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Multi-Year Plan for Experimental Systems Research-Passive and Hybrid Solar Energy Program

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FOR
EXPERIMENTAL SYSTEMS RESEARCH -
PASSIVE AND HYBRID SOLAR ENERGY PROGRAM

I. ACTIVITY DESCRIPTION

A. BACKGROUND

At a number of planning meetings, including the Workshop on Building Energy Research held in Carmel, California in 1983, and at various Topical Review Meetings, it was concluded that accurate measurement of the various mechanisms that affect building performance is required to gain the necessary knowledge to advance the understanding of passive solar energy technology. This understanding includes the ability to acquire data under controlled conditions to measure the thermal behavior of buildings so that the fundamental mechanism of the driving forces that affect change along with the resulting changes can be studied. This information is essential in the development of algorithms which define the relationships between the various physical elements which interact within a building and for determining the accuracy of the various simulation models developed for use in predicting passive heating and cooling performance.

To assure that the data collection effort meets the diversified needs of the passive solar program, three distinct levels of data collection have been established. The first includes the detailed data needed by researchers to determine heat transfer processes and for the development of new algorithms to characterize the behavior of innovative systems and components in buildings and for validation of predictive methods. The second includes medium level of detail needed by developers and builders for determining performance of passive and hybrid systems in occupied buildings. And finally, the third consists of a simplified level of data needed by consumer oriented groups to determine occupant reactions to innovative building designs. These levels are categorized in the passive solar program as follows:

> Class A - involving a high degree of instrumentation and a thorough evaluation of operational performance, producing detailed data in support of specific systems analyses, system studies, and design tool development tasks.
>
> Class B - involving a low-cost, "easy to install" instrumentation package - usually applied to residential or similar structures where energy flows are governed by the interaction between the exterior walls of the building and outside environment.
>
> Class C - a non-instrument survey approach.*

It should be noted that Class A data are collected under the Experimental Systems Research Program and are the focus of the material contained in this plan.

In the past few years, six Class A sites were identified with data collected for either heating or cooling. The sites and facilities are as follows:

NATIONAL BUREAU OF STANDARDS; GAITHERSBURG, MD
  Passive Test Facility

SOLAR ENERGY RESEARCH INSTITUTE; GOLDEN, CO
  Two-Zone Passive Test Cell
  Retrofit Test House

COLORADO STATE UNIVERSITY; FT. COLLINS, CO
  REPEAT Test Facility

TRINITY UNIVERSITY; SAN ANTONIO, TX
  Cooling Test Facility

NEW MEXICO STATE UNIVERSITY; LAS CRUCES, NM
  Roof Pond Test House

UNIVERSITY OF ARIZONA; TUCSON, AZ
  Cooling Test Facility

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* The Class C program has been completed. Final reports are under preparation by the SERI Solar Technical Information Program.

In addition, other test facilities exist which have the capability to collect Class A data among them being the Lo-Cal House, Small Homes Council, University of Illinois, Champaign, IL; the Florida Solar Energy Center Cooling Test Facility, Cape Canaveral, FL; the Solar Energy Analysis Laboratory (SEAL), San Diego, CA; and the Tennessee Energy Conservation in Housing (TECH) Units, University of Tennessee, Knoxville, TN. Because of the reduced DOE budget levels, only some of the Class A facilities were directly funded during FY 84 while research is being conducted at other facilities through separate funding sources.

At the inception of the program, the Class A data gathering effort was integral with the task of validating building energy analysis simulations and development of new algorithms. This overall task included model validation using analytical and comparative techniques in addition to empirical studies. In FY 84, the empirical component was separated, renamed Experimental Systems Research, and the scope broadened to include all Class A data requirements for passive solar energy research. This reorientation was developed to permit the various facilities that have the capability to collect Class A data to support all such detailed data requirements for the passive solar program. This approach has the advantage of allowing these heavily instrumented test facilities to be operated more efficiently in addition to promoting a closer coordination between users of Class A type information.

With the establishment of the Experimental Systems Research program, a comprehensive planning effort was undertaken to achieve a consensus regarding the research to be performed, the most appropriate facility to perform the research, and the funding requirements. Through a series of working meetings and exchange of correspondence, a list of candidate research areas covering both heating and cooling technologies was identified. These candidate areas were defined and ranked and a resulting list of priorities established (see Appendix A). The Multi-Year Research Plan contained herein articulates the results of this effort and details the recommended activities for Experimental Systems Research for FY 85 and beyond.

B. GOALS AND OBJECTIVES

The goal of this program is:

TO CONDUCT THE EXPERIMENTAL SYSTEMS RESEARCH NEEDED TO SUPPORT THE DEVELOPMENT OF PASSIVE AND HYBRID HEATING, COOLING, AND DAYLIGHTING TECHNOLOGIES AND TO ARCHIVE AND DISSEMINATE COLLECTED DATA AND RESULTS TO THE RESEARCH COMMUNITY.

The specific objectives of the program are stated as follows:

- To identify, collect, and evaluate, the detailed empirical data needed to support appropriate elements of the passive solar energy research program (i.e. algorithm development and validation, heat transfer, etc.).
- To continually review experimental systems research requirements to assure that the research is in consonance with the goals and objectives of each subprogram element supported and that it is performed in an effective, consolidated manner at the most appropriate facility.
- To promote a flow of technical information among experimental systems researchers including information on standardized measurement, accuracy requirements, data acquisition techniques, and innovative instrumentation.
- To collect, archive, and disseminate the experimental data in a format and manner to effectively serve the research community and others involved in passive solar technologies.

- To quantify the thermal performance of systems (as opposed to components) where such research is needed and not planned to be done in the other subprograms.

The goals and objectives listed above are general statements relating to Experimental Systems Research and are intended to form the framework for the specific research tasks conducted. To focus on the details, a goal has been included for each specific task proposed in this plan and is included with other task material in Section III, PROPOSED RESEARCH.

C. SIGNIFICANCE

Only through the understanding of the fundamental heat transfer mechanisms involved can the development of passive solar energy techniques be advanced to the degree required to make a serious impact. Although much can be learned through the collection of general data, fundamental research must be conducted in highly sophisticated facilities so that parameters can be controlled and carefully varied so that accurate algorithms, constants, and coefficients can be determined. Although Experimental Systems Research has an immediate application to algorithm development and model validation, the ultimate impact will be felt by the building community through the development of more meaningful, reliable, and accurate design tools.

For example, fundamental research performed in the past with regard to heat transfer through the building envelope has given the building community the necessary body of understanding to effectively design conventional buildings. The design of passive solar buildings, however, requires very advanced information on other factors such as radiation, convection, stratification, etc. Through analysis and carefully designed experimentation conducted under the Experimental Systems Research activity, the body of understanding of these phenomena may also be upgraded with the subsequent impact on how passive solar residential and non-residential buildings are designed.

II. STATUS OF CURRENT RESEARCH (FY1984)

Current activities related to Experimental Systems Research are being conducted at several facilities. The information being developed generally is in support of the Systems Simulation and Analysis activity and is presented below by organization. The information included under Section III, PROPOSED RESEARCH builds upon the research base developed at Experimental Systems Research facilities over the past few years.

COLORADO STATE UNIVERSITY; FORT COLLINS, CO
REPEAT Test Facility

The current research projects at the REPEAT passive solar test building are: 1) natural and forced convection in a three zone geometry, 2) natural and forced convection in a single zone, and 3) determination of heat transfer coefficients using parameter estimation. This effort is a preliminary characterization of the parameters associated with indoor air movement so that later work can more definitively study temperature and velocity profiles within the building.

The three-zone configuration, comprised of a two story sunspace, an upper north zone, and a lower north zone is a very common configuration in passive solar design. The zones are connected by doorways and the velocity of the air stream in the doorways is measured at 11 locations by a hot wire anemometer. Each doorway has its own support mounted in place, so that the hot wire can be moved easily from doorway to doorway during testing. The temperature profile of the air in each doorway is measured using thermocouples. Also measured are the interior surface temperatures of the three zones, and the air temperature profiles in each zone, using existing instrumentation. During an experiment, the data are collected by the data acquisition system, reduced in real time, and plotted.

