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TITLE: PASSIVE AND LOW ENERGY RESEARCH AND DEVELOPMENT: A GLOBAL VIEW

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PASSIVE AND LOW ENERGY RESEARCH AND DEVELOPMENT: A GLOBAL VIEW*

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ABSTRACT

Passive and low energy applications in buildings has become a topic of worldwide interest within the last few years. It has now been demonstrated very clearly that indoor comfort can be maintained with an expenditure of only 10 to 20% of the energy often required by modern buildings. This is accomplished through a combination of conservation measures to minimize the load, passive use of solar energy for heating, natural cooling, and daylighting. Hybrid systems to assist air flow or evaporation are often effective. Accompanying these developments has been an increasing level of research activity. The major research emphasis has been on devising mathematical models to characterize heat flow within buildings, on the validation of these models by comparison with test results, and on the subsequent use of the models to investigate the influence of both design parameters and weather on system performance. The results have clearly shown that correct design is very climate dependent, and many factors must be considered to obtain the best results. To this end, design guidelines have been developed, and simplified methods of analysis have been promulgated. The initial emphasis was on estimating and maximizing energy savings. Now that this is well established, the emphasis is shifting to maximizing the comfort and convenience characteristics of the building, which, when well designed, normally exceed those of conventional buildings. Performance has been monitored in test modules, test buildings, and many residential and commercial buildings. The results both confirm good performance and establish the accuracy of model predictions. A significant change in the research picture has been seen in the last 4 years; whereas the major effort was originally in the United States, research is now being conducted in many countries throughout the world as many people have realized that passive and low energy methods are appropriate in virtually every climate and are well suited to economic, convenient, and reliable building construction and operation.

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KEYWORDS

Passive systems; solar energy; monitored performance; natural cooling; simulation analysis.

INTRODUCTION

Passive and low energy systems have a number of characteristics that have brought them to the attention of a world now acutely aware of energy scarcity and high energy prices. These attributes include the following:

(1) Zero or minimal energy use. Passive systems rely entirely on the natural mechanisms of conduction, convection, radiation, and evaporation. Other nonpassive or hybrid systems use a minimum of external energy to run such devices as a low-pressure fan, a solar system circulating pump, or a water pump to wet evaporative cooler pads. If external energy is used, the coefficient of performance should be at least 10; that is, 10 times as much energy should be transported as input energy required.

(2) Simple and reliable operation. Passive systems usually are built as an integral part of the structure using ordinary building elements such as bricks, concrete, and glass. As such they are well understood by the occupants and, if maintenance is ever required, no special skills are needed. Low energy systems tend to use simple mechanical devices; infrequent repairs can usually be done with locally available parts and skills. The incredible complexity and poor reliability of some of the early active solar systems caused a reaction in favor of passive approaches and led to an emphasis on keeping the system simple.

(3) Low cost and multiple use. These features are combined because low cost often derives from multiple use. For example, if a sunspace provides a valuable working or connection zone, can be used as a greenhouse, and is aesthetically attractive, then most of its cost can be allocated to these functions and the energy benefits are nearly free. Perhaps the best example is a simple window which (when properly located) provides view, daylight, ventilation, and passive solar gains at appropriate times. Low cost and simplicity are also closely related.

(4) Good performance. Monitoring has shown that these systems perform well, both in terms of energy savings and thermal comfort, provided they are well designed.

Most passive and low energy systems rely on designing the building to take advantage of the climate when it is advantageous and to protect the building from the climate when it is not. This results in the use of strategies which are highly dependent on the local climate and which require a greater sophistication on the part of the designer to be able to take advantage of energy-saving opportunities afforded by the climate. The already-difficult job of the designer becomes even more involved because a whole new set of issues and constraints must be considered.

As interest in passive and low energy systems has grown, research and development has been essential to provide both credibility and guidance to designers. The expertise of the technical and scientific community has been enlisted to evaluate and predict performance, to develop design tools, and to assist in the development of new products and methods. Initially, emphasis was placed on passive solar heating, but gradually a much broader view of building energy issues has led to a balanced consideration of conservation, winter heating, summer cooling, and daylighting. Also, an initial emphasis on single residences has broadened to include multifamily residential and both small and large commercial buildings. Whereas research and development was originally concentrated in the United States it has quickly spread to many countries around the world encompassing a wide range of climates and building traditions.

PASSIVE RESEARCH

Research on passive solar heating has been reviewed recently by Balcomb (1982) and this work will only be summarized briefly here. A schematic overview of the key elements is shown in Fig. 1. Mathematical modeling is the critical element providing a bridge between the experimental activities on the left side and the systems analysis on the right side. Thermal network or other mathematical techniques are used to characterize the heat flow and general thermal behavior.

