PH-97-15-2

10545

Developments on Passive Cooling in Buildings—Results from Recent Research

Matheos Santamouris, Ph.D. **Athanassios A. Argiriou, Ph.D.** **Constantinos A. Balaras, Ph.D.**
Associate Member ASHRAE

ABSTRACT

This paper summarizes recent developments in natural and passive cooling in buildings and the main results from the European research project PASCOOL. The project was completed at the end of 1995, after 27 months of theoretical and experimental work resulting in a better understanding of passive cooling techniques and the development of tools and design guidelines. The project was a collaboration of 29 European universities and research organizations from 12 countries.

INTRODUCTION

Alternative energy sources, techniques, and systems can be used to satisfy a major portion of the cooling requirements in buildings. The trend, which started following the energy crisis in the mid-1970s, has developed into an active area of research with significant findings and great success in commercial applications.

This area is commonly referred to as *passive cooling*. The term incorporates various processes and techniques of heat dissipation, modulation, and heat protection that occur naturally. Overall, they do not utilize any form of energy input other than renewable energy sources or use any other major mechanical systems. They incorporate several well-known methods enhanced with new capabilities allowed by technological advancement, better understanding of the physical processes involved, and optimum utilization of their potential effectiveness, in both traditional and modern applications, through a more comprehensive coupling and coordination of the available techniques and systems with the architectural design of the building in its environment.

Passive cooling techniques are also closely linked to the thermal comfort of occupants. Actually, some of the techniques used for passive cooling do not remove the cooling load of the building itself, but rather they extend the tolerance limits of humans for thermal comfort in a given space.

It is also possible to increase the effectiveness of passive cooling with mechanically assisted heat transfer techniques that enhance natural cooling processes. These types of applications are commonly referred to as "hybrid" cooling systems, since there is also low electrical energy consumption by conventional systems. However, there is usually an improved energy efficiency and greater flexibility on potential applications.

Passive cooling refers to techniques that can be used to prevent, modulate, and dissipate heat gains. Protection from or prevention of heat gains may involve some or all of the following design techniques.

1. *Microclimate and site design.* These can greatly influence the thermal behavior of a building. The overall principle is that a building must be adapted to the climate of the region and the microclimate. The site design is influenced by economic considerations, zoning regulations, and adjacent developments, all of which can interfere with the design of a building with regard to the incident solar radiation and the available wind. Vegetation not only results in pleasant outdoor spaces but can also improve the microclimate around a building, reduce the ambient air temperature, and reduce the cooling load for indoor spaces.
2. *Solar control.* This is the primary design measure for heat gain protection. The use of various shading devices in attenuating the incident solar radiation entering into the building can significantly reduce the cooling load. External shading of opaque walls with surrounding natural vegetation and external or internal shading and high-performance glazing can result in satisfactory thermal and optical performance.
3. *Building form, layout, and external finishing.* These determine the exposure of interior spaces to incident solar

Matheos Santamouris is an assistant professor in the Department of Applied Physics at the University of Athens, Athens, Greece. **Athanassios A. Argiriou** and **Constantinos A. Balaras** are research scientists at NOA/IMPAE, Athens, Greece.

radiation, daylight, and wind. The building shape controls both heat losses and heat gains by reducing or increasing the ratio of the exposed surface to volume. It depends on planning regulations, space availability, neighboring site development, architectural styles, client preferences, and cost constraints.