The natural and forced convection research is aimed at determining the temperature profiles and flow patterns in a single room, and how they are influenced by the thermal boundary conditions. Direct gain rooms can have thermal storage in the floor and in a side wall, so the thermal boundary conditions include both heating from below and heating from the side. However, the former case generally is thermally unstable. Measurements of the interior surface temperatures and air temperature profiles are being made using thermocouples and recorded by a data logger. Preliminary results indicate that if the storage wall and floor are (1) at the same temperature and (2) warmer than the air and interior glazing, then the air will be well mixed and isothermal. Also, the average air temperature will be within a degree C of the average of the six interior wall temperatures.

Parameter estimation routines have been developed for three thermal models of increasing complexity. The simplest model entails a lumping of the building into isothermal zones and includes about 10 parameters for the total building. No attempt is made to define modes of heat transfer. Coefficients representing overall zonal UA values and effective zonal thermal capacitances have been determined and the model applied to the single-zone test room and the three-zone main building systems tests. The intermediate level of parameter estimation includes about 30 parameters modelling the physical elements of the building with constant heat transfer coefficients. Surface coefficients are combined coefficients in that they include both radiation and conduction. The advanced level of parameter estimation includes all modes of heat transfer separately, and involves about 60 separate parameters.

NATIONAL BUREAU OF STANDARDS; GAITHERSBURG, MD
Passive Test Facility

The NBS Passive Test Facility is a full-scale reconfigurable, single story four-cell passive solar test building containing such generic passive solar features as a direct gain system, a collector storage wall (Trombe wall) and clerestory windows. Each cell has the flexibility for multiple instrumentation configurations, and the ability to operate in a free-floating or fixed temperature mode. The entire facility contains a 500 channel data acquisition system along with a multi-channel continuous air infiltration monitoring capability. A handbook (NBSIR 84-2911; National Bureau of Standards Passive Solar Test Facility - Instrumentation and Site Handbook - June 1984) has been published describing the NBS facility, thermophysical properties of the materials and building components and sensor locations.

Some initial experimentation was conducted to monitor the performance of the direct gain and Trombe wall cells with the air temperature floating in each cell and to measure the thermocirculation characteristics of the Trombe wall. Additional experiments were conducted during the Winter/Spring months of 1984 and data collected in the test cells including ambient and cell temperature fluctuations; solar radiation; air infiltration; and auxiliary energy supplied. Information collected has been distributed to a number of experimentors and data requested from a number of research organizations in Canada and France.

Although the primary purpose for conducting this experiment was to acquire detailed performance data for model validation, characterization of passive subsystems were also developed especially with regard to the performance of the Trombe wall. A parametric analysis of the data collected during January-February and February-Masrch 1984, indicated that the Trombe wall cell performed best of the three cells in terms of its solar saving fraction and the direct gain cell consumed the largest amount of energy of the three cells while experiencing the largest upward temperature fluctuations (the lower temperatures in the cells were fixed). In addition, because of the good agreement between the data and the predicted values of the ratios of various solar radiation quantities and energy requirements, the methods to predict these quantities outlined in the Passive Solar Design Handbook - Volume Three are adequate for the parameters studied.

Work also proceeded on the validation of Slab/Ground Coupling Heat Transfer algorithms. The algorithm developed by the National Research Council of Canada was added to the NBS's Thermal Analysis Research Program (TARP) to simulate the interaction of the rest of the building with floor slab and ground on an hourly basis. Some specific data for the purpose of preliminary validation of this algorithm have been collected and the preliminary validation of this algorithm is underway. Additional experimental data are needed to complete the validation of the slab/ground heat transfer algorithm.

SOLAR RESEARCH ENERGY INSTITUTE; GOLDEN, CO
Retrofit Test House

A multizone infiltration monitoring system was developed and installed in the SERI retrofit test house as part of the Class A monitoring and validation program. This equipment is very similar to that required to implement a two-gas, two-zone air flow monitoring scheme. The required changes include the addition of a second infrared analyzer in series with the existing one, changes in the plumbing, the addition of a second gas cylinder, and changes in the control and data acquisition hardware and software. The second infrared analyzer is on order and is designed to monitor carbon dioxide (CO_2). This gas was chosen because it is readily available, inexpensive, and can be used in the unoccupied test house without concern for sinks or sources within the building. The original system used sulfur hexafluoride (SF_6), and its use will continue. The system will operate in the decay mode, as mass flow controllers have not presently been ordered. However, the system hardware and software is easily adaptable to conversion to a constant emission mode if this hardware is procured in the future.

The infrared analyzer unit is being designed to be transportable, easily reproduced, upwardly compatible with up to 6 gases and zones, and controlled by a microcomputer. The transportability feature will allow it to be easily moved to other sites. The design will be based, as much as possible, on commercially available hardware and software so that the design can be copied by others in the airflow monitoring field. The hardware and software are being designed so that the system can easily be expanded to 6 gases and zones and will be flexible enough to monitor more complicated buildings as required. The system is being designed to perform all data logging as well as data analysis and display tasks.

The SERI test house will be configured as two connected zones for the infiltration tests. The doors between the zones will be closed, and all other potential airflow paths will be sealed. One-time tracer gas tests will be performed to ensure that the two zones are sealed off from one another. Then, calibrated blower/diffusers will be installed and operated to produce known airflows between the zones and between each zone and the outside. These assemblies will be designed to simulate both the volume flow rates and the flow areas and velocities expected for a naturally convection driven airflow situation in the test house. The airflow monitoring system will then be operated and the data analyzed to estimate these airflows. The results of this analysis will be compared to the known airflow rates.

Adjustments to the experimental setup, such as placement of the sampling tubes, or the experimental procedure, such as the sampling frequency, will be performed until satisfactory agreement between the real and predicted values are reached. The doors will then be opened between the zones, and the natural convection driven airflows will be monitored. It is anticipated that pressure transducers will also be installed in the building to monitor the pressure forces driving the airflows. Complete temperature and meteorologic instrumentation is already installed in the building, so that correlations to wind vectors and appropriate temperature differences can be made.

III. PROPOSED RESEARCH

In order to determine a long range thrust for the Experimental Systems Research effort and to assure that the proposed experiments have a positive impact on the solar passive and hybrid program, a planning exercise was initiated in December 1983. The focus of this exercise was to develop a consensus among the various participants and other interested parties with regard to the research to be conducted, the facilities involved, and the funding levels required. This preliminary planning process phase culminated with a working session on June 11, 1984 and the working material synthesized into a draft report in July 1984. The initial material and perspectives generally were developed by researchers from the passive solar community with their expert knowledge focused on advancing solar technology. To broaden participation by others in the passive solar community and obtain a balanced perspective, the draft report was subsequently circulated for comment to interested building industry associations and professional societies. Although none of these comments affected the ranking of the high priority areas, additional areas for subsequent consideration were identified. The expanded list of program areas will be useful in identifying follow-on project areas when the high priority areas presented below are completed. (A description of the planning process used, the research areas initially and subsequently identified, their rankings, and the conclusions reached are presented in Appendix A.)

Although during the planning process forty-nine research areas were identified which embrace both heating and cooling technologies, the following research technologies surfaced as having the highest priority and being the most appropriate for Experimental Systems Research using Class A facilities. (These are not listed necessarily in priority order):

NATURAL CONVECTION
INFILTRATION
RADIATION/CONVECTION/STRATIFICATION INTERACTION
HVAC INTERACTIONS
EARTH CONTACT
GLAZING
SYSTEMS PERFORMANCE DATA

The research activities described below fall within the context of this high priority listing. Research activities are not recommended for all areas on the list and some activities encompass more than one high priority area. For each activity described a specific goal is presented that complements the general goals and objectives stated under Section IB. In the material that follows, only three priority activities are documented since it would be unproductive to devote time and effort to develop additional activites that realistically are well beyond the funding possibilities in the immediate time-frame. As progress is made on the higher priority areas, subsequent reviews and assessments will reveal other research areas for consideration.

The high priority research activities selected as a result of this planning exercise may be summarized below:

PRIORITY I:	AIR MOVEMENT IN BUILDINGS; SYSTEMS PERFORMANCE DATA
PRIORITY II:	SOLAR RADIATION INSIDE BUILDINGS
PRIORITY III:	INVESTIGATION OF SLAB/GROUND COUPLING HEAT TRANSFER

These research activities generally encompass the listing shown above and impact broadly the various passive and hybrid solar energy subprogram elements. A summary showing the relationships between the high priority research technologies, the subprogram elements, and the research areas selected are shown in Figure 1. It must be emphasized that the material presented herein were developed in an Experimental Systems Research overlay. These areas represent the highest priority activities to be conducted in the highly specialized Class A facilities. This plan does not suggest that analytical or comparative studies, model and algorithm development, or Class B data collection activities may be of lower priority than the collection of highly detailed empirical data. In this regard, the scope of this plan encompasses only the Experimental System Research component for the Passive and Hybrid Solar Energy activity. The details for activities such as algorithm development and validation which are analytical or comparative in nature are reflected in the individual planning documents for those solar passive and hybrid subprograms and integrated, as a total entity, in the overall Passive and Hybrid Solar Energy Multi-year Plan now under development. In this context, a detailed description of the Experimental Systems Research priority items, along with the individual goal for each, is addressed below.