Experimental Work

Test modules have proved to be especially valuable experiments. These have ranged from test boxes of about 1 m on a side to test rooms of about 13 m^3 volume with 2.5 m^2 of glazing and to small test buildings. Test modules in the U.S., described by Moore (1982), are usually operated in actual outdoor weather conditions and provide an opportunity to obtain data, usually on a single passive solar element, under carefully observed

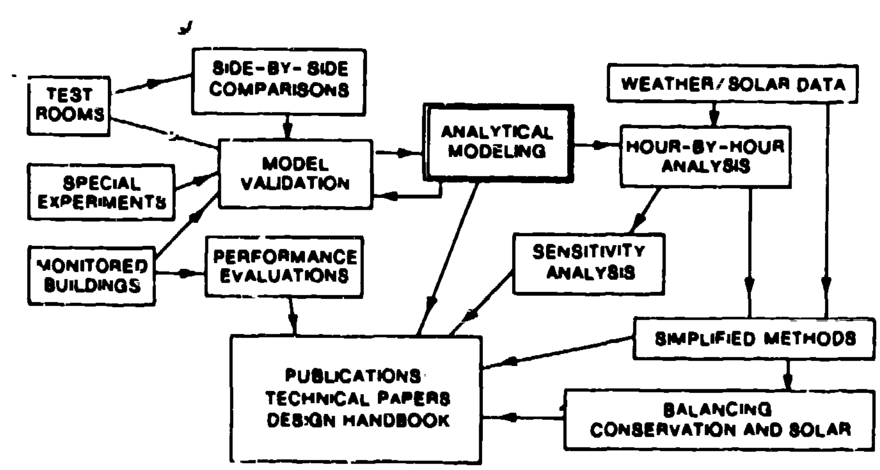

Fig. 1 Schematic of the key elements of the research program.

and controlled conditions. These experiments have provided the bulk of data used for validation of the mathematical models. In most cases, relatively simple models have been adequate to predict average temperatures and back-up heat requirements. For example, combining mass elements can often be done if the only information desired is about average behavior; whereas, if detailed prediction of an individual wall temperature is needed, that wall must be considered separately in the model.

Special experiments are usually set up to obtain information about one specific energy flow mechanism. For example, similitude experiments have been performed by Weber (1978) to obtain data on natural airflow through an aperture, such as doorway between rooms. The experiments were performed in the laboratory using a one-fifth scale model filled with Freon® gas in order to achieve similitude in the important flow parameters. Heat was transfered from a hot plate at the end of one room through the aperture to a cold plate at the opposite end of the other room. Correlations were obtained for the heat exchange (in terms of a Nusselt number) as a function of the room-to-room temperature difference (in terms of a Grashof number). It was determined that the heat exchange is quite sensitive to the door height, presumably because of hot gas trapping above the door top.

Performance Monitoring

Whereas detailed results existed from only a handful of monitored buildings before 1980, there is now a huge volume of data from the monitoring of more than 100 passive solar buildings in the U.S. alone, representing a wide variety of climates and design approaches. Most of this data collection has been the result of the Class B monitoring program and, to a lesser extent, the National Solar Data Network program. Hourly data from 20 or more channels are recorded and computer analyzed to determine building energy requirements, auxiliary heat, and internal heat, usually summarized monthly. Taken as a whole, these data show very good net performance. Measured building load coefficients are usually in the range of 0.8 to 1.5 W/Cm^2, which is about one-half that of conventional contemporary buildings. Auxiliary heat requirements are in the range 0.25 to 0.50 W/Cm^2 in sunny climates and 0.4 to 0.8 W/Cm^2 in less favorable solar climates. Solar gains offset typically 25 to 75% of the building load. There are a wide variety of buildings in the sample including superinsulated, earth sheltered, and all the major passive system types. Internal heat varies widely between the various buildings and makes a major contribution to the heating in some cases. Although no passive type emerges as the best performer, good thermal design is seen to be essential. The energy performance of 48 of the monitored buildings is summarized in Fig. 2.

A deficiency of the monitoring is that evaluation of thermal comfort has been almost overlooked in favor of energy performance measures. While most of the buildings are comfortable, there is a tendency for temperature swings to be too large in some direct gain buildings.

A separate survey by Meier (1984), which includes both passive solar and other low energy houses, finds that space heating energy has been economically reduced to about one-fifth the level required in the average existing house or about one-third the level estimated for typical new homes.