4. *Building envelope construction.* The construction of the outer building envelope influences the physical processes taking place between the outdoor environment and indoor spaces. The objective is to limit thermal gains during the summer due to high outdoor air temperatures and incident solar radiation. Thermal insulation can reduce the heat conducted through the building materials. During the summer it reduces thermal gains and during the winter it reduces thermal losses. The level of thermal insulation in buildings is usually determined by national codes and is mandatory in most countries.
5. *Behavioral and occupancy patterns.* These types of activities can be properly adjusted in order to achieve thermal comfort and, consequently, reduce the energy consumption for cooling. Dressing according to the prevailing weather conditions, adjusting the levels of muscular activity, moving to cooler spaces in the building, and adjusting thermal controls (opening and shutting windows, use of blinds and curtains for shading) are simple yet effective actions.
6. *Internal heat gain control.* The control of internal heat gains can be achieved by proper design and operation of indoor heat sources, such as artificial lighting, equipment, and occupants. Use of energy-efficient lamps can reduce heat dissipation into the space, in addition to reducing electrical energy consumption. Human activity influences internal heat gains, but it is difficult to modify, other than by proper zoning within the building's spaces. Similarly, equipment that demands special air conditions, such as computers or other electronic equipment or spaces with restrictive air temperature conditions, needs to be handled with conventional mechanical equipment. In this case, emphasis should be placed on the previous design techniques.

Heat gain modulation is associated with the capacity of the building to absorb and store heat. The thermal mass of a building (typically contained in walls, floors, and partitions constructed of material with high heat capacity) absorbs heat during the day and regulates the magnitude of indoor temperature swings, reduces peak cooling load, and transfers a part of the absorbed heat into the night hours. The cooling load can then be covered by passive cooling techniques if the outdoor conditions are favorable. A building can also be precooled during the night by night ventilation and then transfer this stored coolness into the early hours of the following day, thus reducing energy consumption for cooling.

Heat dissipation techniques refer to the use of natural heat sinks for transferring excess heat out of interior spaces. This heat dissipation depends on the availability of an appropriate environmental heat sink, on the appropriate thermal coupling, and on a suitable temperature difference for natural heat transfer from indoors to the heat sink. The main processes for heat dissipation include the following:

- *Ventilation.* When the outdoor conditions (temperature and humidity) are favorable, natural or forced ventilation is one of the primary means for reducing the cooling load in buildings (removing heat from indoor spaces) and for extending indoor thermal comfort conditions for humans. Natural ventilation is caused by pressure differences at the inlets and outlets of a building envelope as a result of wind velocity and/or temperature difference. The air can be properly channeled and moved through the building to further enhance its effectiveness. Cross- and single-side night ventilation, wind towers, and solar chimneys are the main natural ventilation techniques. Forced ventilation is achieved by mechanical means—using fans to reach and control the appropriate air speed. Ceiling, attic, or simple portable room fans can be used to control the indoor air movement and achieve the appropriate air changes. Ceiling fans allow for higher indoor air temperatures, since increased indoor air movement enhances occupants' thermal comfort conditions, thus reducing the cooling load.
- *Ground cooling.* Even during hot summer days, ground temperatures remain significantly lower than ambient air temperatures, with almost zero daily variations compared to the diurnal cycle of ambient air temperature and solar radiation due to the high thermal capacity of the soil. The building can be coupled with the ground for cooling purposes, either indirectly or directly. Indirect ground coupling involves a hybrid system. Indoor air is circulated through underground pipes, dissipates heat to the lower temperature heat sink, and then the cooled air is returned back to the building. Alternatively, the building can be placed in direct contact with the ground. Partial or total underground construction is a viable alternative to conventional architectural styles, especially in climates with extreme ambient conditions.
- *Evaporative cooling.* The air plays the role of the heat sink, while heat transfer occurs by evaporation. It applies to all processes in which the sensible heat in an airstream is exchanged for the latent heat of water droplets or wetted surfaces. The majority of evaporative cooling applications use hybrid systems. The water evaporation can occur in a direct, indirect, or two-stage process, depending on the prevailing air conditions and the moisture content.
- *Radiative cooling.* The heat sink is the sky and heat is transferred by radiation. The technique can be used as either a passive or a hybrid one. The building envelope (or another appropriate device such as a metallic flat-plate radiative air cooler) is cooled by dissipating infra-

red radiation to the sky, which acts as a low-temperature environmental heat sink. The amount of radiant exchange depends on the temperature difference between the sky temperature and the building element and the optical characteristics of the radiator. The roof is the most important passive radiative cooling system in a building due to the fact that it continuously faces the sky dome. Roof color influences the thermal performance of a building because it governs the absorption and reflection of incident solar radiation during the day and the emission of longwave radiation at night, especially for light structures.