PRIORITY I - AIR MOVEMENT IN BUILDINGS;
SYSTEMS PERFORMANCE DATA

Two areas were identified as Priority I activities - Air Movement in Buildings and Systems Performance Data. The Air Movement in Buildings Project is a composite Experimental Systems Research activity that addresses several high priority areas in an integrated approach with complementary work to be conducted at three Class A facilities. The activity covers fundamental research in the high priority areas of convection; infiltration; radiation/convection/stratification; and HVAC interactions. The goal of the activity is stated as follows:

Figure 1

PRIORITY, SUB-ELEMENT, TECHNOLOGY INTERFACE SUMMARY

SUB-PROGRAM ELEMENTS	Priority I: Air Movement in Buildings	Priority I: Systems Performance Data	Priority II: Solar Radiation Inside Buildings	Priority III: Slab/Ground Coupling Heat Transfer
Aperture Materials and Components	S	S	S	S
Thermal Storage Materials Research	P	P	P	P
Thermal Transport Subsystems Research	P	P	P	P
Systems Simulation and Analysis	P	P	P	P
Experimental Systems Research	P	P	P	P
Daylighting and Resource Characterization	S	S	S	S
Heat Transfer Research	P	P	P	P
Passive Cooling Research	P	P	P	P
Performance Monitoring and Evaluation	S	S	S	S
Design Tools	S	S	S	S
Technology Transfer	S	S	S	S
RESEARCH TECHNOLOGIES	Natural Convection; Infiltration; Radiation/Convection/Stratification Interaction; HVAC Interactions	Systems Performance	Radiation/Convection/Stratification Interaction	Earth Contact

P = Primary Impact

S = Secondary Impact

AIR MOVEMENT IN BUILDINGS: GOAL - To study the fundamental mechanisms relative to air movement in buildings and, once understood, to support the development of algorithms and design guidelines for use by the building community.

This activity is a collaborative effort to be conducted using the SERI Class A Test House, the CSU REPEAT Test Facility, and the NBS Passive Test Facility. In general, data will be collected to determine temperature and velocity profiles for vertical and horizontal multi-zone configurations. Because of the low velocities involved, this effort will be supplemented by a multi-gas injection system to determine the effects of infiltration on air movement. The CSU REPEAT Test Facility will generally focus on vertical multi-zone experimentation; the NBS Passive Test Facility on horizontal multi-zone studies; and the SERI Class A Test House oriented to actual house measurements and multi-gas infiltration effects. In addition, climate variables can also be assessed since the SERI Class A Test House and the CSU REPEAT facility are located in cold temperature/dry/high solar radiation locations while the NBS Passive Test Facility is in a moderate temperature/humid/moderate solar radiation environment. It is planned that: instrumentation techniques and methods will be standardized, the location of sensors and other measurement devices coordinated, and the multi-gas infiltration system shared to the extent possible. In addition, later experiments will be conducted to determine the interaction of the HVAC and the effects of radiation and stratification on the basic convective air movement. Parameter estimations will be developed to determine heat transfer coefficients which correlate such items as building geometry and thermal storage placement. Also, on a time available basis, preliminary work will be conducted at SERI to collect correlating data on natural ventilation because of the building's "real" house configuration. The above information is summarized in Figure 2.

Figure 2. Air Movement in Buildigns - Summary Information

FACILITY	AREA	APPROACH	CONFIGURATION	CLIMATE
REPEAT TEST FACILITY Colorado State University; Ft. Collins, CO	Convection; HVAC interaction; radiation/ convection/ stratification	Temp/vel profiles; Parameter estimation	2 Story multi-zone reconfigurable	Cold temp/dry/ high solar radiation
SERI CLASS A TEST HOUSE Solar Energy Research Institute; Golden, CO	Infiltration; natural ventilation	Multiple tracer gas	1 Story ranch (real house)	Cold temp/dry/ high solar radiation
NBS PASSIVE TEST FACILITY National Bureau of Standards; Gaithersburg, MD	Convection; HVAC interaction; radiation/ convection/ stratification/ infiltration	Temp/vel profiles; tracer gas	1 Story multi-zone reconfigurable	Moderate temp/ humid/ moderate solar radiation

It is anticipated that the basic thrust of this experimentation during the first two years will lead to a fundamental understanding of heat and mass transport correlations useful to the development of algorithms and simulations characterizing the air movement in buildings and perhaps setting the stage for experimentation addressing other areas such as indoor air quality. The research material developed should be of a nature allowing both the heating and cooling technology relating to air movement to be better understood. Later efforts, years 3 through 5, will be focused on supporting the development of design guidelines for use by the building community.

The associated project identified as a Priority I activity is Systems Performance Data. This project addresses a single area identified under the Experimental Systems Research high priority exercise. The specific goal for this project is:

SYSTEMS PERFORMANCE DATA: GOAL - To generate temperature and load data in passive solar buildings for model validation.

This effort will be conducted at the Solar Energy Analysis Laboratory at their Pala facility near San Diego, CA. Information will be collected relative to four test buildings: the Conventional, High Mass, Trombe Wall, and Direct Gain buildings. Data will be gathered focusing on such areas as solar radiation intensities (horizontal and east, west, and south vertical surfaces plus direct normal); weather parameters including outdoor ambient temperature and wind speed; building temperatures including shielded room air temperatures and temperatures at the surface of and within thermal storage mass; and heat extracted by chilled water loop to maintain cooling thermostat settings. In addition, data will be collected with the test buildings in the "auxiliary cooling" mode (chilled water loop operating); the "free-running" mode (chilled water loop not operating); and the "load-coefficient determination" mode (chilled water loop operating and all windows shaded).

This effort for FY 85 will be a continuation of the data collection project currently underway at the Solar Energy Analysis Laboratory. In FY 86, experimentation integrating the effects of natural ventilation are planned.

PRIORITY II - SOLAR RADIATION INSIDE BUILDINGS

The activity identified as Priority II relates to the Radiation/Convection/Stratification Interaction and interfaces with the air movement in building research described above. Specifically, the goal of this activity may be stated as follows:

SOLAR RADIATION INSIDE BUILDINGS: GOAL - To determine the magnitude and distribution of solar energy radiation inside buildings and the effects of this distribution upon the resulting heating and cooling loads.

This activity will focus on determining the distribution of solar energy radiation inside buildings in order to develop those algorithms necessary to quantify and correlate this distribution with the outside solar radiation source. This work is necessary to refine the parameters developed under the air movement in buildings activity so that the radiation component, which constitutes an element contributing to the air movement driving force, can be fully characterized. It is anticipated that preliminary research will be conducted at the National Bureau of Standards during FY 85/86 and during the FY 87/88 time frame expanded as a coordinated effort between Lawrence Berkeley Laboratory, Solar Energy Research Institute, Colorado State University, and the National Bureau of Standards. The results of this research will also be instrumental in developing design guidelines for use by the building community.

PRIORITY III - INVESTIGATION OF SLAB/GROUND COUPLING HEAT TRANSFER

The activity identified as Priority III addresses the Earth Contact area identified as high priority under Experimental Systems Research. This effort is a continuation of the work started at National Bureau of Standards and has the following goal:

> INVESTIGATION OF SLAB/GROUND COUPLING HEAT TRANSFER: GOAL - To validate slab/ground coupling algorithms for predicting conduction heat transfer through slab floors in passive solar buildings.

Earth contact heat transfer for slab-on-grade floors and basement walls and floors is a major component of the heat balance in many buildings, particularly residences, and therefore significantly affects the heating and cooling energy computation. This earth contact heat transfer is particularly important in mild southern climates zones. Existing building energy analysis simulation (BEAS) programs estimate this heat transfer in a very crude manner. A new algorithm for predicting earth contact heat transfer has been developed by the National Research Council (NRC) of Canada. This algorithm uses a small number of coefficients which are generated from a three dimensional finite element simulation for various building/ground configurations.

