. Less work has been done on how these various components interact on the whole-building scale to determine energy use and other factors. As the understanding of component performance has increased through measurement and modelling, our lack of understanding of the interactions among these individual items has become more apparent. It is difficult to examine these interactions in real homes due to the physical complexity of homes, the uncontrallable nature of the weather, and effects of occupants. This report focuses on opportunities for full-scale testing of residential building interactions in environmental chambers, where one has control of weather conditions and occupant effects. Such research will increase our understanding of the physical nature of these interactions and their effects on energy use, comfort, cost, and other factors. In this report we review past and current research in the area of full-scale testing in environmental chambers and other related work. Based on this review, further research is proposed in several important areas of residential building performance.

12. KEY WORDS (Six to twelve entries; alphabetical order; capitalize only proper names; and separate key words by semicolons)

building performance; energy conservation; environmental chambers; full-scale testing; residential buildings; whole building performance

13. AVAILABILITY	14. NO. OF PRINTED PAGES
☒ Unlimited ☐ For Official Distribution. Do Not Release to NTIS ☐ Order From Superintendent of Documents, U.S. Government Printing Office, Washington, DC 20402. ☐ Order From National Technical Information Service (NTIS), Springfield, VA 22161	19 15. Price

USCOMM-DC 85-6006