Combining different passive and natural cooling techniques with the other architectural aspects for building aesthetics, it is possible to prevent overheating problems, decrease cooling loads, and improve comfort conditions in buildings.

THE PASCOOL PROJECT

The emphasis in this European research project was on the use of passive cooling techniques and systems in buildings. The work was intended to bridge existing scientific gaps and develop a better understanding of the phenomena by collecting new experimental data and through theoretical analysis in order to develop working tools and guidelines for engineers, architects, building physicists, and other professionals for research and applications in passive cooling. A total of 29 European universities and research organizations from 12 countries including Belgium, France, Greece, Italy, Portugal, Spain, Switzerland, the Netherlands, United Kingdom, Slovenia, Hungary, and Bulgaria participated. The coordination of the project was undertaken by a Greek university.

The project combined an interrelated set of research actions under various topics with the following specific objectives set to

- create weather data sets for cooling applications;
- define indoor thermal comfort criteria;
- evaluate the microclimatic enhancement and applicability of natural cooling techniques in Europe;
- develop solar control techniques for year-round performance, combining thermal and daylighting aspects;
- investigate the role of thermal inertia in free-running and air-conditioned buildings;
- investigate the airflow patterns in and around buildings and the role of natural ventilation as a cooling resource; and
- prepare a diagnostic predesign assessment tool and simulation tools and define guidelines for various building types in Europe that incorporate the outputs from the above research topics.

The research activities included extensive test cell experiments, monitoring of representative types of buildings, and laboratory experiments. To carry out the various activities of the project, the operational structure of the project was designed to create a strong, highly motivated, and operational research group. The main activities were organized around four subgroups, namely, the (1) experimental testing subgroup, (2) model development subgroup, (3) climate subgroup, and (4) design guidelines subgroup. The activities of each subgroup are described in the following sections.

Experimental Testing Subgroup

This subgroup was responsible for defining and carrying out the experimental activities, collecting experimental data, and preparing the database with all experimental results. The subgroup translated the requirements from the other groups working on the various scientific topics into suitable experiments and monitoring exercises. The experimental program was the backbone of the project. The major activities concentrated on experiments for the following s.

- *Natural ventilation*, which is a dominant parameter in natural cooling techniques. It involves phenomena, however, that are rather difficult to quantify. Single-sided and cross-ventilation cases with various geometries were studied in both test cells and real buildings. The measurements were based on decay tracer gas techniques. Established limits were placed on the applicability of such methods for measuring high natural ventilation rates and addressing uniform mixing constraints and the duration of data collection periods.
- *Solar control*, to collect data suitable for a detailed characterization of solar control devices. Emphasis was placed on the investigation of complex shading devices with variable geometry, such as louvers. The experiments were carried out simultaneously in test cells at three sites with similar latitudes, namely, Almeria, Spain, Catania, Italy, and Athens, Greece. Measurements included the global and angle-dependent transmission properties of the shading devices, local heat transfer film coefficients on the shading device and on the glazing in the presence of a shading device, and indoor daylight levels using the shading devices. Five shading devices were studied, including external retractable venetian blinds with tilting metallic slats, external shutters with tilting wooden slats, external roller blinds, external jalousies with horizontal plastic fixed slats, and a vertical adjustable insulated fins system. Measurements of the global and angle-dependent transmission properties of the shading devices were also performed with a special two-axis tracking bench in a laboratory environment. The results were validated with the data from the test cell experiments under real weather conditions.
- *Thermal inertia*, which is usually not treated with accuracy, although it is a significant passive control technique. Experiments included monitoring the thermal behavior of various buildings with different levels of thermal mass and a series of experiments in a laboratory facility at Lyon, France.
- *Thermal comfort*, which combined surveys and monitoring of real subjects. Personal monitoring equipment was specifically designed for this project.

design guidelines for the efficient use of thermal mass in buildings.