Although much ground heat transfer work has been and is being done at the University of Minnesota, this work is oriented toward earth sheltered buildings and ignores slab-on-grade configurations. The importance of this research has been reinforced by the Passive and Hybrid Solar Energy Multi-year Program Plan (Draft, September 10, 1984) in that earth contact research has been identified as an important passive solar technology area that is only moderately understood.

For this two year research activity, work will continue at the National Bureau of Standards through the installation of additional sensors for measuring the slab floor surface temperature and slab/ground coupling flux. Necessary data will be collected, and analysis for validating the slab/ground coupling algorithm will be completed. The data and findings will also be made available to other researchers.

OTHER CONSIDERATIONS

Although the priority activities described above are primary to understanding passive and hybrid solar technology, coordinating efforts will continue to assure that information is collected in a generally consistent mode and the resulting data archived properly. Investigations will continue toward developing a suitable archiving infrastructure so that maximum access is provided to researchers and computer code developers to applicable data collected at Class A type facilities. Such efforts will enhance the Experimental Systems Research program and provide a strong interface to the technology transfer activities for passive and hybrid solar energy.

IV. BUDGET

The funding levels required for the high priority research activities described in Section III, PROPOSED RESEARCH are shown in Figure 3. If available funding cannot fully support the levels shown, adjustments may be needed to consolidate activities, along with an appropriate stretch-out in schedule, in order to achieve the planned research objectives.

Figure 3. Experimental Systems Research - Funding Levels

PRIORITY	PROJECT	FACILITY	FY 85	FY 86	FY 87	FY 88	FY 89
I	Air Movement in Buildings	SERI	150	150	50	50	50
		NBS	150	150	50	50	50
		CSU	150	150	50	50	50
	System Performance Data	SEAL	50	50	-	-	-
II	Solar Radiation Inside Buildings	LBL	-	-	100	100	100
		SERI	-	-	100	100	100
		CSU	-	-	100	100	100
		NBS	50	50	100	100	100
III	Investigation of Slab/Ground Coupling Heat Transfer	NBS	50	50	50	50	50
	TOTAL		600	600	600	600	600

The research activity scheduling and funding levels have been phased to present an effort over the next five years that is constant with reasonable funding levels and provides the needed continuity to effectively achieve the desired technical thrust. Additional activities chosen from the high priority listing could also be conducted and provide further understanding of passive solar technology through enhanced funding levels.

V. PARTICIPANTS

The following individuals received complete information regarding the planning process and material described herein. All were invited to actively participate and many responded directly by providing input, comments, suggestions, and/or meeting attendance.

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APPENDIX A

THE DETERMINATION OF HIGH PRIORITY AREAS FOR EXPERIMENTAL SYSTEMS RESEARCH

THE DETERMINATION OF HIGH PRIORITY AREAS FOR EXPERIMENTAL SYSTEMS RESEARCH

1. INTRODUCTION

Experimental Systems Research (also called Class A data acquisition) is characterized by the collection of a large amount of integrated data involving a high degree of instrumentation, collected in a highly controlled environment using test cells and other special buildings. As such, the design of each experiment along with the data collection activities involve an extensive effort that is both time consuming and costly. In addition, these activities are highly sensitive to seasonal conditions and every opportunity must be used for the timely collection of heating and cooling data to avoid long delays necessitated by the missing of a seasonal cycle.

To assure that the effort expended on the Experimental Systems Research activity will produce the data required to understand the technology most needed to advance the passive solar program, a series of planning exercises were conducted to identify candidate research areas and to develop a consensus by those involved. The following describes the organizations involved, the methodology used to identify and prioritize research areas, and the conclusions reached.

2. CHRONOLOGY

This planning activity was initiated at a working session conducted at Trinity University in San Antonio, Texas on December 14 and 15, 1983. The meeting was attended by approximately twenty of the thirty individuals invited. The main purpose of this working session was to identify (without overall ranking or other such considerations) those project areas that would benefit by the collection of empirical data in the degree of detail and sophistication that would contribute to the advanced understanding of passive solar energy systems and included both heating and cooling technologies. Although the thrust of the projects identified were primarily aimed at collecting data for model validation and algorithm development, the scope of the Experimental Systems Research effort encompassed other areas as well. In effect, Experimental Systems Research was defined as a task to collect "Class A" data in support of the overall passive solar effort and in this scope, it was anticipated that economies could be achieved through integrated planning and data collection.

The major part of the December meeting consisted of a working session focused on defining those research areas requiring the use of specialized facilities to collect detailed data in support of the overall activities conducted for the solar passive program. The research areas which were identified were subdivided into heating and cooling technologies with the cooling technologies additionally subdivided into ventilative cooling, radiative cooling, dehumidification, earth contact, load avoidance and thermal storage. (These are summarized in Table 1.) These needs were further characterized as data required to broadly support the understanding of the fundamental mechansim of the technology or whether the data requirements were more bounded in scope and generally applicable only to a particular system. During the meeting, a brief description was developed for many of the requirements identified.

Because of the expense and time involved in travel, at the conclusion of the meeting it was decided to continue the planning process by mail. On January 11, 1984, a memorandum was sent to all participants documenting the information developed during the December San Antonio meeting. The participants were requested to review the material carefully since the research areas identified would form the basis for the subsequent efforts of evaluating and prioritizing the Experimental Systems Research activities. In addition, a number of resource documents were transmitted in order to aid and expedite the review.

Comments received from the participants were generally in agreement with the notes transmitted in the January 11, 1984 package. A few changes were suggested for combining some of the identified program areas and several changes were suggested to modify, expand, or clarify the project descriptive material. Even after the changes were made, it was recognized that the overall material was not uniform in content, some definitions were incomplete or not developed, and some redundancy existed between definitions. Nevertheless, despite the problems noted the material was in reasonable form to be used as the basis for the exercises conducted subsequently.

A memorandum was transmitted to all participants on March 6, 1984 which included a summary of all comments received and an updated list of research areas along with a set of refined definitions. In total, forty-nine areas were identified. (This information is shown in Table 2.) In addition, a format was developed along with instructions for ranking the identified projects. The instructions requested each recipient to apply the prioritization criteria which reflected his own integrated view of the Experimental Systems Research needed to advance the understanding of passive solar technology and to indicate which passive program element(s) would be directly affected or impacted by this research. This approach was necessary because the geographical dispersion of the respondents and the time constraints imposed prevented the development of a formal list of ranking criteria that would be concurred with and understood by all. Completed ranking information subsequently received were tabulated and analyzed and are presented in Section 4, RESULTS.

3. PARTICIPANTS

A number of organizations were invited to participate in this exercise, and individuals from the following institutions were actively engaged in the development of the Experimental Systems Research project areas, subsequent refinement, and initial prioritization.

Department of Energy - Headquarters

Department of Energy - Chicago Office

National Bureau of Standards

Lawrence Berkeley Laboratory

Colorado State University

Trinity University

University of Texas

Los Alamos National Laboratory

Solar Energy Research Institute

Solar Energy Analysis Laboratory

Florida Solar Energy Center

Energy Technology Engineering Center (Rockwell International)

The MEMPHREMAGOG Group

In addition, in an effort to expand participation, other organizations were invited to share in this process and information was sent to them for review and comment. They are:

American Institute of Architects Foundation

American Consulting Engineers Council

American Planning Association

Architectual Energy Corporation

American Society of Heating, Refrigerating and Air-Conditioning Engineers

American Society of Mechanical Engineers

Building Energy Design Tool Development Council

Lighting Research Institute

Manufactured Housing Institute
Masonry Research Foundation

National Concrete Masonry Association

National Fenestration Council

The review process by these other organizations surfaced some project areas not considered in the initial ranking. (These areas are shown below under ADDITIONAL PROJECT AREAS). It was generally concluded, however, that these project areas should be considered as follow-on candidates to be conducted after the completion of the high priority projects described in this plan.

4. RESULTS

After receipt of individual comments and ranking lists, a summary of research area rankings representing all information received is shown in Table 3. Research areas are listed by reference number (1 to 49) and individual rankings indicated for each project. (The reference number directly key to the List of Research Areas shown in Table 2.) All respondents generally used a 1 through 49 ranking index with 1 being the highest rated area. One set of rankings, however, were coded 10 through 1, where 10 represents the highest priority area. A distinctive marking is used on Table 3 to distinguish this different scaling. In addition, those areas in the upper 20% of the scale have been highlighted for emphasis. Also indicated on Table 3 is the project technology (heating, cooling-ventilative, evaporative, etc.). It should be noted that in preparing Table 3, no attempt was made to combine, consolidate or eliminate any area.