Data from monitoring are a valuable resource for many purposes. Regression analysis has been used to determine constants in simple thermal network models using the hourly monitored data. Validation of design tools, such

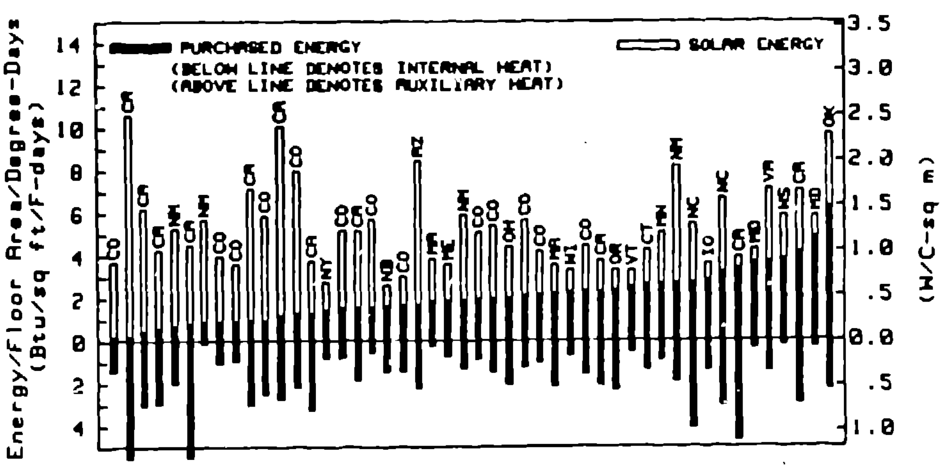

Fig. 2 Results of the monitoring of several buildings. The bars show seasonal energy (usually for 5 or 6 months) divided by the building floor area and the actual degree days for the season, calculated for a base temperature of 18.3°C (65°F). The black portion of the bar denotes purchased energy; the portion below the bar is internal energy, and the black portion above the bar is auxiliary heat. The total length of the bar is the total heat required by the building, determined using the building heat load coefficient and the measured inside/outside ΔT integral. Thus, by subtraction, the white portion of the bar is the solar energy absorbed less any vented energy. The state in which the site is located is indicated above the bar. The buildings are rank ordered according to auxiliary heat. Several buildings with low internal heat were unoccupied but were thermostatically controlled to normal levels.

as solar load ratio correlations, is underway. In addition to the Class B data, much more detailed data are now becoming available from the Class A monitoring program. A primary objective is detailed and comprehensive validation of computer simulation models of buildings.

Systems Analysis

Systems analysis has consisted mainly of running computer simulation models through an entire year using historical hourly weather and solar data taken from a large number of sites. The results have been used both to study the effect of various design parameters on performance and as a data base for the development of design tools.

Sensitivity to the selection of design parameters has usually been presented as a graph showing how a single parameter, such as Trombe wall thickness, affects annual performance in a particular city. The results are depicted either in terms of heating and cooling energy (as in the California Passive Handbook) or in terms of a dimensionless solar savings fraction (as in the Passive Solar Design Handbook). Since there are many parameters, the job of analyzing and presenting results becomes a large one.

A variety of passive solar design tools have emerged. Perhaps it would be more accurate to categorize these as analysis tools helpful in design. These are normally based on correlation techniques and require much less calculation than a simulation, although many are quite complex and are most suitable for computer analysis. Others are more simplified, but usually at the cost of being less comprehensive.

The solar load ratio method (Balcomb, 1982) has been widely used, in which correlations for each of 94 passive system types have been developed. Calculations are done monthly, based on long-term average temperature and solar statistics; the analysis, however, can be reduced to a much simpler annual calculation if prepared tables are available for the site of interest.

Balancing Conservation and Solar

A technique has been developed by Balcomb (1980) to determine the optimal mix between conservation and solar strategies. To obtain an answer, one needs the cost characteristics of both the passive solar system and the energy conservation features. This information will generally be in the form of the cost per R per unit area for the wall and ceiling insulation, the cost per additional glazing for windows, the cost of reducing infiltration (including the cost of adding an air-to-air heat recovery unit if needed), and the cost per unit area for the passive solar collection aperture. Given this information, the method provides simple equations that can be used to trace the economic optimal-mix line for a particular locale.