- *Thermal simulation program development.* The group developed a new building thermal simulation program that incorporates the main outputs from the various research activities on natural ventilation, shading, and thermal mass, not available in other tools. It is a computational tool for DOS-compatible microcomputers. Overall, the emphasis during the development of this program was placed on dealing with problems related to cooling of buildings, especially by natural and passive techniques. However, the program can also deal with year-round calculations. The main features of the program include a more detailed treatment of the thermal mass problem accounting for the role of the building's surrounding external environment, small-scale microclimate, external remote obstacles, external shading devices such as louvers, and improved treatment of natural ventilation phenomena. The program is intended for any professional, researcher, or student involved in the design, construction, retrofitting, operation, or study of buildings. An intermodel comparison was used to compare the results from the program with existing and well-known simulation tools and against experimental data from the extended building monitoring campaign. The results were found to be in excellent agreement with the experimental data and the results from other well-validated tools.

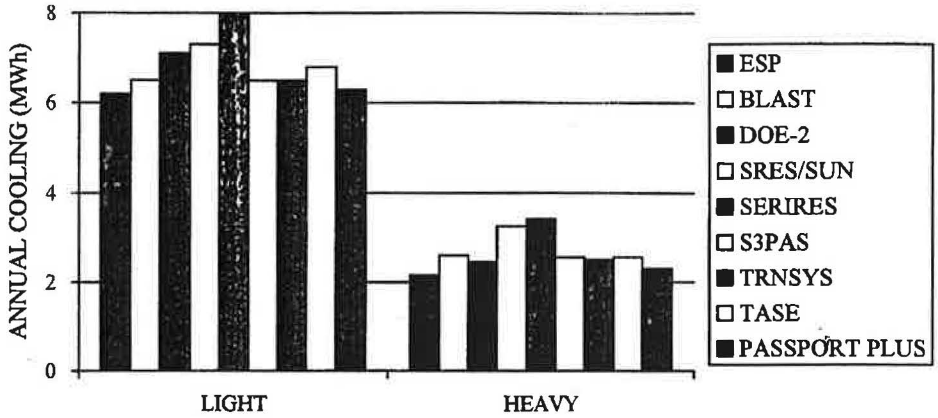

Figure 1 *Calculated annual cooling energy consumption for a base case of light and heavy building construction, using nine different models for an intermodel comparison.*

The intermodel comparison was performed using the program and eight other models to perform simulations of a typical building with various types of construction (light and heavy mass) for free-running and air-conditioned conditions with and without shading. The calculations included annual heating and cooling load, annual hourly integrated peak heating and cooling load, maximum annual hourly zone temperature, and representative daily hourly indoor air temperature. Representative results for the calculated annual cooling load for the light and heavy mass building base case are shown in Figure 1.