After analysis and review of comments received, Table 4 was prepared using the same data and format as Table 3. Consideration this time was given to problems encountered with the original List of Research Areas shown in Table 2 since many areas could be consolidated; some were sub-sets of other areas; some areas overlapped other areas, etc. In effect, this new grouping has reflected these changes and has also by consensus, surfaced those areas that could be considered high priority candidates for

Experimental Systems Research. As a by-product, the review process also identified those research areas that, if required for passive solar understanding, perhaps should be conducted in non-Class A data acquisition facilities.

5. CONCLUSIONS

Based on a review of Table 4, the highest priority activities for Experimental Systems Research activities lie in the following areas (not necessarily listed in priority order):

Natural Convection
Infiltration
Radiation/Convection/Stratification Interaction
HVAC Interaction
Earth Contact
Glazing
Systems Performance

These areas generally encompass the study of fundamental mechanisms as opposed to component and systems studies and include both heating and cooling.

6. ADDITIONAL PROJECT AREAS

During the review process, several of the industry and professional organizations suggested additional project areas not included in the initial project area listing. Since they were submitted in a later time frame during the planning process, they were not formally ranked, however, it was concluded that these areas were generally of a lower priority than those areas selected for immediate implementation. They are, of course, candidates for follow-on activities to be conducted after the completion of the high priority projects described in this plan. The areas are documented below, for the record, to be included in any subsequent planning exercises for Experimental Systems Research.

Effects of Trees and Shrubs on the Building Heating/Cooling Load
Evaluation of Skylight Performance
Inddor Air Quality/Natural Convection
Innovative Glazing
Innovtive Roofs and Walls

Several of the other areas suggested were already included in the initial project area listings and are not repeated above.

Table 1

LIST OF HIGH PRIORITY RESEARCH AREAS
(UNPRIORITIZED)

HEATING TECHNOLOGIES

INTERZONE COUPLING (VERTICAL AND HORIZONTAL)

STRATIFICATION

INTERNAL DISTRIBUTION OF RADIATION

SURFACE CONVECTION COEFFICIENTS

GROUND COUPLING

INNOVATIVE GLAZING

INNOVATIVE ROOFS/WALLS

STRUCTURAL CAVITY STORAGE

PHASE CHANGE MATERIALS

INTEGRATION/INTERACTION WITH MECHANICAL SYSTEMS (CONTROLS; LOAD MANAGEMENT)

MIXED PASSIVE SYSTEMS

ZONE HEATERS

RADIATION WITHIN ENCLOSURES (INFRARED)

GUARDED HOT BOX

THERMOSYPHON AIR PANEL SYSTEMS (TAPS)

RADIANT HEATING PANELS

AIR-TO-AIR HEAT EXCHANGERS

COOLING TECHNOLOGIES

VENTILATIVE COOLING

*CONNECTIVE TRANSFER COEFFICIENTS INSIDE BUILDINGS

*FLOW RATES AND FLOW DISTRIBUTIONS

*INTERZONE HEAT TRANSFER

*INFILTRATION EFFECTS

*STRATIFICATION

FIELD TESTING OF INNOVATIVE SYSTEMS

FIELD TESTING OF AIR CORE/VENTILTED MASS COOLING

HVAC SYSTEMS INTERACTIONS

EVAPORATIVE COOLING

DIRECT AND INDIRECT EVAPORATIVE SYSTEMS PERFORMANCE

PERFORMANCE OF OPEN EVAPORATIVE SYSTEMS

DISSIPATOR/STORAGE COUPLING TO INTERIOR SPACE

INNOVATIVE DISSIPATOR PERFORMANCE

*ALGORITHM DEVELOPMENT

DIFFUSION/OSMOSIS/ABSORPTION

MATERIALS DEGRADATION

RADIATIVE COOLING

*EXTERIOR COUPLING ELEMENTS

*RADIATION/CONVECTION INTERACTION

*SOLAR RADIATION AND SURFACE ORIENTATION

RADIANT DISSAPATORS

DEHUMIDIFICATION

MODELING OF SOLID AND LIQUID DESICCANT SYSTEMS AND COMPONENTS

SYSTEMS PERFORMANCE AND CONTROL OF DEHUMIDIFICATION SYSTEMS

*MOISTURE BALANCE ALGORITHMS FOR MATERIALS

*COMFORT STANDARDS

INTERFACE WITH MECHANICAL SYSTEMS

EVAPOTRANSPIRATION OF PLANTS

EARTH CONTACT

EARTH COOLING TUBES

*THERMOPHYSICAL PROPERTIES

*SLAB/EARTH CONTACT MODELS

*EARTH HEAT TRANSFER MODEL

SURFACE TREATMENTS

LOAD AVOIDANCE

GLAZING SYSTEM PERFORMANCE

THERMAL MASS/SOLAR GAIN/HVAC SYSTEM INTEGRATION

RADIANT BARRIERS

MOVEABLE INSULATION/SHADING

THERMAL STORAGE

*COUPLING COEFFICIENTS TO STORAGE ELEMENTS

PRESSURE DROP THROUGH STORAGE ELEMENTS

*PHASE CHANGE MATERIALS

SELECTIVE SURFACES

*FUNDAMENTAL MECHANISMS FOR COOLING TECHNOLOGIES

Table 2
List of Research Areas

1. <u>INTERZONE CONVECTION (VERTICAL/HORIZONTAL)</u>

Air flow from zone to zone will be considered. Smoke, hydrogen bubble or other flow visualization techniques should be used to define the energy transfer coefficients from zone-to-zone. Both vertical zoning (floors) and horizontal zoning (rooms) should be investigated. In addition, heat transfer coefficients must be measured or estimated in order to define the heat transfers to the air as it circulates through the zones. These should be used to establish design guidelines for location and sizes of openings.

2. <u>MULTIZONE INFILTRATION</u>

The measurement of the air flow rates, including interzonal, infiltration and exfiltration will be performed in a multizone building. Measurements of pressure differences and driving functions, temperature and wind, will also be included. These measurements can be used to validate air flow models, and to provide inputs needed to validate general building energy analysis simulations.

3. <u>INTERACTION BETWEEN RADIATION, CONVECTION AND STRATIFICATION - SINGLE ZONE</u>

The different modes of heat transfer should be examined in a "systems" sense (i.e. the interactions between the modes will be studied). For example, stratification will cause the ceiling to gain heat which will increase the temperature of the ceiling. The increased temperature of the ceiling will result in increasesd radiative heat transfer to the walls and floor which in turn may increase the convective heat transfer to the ceiling. The overall effect would lead to the understanding of the complicated interaction between all modes of heat transfer. This is preparatory work in studying these effects in a multizone investigation (see 4. below).

4. <u>INTERACTION BETWEEN RADIATION, CONVECTION AND STRATIFICATION - MULTIZONE</u>

Same as "Interaction Between Radiation, Convection, and Stratification - Single Zone" (See 3. above) - existing in multizone situations.

5. <u>SOLAR RADIATION (INTERACTION BETWEEN SPLIT, SHADING, DISTRIBUTION)</u>

To better calculate the following solar radiation quantities:

a. Incident on surfaces of varying orientation

b. Incident on windows and shaded surfaces of varying orientation

c. and transmitted through glazings and distributed on internal surfaces.

it is necessary to statistically understand the distribution of diffuse solar radiation in the sky dome under varying conditions of clearness. These data will lead to the validation of or development of more accurate sky models, and consequently better calculation of the solar radiation incident on and within buildings.

6. HEAT LOSS THROUGH THE GLAZING PORTION OF THE ENVELOPE

This is defined as the total heat loss/gain through the glazing envelope of a building by radiation, conduction and convection. There is a need to measure: convective heat transfer coefficients both external and internal, and the optical and thermophysical properties of glazings. Other investigations include: number of glazing layers and spacing (air gap) between the layers. Investigation could include side-by-side testing of components in a calorimeter while measuring the systems performance of identical components coupled to a room.