Passive Cooling

Although passive cooling (sometimes referred to as natural cooling) has received much attention since about 1978, the evolution from research results to quantified performance evaluation, design tools, and appropriate products has been much slower than for passive heating. This is partly because of the nature of the problem. For natural cooling, the building is frequently open to the atmosphere, for example, to promote natural ventilation, whereas for heating it is normally closed. Thus the problem is less tractable to simple analytical modeling because terrain, external velocity and pressure distributions, and details of building geometry become relatively much more important. A second reason is that natural cooling comprises a set of strategies which are only related in that the objective is to promote heat rejection. These are natural ventilation, radiation, earth contact, and evaporation. Nonetheless, these systems must work together. Also, it is often the case that the most important strategy is not cooling itself but the avoidance of a cooling load through strategies such as shading and light exterior colors. The need for dehumidification is often the remaining major issue when defensive strategies have been employed. Thus the problem is highly interrelated and nonlinear. The main approach has been brute force computer simulation, and it has proved to be difficult to categorize the results into a simple set of guidelines and analysis procedures.

Nonetheless, passive cooling works. Radiative cooling has been the most researched probably because it is analytically the most tractable. It works best in arid climates at night when the sky temperatures are low. Earth contact has also been well studied; although cooling can be achieved through earth contact, the amounts are small. It is most appropriate to midcontinental climates with cold winters and hot summers. The primary benefit is probably buffering the building facade from the extremes of the outside climate. An unfortunate side effect is that the opportunity for natural ventilation is reduced.

Natural ventilation, especially ventilation at night when outside air temperatures are low enough, is probably the most effective passive cooling strategy. It is also the least amenable to precise analysis and prediction. Major studies and experiments are underway to study all these effects, and more research results should be forthcoming in the next few years.

PASSIVE SOLAR RESEARCH AROUND THE WORLD

The following are a few selected examples of passive solar heating research being performed in various countries to give a flavor for the different issues being addressed and different approaches being taken.

Portugal

A demonstration and research passive solar test house has been constructed by the faculty of engineering at the University of Porto. The house, called "Thermally Optimized House-Laboratory" has a gross floor area of 145 m^2 on two levels. It is built in close accordance with contemporary construction practices and materials except that insulation is added outside the wall and roof mass to bring the overall daily loss coefficient (per unit floor area) down to 27.5 Wh/m^2-C-day. The wall U-value, for example, is 0.6 W/m^2-C. Passive solar collection area is 24.5 m^2 consisting of water wall, Trombe wall, and direct gain. These values are consistent with conservation and solar balancing guidelines developed for Porto based on the procedure referenced above.

Simulation analysis has been performed for the building, based on the thermal network model shown in Fig. 3. This indicates that good comfort conditions will be achieved and that the building will respond in a very slow and well-behaved way to normal and extreme weather transients. Total auxiliary heat is expected to be about 1400 kWh during a normal winter based on 1615 heating degree days (18^oC base).

The building is very thoroughly instrumented and a microprocessor-based system is being used for data acquisition and recording. Provision is made to transfer data to a central computer facility for subsequent analysis and model validation. The building is a very well conceived response to the social and climatic and economic needs of Portugal and the results will be quite valuable in enhancing the credibility of passive solar as well as providing valuable research results to guide evaluation of design guidelines.

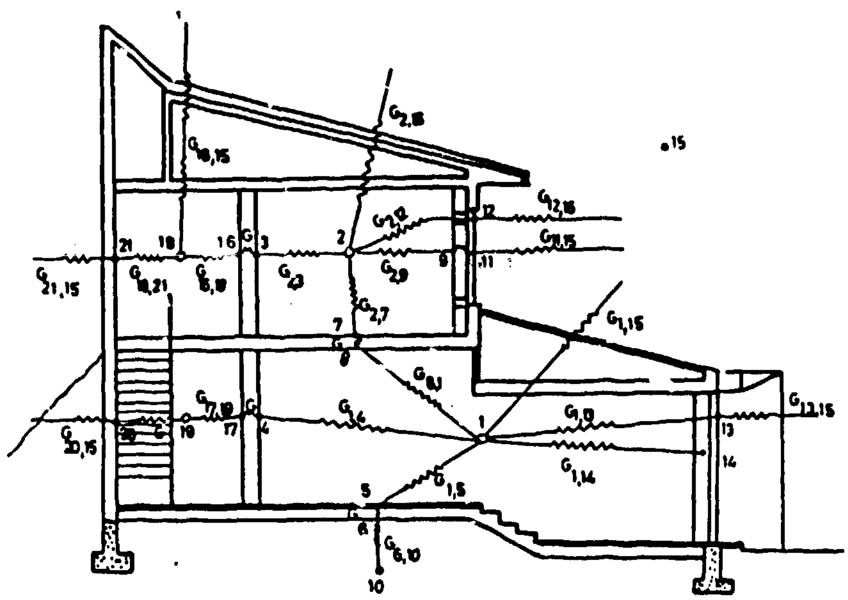

Fig. 3 Thermal network of the Porto solar house. Numbered circles show points at which temperatures are calculated. Resistor connections show heat flow paths, labeled G. The model is driven using outside temperature and solar radiation inputs.