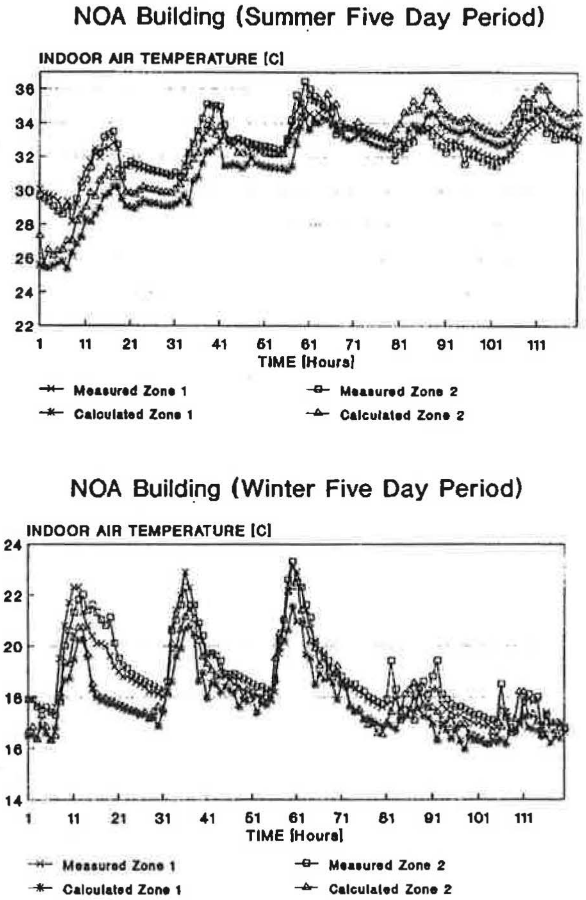

Figure 2 *Calculated by the thermal simulation program using measured indoor air temperatures from two zones of a building in Athens during five-day summer and winter periods.*

Representative results of calculated hourly indoor air temperature using the program and measured data from a building in Athens are illustrated in Figure 2. The building is a heavy-mass, two-story office building near the center of Athens. The data refer to two zones on the first floor during five-day periods in summer and winter.

The simulations were performed using the program to calculate the hourly number of air changes under free-running conditions during summer. The indoor air temperature variation is only a few degrees during the 24-hour period as a result of the building's heavy mass structure. For the first three days during winter, the building's heating system operates during office hours, while the last two days correspond to a weekend when the building operates under free-running conditions. The calculated and measured data are in good agreement and follow a common trend.

Climate Subgroup

This subgroup developed (1) test meteorological years; (2) an atlas on the potential of natural cooling techniques, namely radiative, evaporative, and ground cooling; and (3) a method for calculating the airflow characteristics around buildings. The climate subgroup prepared the following:

1. *Test reference years*, with an emphasis on summer conditions, were produced utilizing available and measured data. The group developed algorithms and a software tool for the generation of a typical meteorological year and created a climatic database and test reference meteorological years for several European locations.
2. *An atlas on natural cooling techniques*. The group developed a comprehensive tool that incorporates algorithms describing radiative cooling using night sky radiators, evaporative cooling using mechanical evaporative coolers, and ground cooling using buried ducts into a single software. The developed design methodology is based on the concept of gross cooling potential, net cooling potential, available cooling energy, and useful cooling energy. The software estimates the temperature of natural heat sinks (sky temperature, wet-bulb and ground temperatures) and their cooling potential. The atlas was prepared using this simulation tool to predict the potential for natural cooling techniques at various European locations.
3. *Calculation method*. The group developed a new method for calculating the pressure difference around buildings, based on data collected from wind tunnel experiments and existing knowledge.

Design Guidelines Subgroup

This subgroup integrated the results from this project into a diagnostic, predesign assessment procedure and developed design guidelines included in the *Passive Cooling Handbook* (Yannas and Maldonaso 1995), the *Electronic Metahandbook* (Weber 1995b), and (3) the *Predesign Tool* (Maldonado et al. 1995). The group also incorporated the overall research for the comfort activities. The Design Guidelines Subgroup prepared the following:

1. The *Passive Cooling Handbook*, which presents design-related information on comfort, climate, and building design; microclimate and outdoor spaces; solar control; thermal inertia; natural ventilation; and ground, radiative, and evaporative cooling. The *Handbook* provides well-documented monitored and theoretically analyzed buildings as case studies. The *Handbook* combines existing knowledge with the new project findings.

2. *Metahandbook* Tool. This is an electronic tool utilizing multimedia technology. The user can assess lively descriptions of surveyed buildings and the various software developed in this project. Climatic data from various locations are also incorporated. The *PASCOOL Electronic Metahandbook* (PEM) allows architects and engineers to have easy access to visual and graphic information on model buildings and to get tools to evaluate the thermal behavior of buildings in the predesign stage. PEM provides photographs and a guided visit to the reference buildings, architectural drawings for buildings and detail , climatic information for the site, a description of the main architectural and passive cooling concepts of the building, monitoring data and results from sensitivity analyses, general meteorological data from 38 locations throughout southern Europe, and a collection of tools for shading, U-value calculations, comfort, natural cooling techniques, direct solar gains from windows, and unit conversion.