7. ACTIVE CHARGE/PASSIVE DISCHARGE THERMAL STORAGE SYSTEMS

Measure system performance of thermal storage systems that are charged actively by forced convective heat transfer and discharged passively by conduction, convection, and radiation to the occupied space. Included are: rock beds, air-core floors, and air-core walls. Temperature and pressure drop data are required to calculate critical heat transfer coefficients and to validate analytical algorithms.

8. INTERACTION OF SOLAR DRIVEN NATURAL CONVECTION WITH FORCED-AIR HVAC SYSTEMS

The impact of forced air heating systems with the free convection between zones needs investigation. In effect, the heating registers create local pressure differences which interact with the single-zone recirculating boundary layers and with the free convection air movement from zone-to-zone. The impact upon comfort will also be calculated (i.e. setting the heating register to discharge upon the window will increase the comfort but will also increase the energy loss). Included in this investigation is the balance between comfort and energy usage through the application of appropriate control strategies.

9. RADIANT SOLAR FLUX DISTRIBUTIONS IN SUNSPACES

Detailed measurements will be made of the radiant solar flux distributions on the interior surfaces of sunspaces to support the validation of models that have been recently developed. These models, which are particularly powerful in analyzing sunspaces and atruims, provide for detailed treatment of the beam and diffuses radiant energy with regard to internal shading, reflection, and possible retransmission but have not been verified experimentally.

10. FLOOR SLAB/GROUND COUPLING

Detailed measurements will be made of earth contact heat transfer for slab-on-grade floors with special attention paid to the asymetric solar heating of floors in direct gain spaces. These data are needed to verify state-of-the art predictive techniques such as the method developed at the National Research Council of Canada.

11. CONVECTIVE HEAT TRANSFER COEFFICIENTS INSIDE BUILDINGS

Determine the rate of heat removal from warm building structural surfaces to cool ventilation air. The air movement mechanism can be representative of 1) mechanically driven (fans), 2) wind-driven, or 3) buoyancy-driven ventilation. The geometry can be representative of a wide range of building configurations, including: exposed massive walls, plenumed mass, and hollow-core concrete.

12. FLOW RATES AND FLOW DISTRIBUTIONS

Determine the air velocity distribution within the building occupied space under ventilation air flow conditions. Air movement can be due to forced or natural convection. Air velocities will be dependent on building geometry and the nature, strength, and direction of the driving force.

13. INTERZONE HEAT TRANSFER

Determine the rate of convective heat transfer between building zones and its effect on the performance of the building ventilative cooling system. Interzone air flow can be due to forced or natural convection.

14. INFILTRATION EFFECTS

Infiltration as a function of change in temperature and velocity should be studied. This includes infiltration from the outside environment as driven by the wind and other forces as well as interior infiltration between building rooms and zones.

15. STRATIFICATION

The effects of stratification on air movement and heat transfer should be investigated to determine the effects of temperature gradiants in passive solar design. If stratification is a sensitive parameter, then strategies to investigate its effects should be developed.

16. FIELD TESTING OF INNOVATIVE SYSTEMS

Field test innovative ventilators, such as cowls or cupolas. Performance should be characterized in terms of induced air flow rates and flow distribution in the space as functions of wind speed and direction and control strategies.

17. FIELD TESTING OF AIR CORE/VENTILATED MASS COOLING

Determine the performance of air core, ventilated mass cooling systems such as hollow core concrete floors or concrete block walls. Characterize in terms of: climate, control strategies, return or supply side storage, parasitic power, and system COP; and measure performance in terms of: each component of parasitic power, overall system COP, and cooling effect.

18. HVAC SYSTEMS INTERACTIONS

Determine and characterize the interactions between HVAC systems and ventilative cooling systems. Control fan systems using outside air, and wind or stack driven natural ventilation systems (or combinations thereof) are to be considered. Parameters of interest include humidity control, control systems, control of operable sash, and climate optimization.

19. DIRECT AND INDIRECT EVAPORATIVE SYSTEMS PERFORMANCE

Determine the performance of direct and indirect evaporative systems (and combination thereof). This task includes the determination of part load and design condition performance in terms of system COP, heat exchanger effectiveness, water consumption, fan energy, etc. Integration with auxiliary cooling provided by the conventional HVAC system is included, as are multi-stage processes. Investigation of control strategies is also included.

20. PERFORMANCE OF OPEN EVAPORATIVE SYSTEMS

Determine the performance of spray pond, trickle roof or sprayed roof cooling systems. Performance is to be characterized by system COP and water consumption. Parameters of interest are control strategies, climate effects, and coupling with the space air.

21. DISSIPATOR/STORAGE COUPLING TO INTERIOR SPACE.

Determine the coupling relationships among evaporative dissipators (e.g. sprayed roofs, roof ponds), thermal storage, and the space air. Coupling mechanisms such as fan coil units, radiative panels, etc. will be considesred. Measurements of heat fluxes, air or water flow rates, and temperatures are required.

22. INNOVATIVE DISSIPATOR PERFORMANCE

Roof pond system performance is well characterized. Other promising radiant dissipators are not well characterized. Some of these have the advantage of compatibility with conventional architecture. Examples are the convectively coupled plenum roof (no movable insulation required) and the nocturnal trickle roof (retrofittable). (Note that in all but arid climates the trickle roof actually dissipates most of its heat through radiation, not evaporation). This work would:

a. Measure performance of air plenum radiant dissipator roof(s) in sufficient detail and in wide enough range of conditions to serve as validation data for algorithm/subroutine.

b. Same as above for trickle roof.

23. ALGORITHM DEVELOPMENT

Algorithms which describe the performance of evaporative cooling processes are not well defined for some phenomenon. Of particular interest is the performance of droplet versus film evaporative systems in heat exchangers and mass and heat transfer rates in falling water systems. Spray ponds and cooling towers in which the water is used as both the dissipator and thermal storage medium are examples of the phenomenon. This work would:

a. Survey existing (rich) literature on heat/mass transfer data applicable to (1) wet surface compact air to air heat exchanger (e.g. indirect evaporation coolers) and (2) spray ponds.

b. Identify state of the art in existing data. If sufficient applicable data exists, develop generalized algorithms for indirect evaporation and spray cooling sytems. If sufficiently advanced or applicable data are not yet vailable in spite of long history of such measurements, make the measurements.

24. DIFFUSION/OSMOSIS/ABSORPTION

Moisture migration in and through building envelopes is not well modelled or understood in many cases. Certain membranes may have the potential to function as moisture valves moving moisture in only one direction. This potential should be explored. In addition, building moisture balance algorithms as they currently exist are crude at best. Only a limited amount of information exists on the absorption and desorption rates of building materials and furnishings. Under conditions imposed by passive cooling systems moisture condensation can become significant. For example, a night-only ventilated building in a humid environment will store some amount of moisture which must be removed later. The adsorption and desorption rates under such conditions become critical analytical parameters. This work would:

a. Review existing literature and determine material characteristic data base which is available.

b. Perform experimental validation studies in full scale (room sized) enclosures with sufficient detail to provide model validation data.

c. Incorporate moisture diffusion algorithms in thermal modellilng routines and perform parametric sensitivity studies for various climates.

25. MATERIALS DEGRADATION

Includes the studies of molds, mildew, and corrosion and establishes limiting conditions and thresholds to prevent these adverse effects in a passive solar environment. This scope excludes human comfort covered under dehumidification.

26. EXTERIOR COUPLING ELEMENTS

Includes the effects of ground temperature and diffuse sky radiation on the exterior building envelope and the resulting forces contributing to interior temperature changes and air movement parameters.

27. RADIATION/CONVECTION INTERACTION

Includes the study of radiation barriers and addresses the effects of such elements as attics, cavity walls, and radiation panels on indoor temperatures and air velocities.

28. SOLAR RADIATION AND SURFACE ORIENTATION

The effects of solar radiation and surface orientation should be studied in depth to determine the effects of the beam/diffuse split and diffuse distribution as driving forces in a passive solar structure.

29. RADIANT DISSIPATORS

The performance of radiant dissipators will be studied under different configurations and conditions. Included are such dissipators as roof systems, panels, and walls that have potential for use in passive solar buildings.

30. MODELING OF SOLID AND LIQUID DESICANT SYSTEMS AND COMPONENTS

Modeling of solid and liquid desicant systems and components will be studied to advance the heat/mass transfer understanding. In addition, the effects of contaminants on system performance will be reviewed as applicable to passive solar systems.