Argentina

A team of architects, engineers, and physicists has been assembled at IADIZA (Argentine Institute for Arid Zone Investigations, a government-sponsored agency) in Mendoza (33 degrees S latitude). The group has been assimilating information on appropriate climatic design from around the world with the help of consultants brought in for a few weeks. A small test house incorporating Trombe walls, direct gain, and thermosiphon solar water heaters was built in 1980 and has provided valuable feedback to the group.

Argentina has a large public housing program and there are clear indications that climatic factors should be considered in the design (the houses are sometimes referred to as "horintos" -- little ovens). The IADIZA group has investigated means of retrofitting existing houses to be better behaved thermally and has developed designs for multistory apartment buildings that will pass the demanding earthquake standards of Mendoza. The favorable weather conditions of the area indicate that very small heating and cooling loads can be achieved through good design.

A very different design challenge has been addressed by the group at the University of Salta for buildings to be located in the altiplano of northwest Argentina (22 degrees S latitude). The high altitude (3300 m) and extremely low humidity results in a very sunny but quite cold climate (3230 degree days) characterized by huge diurnal temperature swings (-7 to +15 C in midwinter) and a year-round need for heat but no need for cooling. These conditions coupled with the low latitude lead to different design strategies such as a central atrium with horizontal glazing. One building has been constructed with east- and west-facing Trombe walls in addition to normal north-facing solar collection planes.

China

Reseachers at the Gansu Natural Energy Research Institute at Lanchou in north central China are setting up a series of test buildings that include passive solar heating strategies appropriate to the cold, sunny winters of this continental climate. Favorable data have already been obtained on a modified Trombe wall house at Xinging. The particular challenge for this group is to develop approaches and materials suitable for a country where glass is not readily available in large sizes at affordable prices, and where there is no established large-scale building insulation industry. Traditional buildings are already designed in accordance with good passive solar features such as correct orientation, building shape, location of windows, window overhangs, and high thermal mass. But performance is limited by high heat losses and poor glazing performance. Results of the research will be used to guide government policy regarding materials manufacture, retrofit of existing buildings, and the design of new buildings for the 200 million people living in this climate zone.

Spain

Researchers at the Gas and Electricity, S.A., on the Mediterranean island of Mallorca have built a small test house to experiment on a hybrid heating system. Solar heat is collected in a vertical air-heating panel incorporated into the structure of the building's south wall. The heated air is forced through ducts by a low-power fan to a central partition wall having labyrinthine channels built of ordinary brick wall tiles sandwiched between massive wall surface elements. The purpose is to develop a means of distributing heat from the south side of a building to thermal storage within north rooms, a common design concern in high-density housing. Heat distribution to the house is by passive conduction through the wall and radiation and convection to the space. Daily collection efficiencies exceeding 35% have been obtained along with very stable and comfortable room temperature .

A related problem in high-density housing is the distribution of daylight into interior rooms located below the upper story. Architect Rafael Serra at the University of Barcelona has experimented with vertical ducts which extend from light scoops located above the roof downward into the building. The scoop and ducts are lined with mirrors to obtain high light transfer efficiency. Reasonable lighting levels can be achieved in several rooms feeding off a single duct. The aesthetic quality achieved is excellent and exciting.

European Community

Lebens (1983) has reported on a variety of design issues and concerns that have been addressed in a multinational way under the Commission of European Communities Passive Solar Program. Their activities include sponsoring two separate European Passive Solar Design Competitions, funding many component research and development projects, developing performance monitoring techniques and monitoring buildings, evaluating both simple and simulation design models, developing design guidelines, constructing test facilities, and publishing an extensive European Passive Solar Design Handbook. The overall scope of research work is huge; it is a well-coordinated effort involving nine countries having a similar set of climatic and design concerns.

United States

Research on active solar in the U.S. started gaining momentum in 1974 and in passive solar in 1978. This broad effort has involved thousands of researchers in both small and large groups located throughout the country at government laboratories, in universities, in industry and industry associations, and in private offices. Many of the results have been reported at the annual conferences and the eight passive solar conferences sponsored by the American Solar Energy Society. The proceedings of these conferences provide an access point into most of the U.S. research work.

Research on passive and low energy buildings has decreased dramatically in the U.S. since 1980 as a result of reductions in government funding, and is probably at no more than 25% of the 1980 level today. The nature of the program has shifted from an emphasis on commercialization to an emphasis on more fundamental research and development.

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