3. *Predesign Tool*. This is a simple yet accurate tool to predict indoor temperatures for free-running buildings during summer. Predictions were compared with experimental results from the short-term experiments, showing that the tool results in reasonable accuracy. The free-floating internal temperature (FIT) program calculates the heating and cooling balance point temperature for a given building and its average internal temperature distribution over a summer. The method is based on ASHRAE's CLTD procedure (ASHRAE 1993), while the building's internal gains are specified by the user. The instantaneous gains (envelope and internal gains) are transformed into cooling loads by the use of appropriate weighting factors (or room transfer functions), which were developed for typical southern European building types with high thermal inertia. Heating and cooling balance points are derived for the desired indoor temperature setpoints for each season. Dynamic indoor daily temperature profiles are obtained for the summer season, assuming a linear relationship between outdoor ambient temperature and solar radiation levels. Bin climatic data for the building site are used to translate the daily indoor temperature profiles into cumulative indoor temperature distributions, producing a plot of the number of hours with overheating for each temperature level. The model has been compared with data from the short-term monitoring and test cell experiments, with observed average differences of about 1.5°C (about 3°F) and a mean maximum deviation of 2°C (about 3.5°F).

FINAL PRODUCTS

The project's final products are presented below. The products are useful to designers, engineers, and building professionals who wish to gain a better understanding of the phenomena and techniques for reducing energy consumption for cooling in buildings while improving indoor conditions. The main final products are the following.

1. Final report of experimental subgroup (Maldonado 1995), including a presentation of all the experimental procedures followed during this project, monitoring exercises, data quality, collected data along with their classification and documentation, presentation and description of equipment and material used, and evaluation of implemented methodologies and procedures.

2. Final report of model development subgroup (Sciuto 1995a), including an overview of the activities of this subgroup and the scientific work performed for solar control, natural ventilation, thermal mass, and the thermal simulation program.

3. Final report of ventilation and thermal mass tasks (Allard 1995), including the description of the experimental and theoretical studies on natural ventilation and thermal mass. Presented in this report are all the experimental activities performed in laboratories, test cells, and real buildings for single- and cross-ventilation, internal openings, and thermal mass. The algorithms developed in each area are presented in detail, along with a full description of the scientific background of the airflow network model.

4. Airflow network model user manual and program (Dascalaki and Santamouris 1995). A new program to predict natural airflow in multizone buildings. The report includes information on the use of the software, tutorials for efficient use of the program, application examples, and a copy of the program for PC applications.

5. Final report of solar control task (Sciuto 1995b), including the detailed presentation of experimental and theoretical studies performed in this area. All laboratory and test cell experimental work is presented in detail. The testing methodology developed, as well as the new algorithms developed to predict the dynamic thermal and visual performance of various solar control devices, are also presented and analyzed. The report includes results from market surveys on solar control devices.

6. Final report of thermal simulation program (Alvarez and Balaras 1995), including a presentation of all algorithms and the program structure of this new building thermal simulation program. The report describes in detail the new algorithms implemented in the program, the techniques developed for the solver, the validation procedure through the intermodel comparison, and the results from the comparison of predictions with experimental data.

7. Thermal simulation program user manual and program (Balaras and Alvarez 1995). A new building thermal simulation program. The report includes detailed information on the program structure, information on the use of the software, tutorials for efficient use of the program, application examples, and a copy of the program for PC applications.

8. Final report of comfort task (Baker and Standeven 1995), including a detailed presentation of the experimental and theoretical work from the thermal comfort campaign, descriptions of the methodology and overall approach, the new equipment and material used to carry out the field studies, the results obtained, main conclusions, and the proposed new comfort model.

9. Comfort user manual and program (Berger 1995). A new program for human thermal comfort analysis. The report includes information on the structure of the new program, detailed information on the use of the software and its scientific background, tutorials for efficient use of the program, and a copy of the program for PC applications.