31. SYSTEMS PERFORMANCE AND CONTROL OF DEHUMIDIFICATION SYSTEMS

Included in the study of systems performance and control of dehumidification systems is the operation of these systems under full and part load conditions leading to the development of effective dehumidification control strategies and techniques.

32. MOISTURE BALANCE ALGORITHMS ON MATERIALS

A study of the effects of moisture on the various materials used in passive solar construction and application will be made including the impacts of mold and mildew. Moisture balance algorithms will be developed, as appropriate, to characterize the performance of these materials under a variety of conditions.

33. COMFORT STANDARDS

Studies are needed to develop a framework for comfort standards applicable to passive solar designs. Included is the determination of dew point versus relative humidity limits, air movements, and pathogenic limits.

34. INTERFACE WITH MECHANICAL SYSTEMS

Passive solar systems generally depends on natural convection to provide air movement within the enclosed spaces. These systems are supplemented by mechanical systems to provide the necessary auxillary energy required to maintain human comfort. This project area studies the interface between the natural and mechanical systems to determine applicable design concepts and control strategies.

35. EVAPOTRANSPIRATION OF PLANTS

Includes the characteristics and effects of plants on energy balance. This is an issue that also pertains to passive heating by an attached sunspace. The moisture itself is not necessarily a problem in the winter but the effect of the latent heat of evaporation probably is important.

36. EARTH COOLING TUBES

Earth contact cooling tube systems have been tried over the years using various materials (Plastic tubes, red clay pipe, concrete pipes, etc.). These systems have had varying degrees of success and some have been documented to a degree. A complete literature search is definitely in order to accumulate and quantify what is known versus just assumed. (Some design guidelines may be available also.) The problem seems to be basically associated with the thermophysical properties of the various soils. The resource is fairly well known i.e. soil temperature, density, BTU's available on a gross basis.

It seems like what isn't known is how to quantify systems to utilize the resource. Design guidelines and algorithms need to be developed and tested out to aid in optimizing system designs. Earth contact systems testing must consider:

a. Various soil types in accordance with standard civil engineering categories.

b. Soil moisture measuring techniques (ones that don't in and of themselves cause moisture migration).

c. Air flow rates through pipes.

d. Pipe lengths, diameters and arrangements to keep pumping power down and heat exchange rates up.

e. Moisture/mold problems (dehumidification of the air).

f. Soil surface treatments in various climates to enhance the system's operation.

g. Integration of earth pipe systems with conventional systems (controls, etc.).

37. <u>THERMOPHYSICAL PROPERTIES</u>

The thermophysical properties of soil should be determined as applicable to passive solar building design. Soil property measurement should be conducted and characterized as a guide to designers and engineers.

38. <u>SLAB/EARTH CONTACT MODELS</u>

Slab/earth contact models are needed to define the physical attributes at that interface. Included are vertical and horizontal slabs and two and three dimensional models. In addition, simplified corner effects should be studied to develop the necessary algorithms for a more representative model.

39. <u>EARTH HEAT TRANSFER MODEL</u>

Includes the synthesis of an earth heat transfer model operating in a solar passive context and based on appropriate algorithm development and validation. The earth heat transfer model should interface and complement other models developed for passive solar energy.

40. <u>SURFACE TREATMENTS</u>

Surface treatments to enhance the overall performance of passive solar systems should be studied. Included in the studies are such elements as the effectiveness of the Givoni Concepts and the desirability of long term seasonal storage.

41. <u>ADVANCE GLAZING SYSTEMS</u>

New materials should make it possible to admit visible light, reject infrared and prevent conduction. Example: "Aerogel" with heat mirror coating on the exterior. An approach would be to measure the daylighting and thermal transfer performance of new glazing systems.

42. <u>THERMAL MASS/SOLAR GAIN/HVAC INTERACTION</u>

The flywheel effects of building mass (particularly in non-residential buildings) can have both positive and negative effects on total cooling energy. Result depends on climate, whether night flush is used and magnitude of internal load. The approach would:

a. Simulate effect in various climates, building types, operating modes and identify most sensitive types.

b. Measure effects in non-residential building program.

43. RADIATIVE BARRIERS

Collect, evaluate, and consolidate laboratory and field data (Class A Level) on temperature and heat fluxes in attic spaces and wall cavities that include radiative barriers. Determine cooling load reduction effect of radiative barriers for both sloped and flat roofs and for walls.

44. MOVABLE INSULATION/SHADING

Collect field data showing the cooling load reduction for several types of external and internal shading devices and for movable insulation.

45. SYSTEMS PERFORMANCE DATA

System performance data are required to validate systems models and design guidelines. The data should include cooling energy requirements for full-scale passive buildings with various combinations of window areas and orientations, interim mass, and passive solar heating components.

46. COUPLING COEFFICIENTS TO STORAGE ELEMENTS

Thermal storage systems are viable methods for application in passive solar energy systems. To fully understand the performance of these systems in passive solar buildings, the coupling coefficients between the surrounding air and the storage system must be understood and determined for both thermal storage and thermal retrieval.

47. PRESSURE DROP THROUGH STORAGE ELEMENTS

Since natural convection is a prime mechanism of heat transfer and heat transport in solar energy systems, thermal storage elements by nature of their configuration and placement form resistance paths impeding air flow. This study should determine the pressure drops associated with these thermal storge elements and include such items as structural cavities, rock beds, and interior surfaces.

48. PHASE CHANGE MATERIALS

Phase change materials have the potential for saving storage space and have the advantage of operating in an isothermal mode. As such, the operational potential of these devices should be studied to determine the internal heat transfer and conductivity and to characterize these devices with regard to applicability for use in passive solar structures.

49. <u>SELECTIVE SURFACES</u>

Selective surfaces will be studied in conjunction with thermal devices as they can be applied to passive solar buildings.

COOLING																		
THERM STORAGE	LOAD AVOIDANCE	EARTH CONTACT	DEHUMIDIFICATION	RADIATIVE	EVAPORATIVE	VENTILATIVE	HEATING	REF. NO.	TITLE	INDIVIDUAL RATINGS								REMARKS
							X	1	Interzone Convection (Vert/Horiz)	2	1	1	2	24	3	10	6	
							X	2	Multizone Infiltration	17	2	3	39	37	38	10	11	
							X	3	Interaction Between Radiation, Convection and Stratification - Single Zone	21	3	4	3	23	18	8	1	
							X	4	Interaction Between Radiation, Convection and Stratification - Multizone	22	21	5	38	36	2	8	1	
							X	5	Solar Radiation (Interaction Between Split, Shading, Distribution)	37	5	2	19	35	11	7	7	
							X	6	Heat Loss Through Glazing Portion of the Envelope	35	16	6	37	15	40	7	5	
							X	7	Active Charge/Passive Discharge Thermal Storage Systems	8	20	25	36	45	4	3	13	
							X	8	Interaction of Solar Driven Natural Convection with Forced Air Hvac System	13	13	7	34	22	26	10	10	
							X	9	Radiant Solar Flux Distributions in Sunspaces	36	22	8	35	34	48	2	3	
							X	10	Floor Slab/Ground Coupling	7	4	9	23	4	7	8	4	
						X		11	Convective Heat Transfer Coefficients Inside Buildings	3	6	10	5	33	14	6	9	
						X		12	Flow Rates and Flow Distributions	19	7	11	4	16	24	8	12	
						X		13	Interzone Heat Transfer	1	-	12	40	25	25	8	1	
						X		14	Infiltration Effects	34	-	13	27	1	13	10	8	
						X		15	Stratification	32	12	27	30	26	19	10	1	
						X		16	Field Testing of Innovative Systems	27	37	28	26	41	47	2	17	
						X		17	Field Testing of Air Core/Vented Mass Cooling	4	9	26	6	43	6	6	18	
						X		18	HVAC Systems Interactions	5	11	14	33	27	27	10	10	
					X			19	Direct and Indirect Evaporative Systems Performance	10	10	38	7	12	16	4	22	
					X			20	Performance of Open Evaporative Systems	26	26	39	11	42	29	3	23	
					X			21	Dissipator/Storage Coupling to Interior Space	25	27	37	29	44	30	9	24	
					X			22	Innovative Dissipator Performance	11	29	40	10	13	31	4	25	
					X			23	Evaporative Cooling Algorithm Dev	20	28	15	21	21	17	0	26	
					X			24	Diffusion/Osmosis/Absorption	14	14	45	22	14	37	6	27	
					X			25	Materials Degradation	31	34	46	14	38	45	1	28	
				X				26	Radiative Cooling-Exterior Coupling Elements	-	30	33	15	28	49	7	20	
				X				27	Radiation/Convection Interaction	23	8	16	20	32	22	6	1	
				X				28	Solar Radiation and Surface Orient	38	-	17	18	30	12	7	7	
				X				29	Radiant Dissipators	12	-	41	12	11	33	4	29	
			X					30	Modeling of Solid and Liquid Desicant Systems and Components	31	31	42	16	17	36	2	30	
			X					31	Systems Performance and Control of Dehumidification Systems	30	-	43	17	29	35	2	31	
			X					32	Moisture Balance Algorithms on Materials	28	-	44	13	20	46	4	32	
			X					33	Comfort Standards	24	17	47	26	18	20	1	33	
			X					34	Interface with Mechanical Systems	-	32	18	47	2	28	7	10	
			X					35	Evapotranspiration of Plants	18	42	48	31	40	34	1	34	
		X						36	Earth Cooling Tubes	40	33	19	32	8	32	6	35	
		X						37	Thermophysical Properties	39	18	20	46	5	10	7	18	
		X						38	Slab/Earth Contact Models	7	-	21	24	7	8	3	14	
		X						39	Earth Heat Transfer Model	6	24	22	25	6	9	3	15	
		X						40	Surface Treatments	16	36	35	8	39	43	7	40	
	X							41	Advance Glazing Systems	15	23	29	41	3	39	7	39	
	X							42	Thermal Mass/Solar Gain/HVAC Interaction	29	25	23	42	9	42	7	10	
	X							43	Radiative Barriers	30	15	34	43	10	23	8	38	
	X							44	Movable Insulation/Shading	33	35	30	44	46	41	6	15	
	X							45	Systems Performance Data	-	19	31	1	31	1	6	2	
X								46	Coupling Coefficients to Storage Ele.	-	38	32	45	47	15	6	19	
X								47	Pressure Drop Through Storage Elements	9	39	24	9	45	5	1	36	
X								48	Phase Change Materials	41	40	49	49	19	21	7	21	
X								49	Selected Surfaces	42	41	36	46	49	44	7	37	

TABLE 4

COOLING										INDIVIDUAL RATINGS								REMARKS
THERM STORAGE	LOAD AVOIDANCE	EARTH CONTACT	DEHUMIDIFICATION	RADIATIVE	EVAPORATIVE	VENTILATIVE	HEATING	REF. NO.	TITLE									
									HIGH PRIORITY									
							X	1	Interzone Convection (Vert/Horz)	2	1	1	2	24	3	10	6	combine
						X		13	Interzone Heat Transfer	1	–	12	40	25	25	8	1	
							X	2	Multizone Infiltration	17	2	3	39	37	38	10	11	combine
						X		14	Infiltration Effects	34	–	13	27	1	13	10	8	
							X	3	Interaction Between Radiation, Convection, and Strat.-Single Zone	21	3	4	3	23	18	8	1	
							X	4	Interaction Between Radiation, Convection, and Strat.- Multi-zone	22	21	5	38	36	2	8	1	closely related
				X				27	Radiation/Convection Interaction	23	8	16	20	32	22	6	1	
							X	5	Solar Radiation (Interaction Between Split, Shading, Distribution)	37	5	2	19	35	11	7	7	
							X	6	Heat Loss Through Glazing Portion of the Envelope	35	16	6	37	15	40	7	5	closely related
	X							41	Advance Glazing Systems	15	23	29	41	3	39	7	39	
							X	7	Active Charge/Passive Discharge Thermal Storage Systems	8	20	25	36	45	4	3	13	
						X		11	Convective Heat Transfer Coefficients Inside Buildings	3	6	10	5	33	14	8	9	
						X		12	Flow Rates and Flow Distributions	19	7	11	4	16	24	8	12	related
						X		17	Field Testing of Air Core/Vented Mass Cooling	4	9	26	6	43	6	8	18	
X								47	Pressure Drop Through Storage Elements	9	39	24	9	45	5	1	36	
							X	8	Interaction of Solar Driven Natural Convection with Forced Air Hvac System	13	13	7	34	22	26	10	10	
						X		18	HVAC Systems Interactions	5	11	14	33	27	27	10	10	closely related
			X					34	Interface with Mechanical Systems	–	32	18	47	2	28	7	10	
	X							42	Thermal Mass/Solar Gain/HVAC Interaction	29	25	23	42	9	42	7	10	
							X	9	Radiant Solar Flux Distributions in Sunspaces	36	22	8	35	34	48	2	3	
							X	10	Floor Slab/Ground Coupling	7	4	9	23	4	7	3	4	
		X						37	Thermophysical Properties	39	18	20	46	5	10	7	16	related
		X						38	Slab/Earth Contact Models	7	–	21	24	7	8	3	14	
		X						39	Earth Heat Transfer Model	6	24	22	25	6	9	8	15	
					X			19	Direct and Indirect Evaporative Systems Performance	10	10	38	7	12	16	4	22	
	X							45	Systems Performance Data	–	19	31	1	31	1	8	2	
									LOW PRIORITY									
						X		15	Stratification	32	12	27	30	26	19	10	1	included in #3-no definition
						X		16	Field Testing of Innovative Systems	27	37	28	26	41	47	2	17	
					X			20	Performance of Open Evaporative Systems	26	26	39	11	42	29	3	23	
					X			21	Dissipator/Storage Coupling to Interior Space	25	27	37	29	44	30	7	24	
					X			22	Innovative Dissipator Performance	11	29	40	10	13	31	4	25	combine
				X				29	Radiant Dissipators	12	–	41	12	11	33	4	29	
					X			23	Evaporative Cooling Algorithm Dev	20	28	15	21	21	17	0	28	
					X			24	Diffusion/Osmosis/Absorption	14	14	45	22	14	37	8	27	
			X					30	Modeling of Solid and Liquid Desicant Systems and Components	31	31	42	18	17	36	2	30	combine
			X					32	Moisture Balance Algorithms on Materials	28	–	44	13	20	48	1	32	
					X			25	Materials Degradation	31	34	48	14	38	45	1	28	
				X				26	Radiative Cooling-Exterior Coupling Elements	–	30	33	15	28	49	1	20	
				X				28	Solar Radiation and Surface Orient	38	–	17	18	30	12	1	7	included in #5
			X					31	Systems Performance and Control of Dehumidification Systems	30	–	43	17	29	35	2	31	
			X					33	Comfort Standards	24	17	47	28	18	20	1	33	
			X					35	Evapotranspiration of Plants	18	42	48	31	40	34	1	34	
		X						36	Earth Cooling Tubes	40	33	19	32	8	32	8	35	
		X						40	Surface Treatments	18	38	35	8	39	43	1	40	included in #10, #37, #38, #39
	X							43	Radiant Barriers	30	15	34	43	10	23	8	38	included in #27
	X							44	Movable Insulation/Shading	33	35	30	44	48	41	8	15	
X								46	Coupling Coefficients to Storage Ele.	–	38	32	45	47	15	8	19	included in #11-no definition
X								48	Phase Change Materials	41	40	49	49	19	21	7	21	
X								49	Selected Surfaces	42	41	38	48	49	44	1	37	no definition

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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)

This report addresses the development of a multi-year plan for Experimental Systems Research focused at gaining the necessary knowledge to advance the understanding of passive and hybrid solar energy technology. This understanding includes the ability to acquire building performance data under controlled conditions so that the fundamental mechanism of the driving forces that effect change, along with the resulting change, can be studied. This information is basic for algorithm development defining relationships between the various physical elements which interact within a building and also in determining the accuracy of the various models and simulations developed for use in heating and cooling applications. Specifically, the report covers the comprehensive planning effort undertaken to achieve a consensus regarding the research to be performed, the most appropriate facility to perform the research, and the funding requirements. It includes the process whereby through a series of working meetings and exchange of correspondence, a list of candidate research areas were identified for both heating and cooling technologies. These research areas are defined and ranked and a resulting list of priorities established. This report articulates the results of this effort and details the recommended Experimental Systems Research Activities for solar passive and hybrid technologies for FY85 and beyond.

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

Building Performance; Class A Data; Experimental Systems Research; Heating & Cooling Technology; Passive Solar Energy; Project Prioritization; Research Plan; Test Cell.

13. AVAILABILITY

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