10. User manual and program for method of calculating pressure difference around buildings (Grosso 1995). A new program that calculates the wind pressure coefficient around buildings. The report includes a description of the method followed, a description of the experimental work performed to develop the algorithms, a presentation of the proposed expressions, tutorials for efficient use of the program, and a copy of the program for PC applications.

11. Multizone tracer gas measurement calculation fundamentals, user manual and program (Amara 1995). A new program that calculates experimental airflows when tracer gas decay techniques are used. The report includes a description of the method used to develop the proposed algorithms, tutorials for efficient use of the program, and a copy of the program for PC applications.

12. TRMY development, fundamentals, user manuals, and program (Petrakis 1995a). A new tool developed to create test reference meteorological years from existing multiyear data sets. The report includes a presentation of fundamentals for developing the overall procedure, the structure of the program, tutorials, and a copy of the program for PC applications.

13. Test meteorological year program (Petrakis 1995b). A total of 12 data sets, for selected locations in southern and central Europe with available complete multiyear climatic data, have been created. The developed TMY sets can be used by designers interested in evaluating climatic conditions at specific locations. They can also be used to perform building thermal simulations.

14. Final report of the climate subgroup—Part I: Test meteorological years (Alvarez 1995a), including a presentation of the methodology followed to develop the test meteorological years, the results obtained, the tests performed, and the software developed. This report can be useful for scientists and climatologists interested in creating test meteorological years from existing climatic data.

15. Final report of the climate subgroup—Part II: Natural cooling techniques (Alvarez 1995b), including a presentation of the algorithms developed to assess the potential of natural cooling techniques, the methodology followed to classify the

cooling potential, and the results obtained and used to develop the Atlas on Natural Cooling Techniques.

16. Lamas user manual and program (Coronel and Alvarez 1995). A new program developed to calculate the thermal exchange in an enclosure composed by the glazing, the setback, and the external louver's shading devices with flat horizontal or vertical slats. The report includes the fundamentals of the method, the program structure, tutorials for efficient use of the tool, and a copy of the program for PC applications.

17. Predesign tool, user manual and program (Maldonado et al. 1995). A new program developed to assist architects during the initial phase of the building design. The report includes information on the principles behind the need and use for this overall approach, describes the algorithms used in this tool and the structure of the program, and provides tutorial information and a copy of the program for PC applications.

18. Temperature program user manual and program (Maestre and Alvarez 1995). A new program developed to calculate the temperature of the environmental heat sinks and cooling potential of evaporative, radiative, and ground cooling. The report includes information on fundamentals, a description of the methodology used, the structure of the program, tutorial information, and a copy of the program for PC applications.

19. Final report of *Electronic Metahandbook* (Weber 1995a), including a presentation of the contents, the tools, and the methodologies incorporated for the development of this handbook. The handbook describes various types of buildings that are included, along with an analysis of the classification of integrated information.

20. *Electronic Metahandbook* user's manual and program (Weber 1995b). This new electronic multimedia tool provides assistance to designers and engineers with a lively presentation and relevant information on the buildings surveyed, the various software programs developed within this project, and access to climatic data for several European localities. The report includes a presentation of fundamentals and program structure, tutorials, and a copy of the program for PC applications.

21. Cool-DB (Strachan and Lindsay 1995). This is a database developed to classify all experimental data collected during the various experiments of the project. The database provides information on its contents, structure, and user instructions for its efficient use. Almost 80 data sets on solar control, natural ventilation, thermal comfort, thermal mass, and data from the short monitoring and extended monitoring campaigns are included.

22. *PASCOOL Handbook—Designing for Coolth* (Yannas and Maldonado 1995). The handbook discusses all aspects of passive cooling for buildings and provides useful information for designers and engineers. The passive cooling handbook presents design-related information on comfort, climate, and building design, microclimate and outdoor spaces, solar control, thermal inertia, natural ventilation, ground cooling, radiative cooling, and evaporative cooling. It provides well-documented, monitored, and theoretically studied building examples. The handbook combines existing knowledge with the new project findings. It is published in two volumes. The first volume provides general and design information, while the second volume presents fully analyzed, studied, and monitored case studies.

23. Atlas on Natural Cooling Techniques (Alvarez 1995c). The atlas presents information on the potential of natural cooling techniques and provides ready-to-use information on the potential of specific natural cooling techniques and systems, such as evaporative, radiative, and ground cooling. This information can allow for efficient and appropriate integration of natural cooling components in buildings.

CONCLUSIONS

The PASCOOL project has succeeded in developing techniques, tools, and design guidelines on various topics related to the application of passive cooling in buildings and has contributed to significant progress in this field. Detailed results and technical information are available in the project's final products, which are available through the project's coordinator.

ACKNOWLEDGMENTS

PASCOOL was mainly financed by the European Commission of the Directorate General for Science, Research & Technology, in the frame of the JOULE II European Research Programme.

REFERENCES

Allard, F., ed. 1995. Final report of ventilation and thermal mass tasks. La Rochelle, France: University of La Rochelle.

Alvarez, S., ed. 1995a. Final report of the climate subgroup—Part I: Test meteorological years. Seville, Spain: University of Seville.

Alvarez, S., ed. 1995b. Final report of the climate subgroup—Part II: Natural cooling techniques. Seville, Spain: University of Seville.

Alvarez, S., ed. 1995c. *Atlas on natural cooling techniques*. Seville, Spain: University of Seville.

Alvarez, S., and C.A. Balaras, eds. 1995. Final report of Passport Plus. Seville, Spain, and Athens, Greece: University of Seville and University of Athens.

Amara, F., ed. 1995. *Exac, fundamentals, user manual and program*. Lyon, France: LASH/ENTPE.

ASHRAE. 1993. *1993 ASHRAE handbook—Fundamentals*. Atlanta: American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc.

Baker, N., and M. Standeven, eds. 1995. Final report of Comfort Task. Cambridge, U.K.: University of Cambridge.

Balaras, C.A., and S. Alvarez, eds. 1995. *Passport Plus, user manual and program*. Athens, Greece, and Seville, Spain: University of Athens and University of Seville.

Berger, X., ed. 1995. *COMFORT, user manual and program*. Lyon, France: CNRS.

Coronel, J.F., and S. Alvarez, eds. 1995. *Lamas, user manual and program*. Seville, Spain: University of Seville.

Dascalaki, E., and M. Santamouris, eds. 1995. *Passport Air, user manual and program*. Athens, Greece: University of Athens.

Grosso, M., ed. 1995. *Cpcalc Plus, fundamentals, user manual and program*. Torino, Italy: Politechnico di Torino.

Maestre, I.R., and S. Alvarez, eds. 1995. *Sink, user manual and program*. Seville, Spain: University of Seville.

Maldonado, E., ed. 1995. Final report of experimental subgroup. Porto, Portugal: University of Porto.

Maldonado, E., L. Graca, and S. Yannas, eds. 1995. *Predesign tool, user manual and program*. Porto, Portugal, and London: University of Porto and Architectural Association School of Architecture of London.

Petrakis, M., ed. 1995a. *TRM development, fundamentals, user manuals and program*. Athens, Greece: IMPAE-National Observatory of Athens.

Petrakis, M., ed. 1995b. Test meteorological years program, IMPAE-National Observatory of Athens, Greece.

Sciuto, S., ed. 1995a. Final report of model development subgroup. Catania, Italy: Conphoebus s.c.r.l.

Sciuto, S., ed. 1995b. Final report of solar control task. Catania, Italy: Conphoebus s.c.r.l.

Strachan, P., and M. Lindsay, eds. 1995. Cool-DB. ESRU, University of Strathclyde, U.K.

Weber, W., ed. 1995a. Final report of electronic metahandbook. University of Geneva, Switzerland.

Weber, W., ed. 1995b. *Electronic metahandbook user's manual and program*. Geneva: University of Geneva.

Yannas, S., and E. Maldonado, eds. 1995. *PASCOOL handbook—Designing for coolth*. London and Porto, Portugal: Architectural Association, School of Architecture of London, and University of Porto.