BUILDING THERMAL SIMULATIONS USING A NEW TOOL - PASSPORT PLUS

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ABSTRACT
Passport Plus is a new design tool for building thermal analysis which was developed within the European research project PASCOOL of the European Commission. The program is structured in such a way as to be able to easily handle future additions and enhancements. Some of the program's features include a more detailed treatment of thermal mass, the building's surrounding external environment, small scale micro climate, external remote obstacles, external shading devices like louvers, improved treatment of natural ventilation phenomena. The program is intended for professionals and researchers. The program calculates indoor air and wall surface temperatures, indoor air flows, cooling or heating loads and indoor thermal comfort conditions, but it does not treat HVAC systems. The accuracy of results have been compared against a number of other commonly used programs and experimental data from two monitored buildings, with very good results.

INTRODUCTION
Energy conscious design of buildings for cooling purposes introduces a set of substantial constraints when passively cooled buildings are compared with actively cooled buildings, or actively-passively heated buildings. This fact leads to different requirements of the models used to predict their performance (Alvarez et al, 1997). Passport Plus is a new design tool for building thermal analysis which was developed within the European research project PASCOOL (Passive Cooling of Buildings) of the European Commission.

Architects, engineers, building designers and analysts, can use this program to assess the thermal performance of a building, evaluate alternative solutions and design options for an energy efficient final selection. The user does not have to be experienced with computers to use the program. However, some expertise on the overall approach for dealing with building thermal analysis are necessary, in order to define an overall strategy.

Simplified design tools are easy to use, do not require detailed inputs and provide relatively accurate information. Usually, higher accuracy means a more difficult to use program or a more demanding computer environment. A recent review of several computational methods (Balaras 1996) has listed 14 simplified design tools for estimating the cooling load and indoor air temperature of a building, which also account for the thermal mass effects, a determining parameter for this type of calculations.

There are also several advanced computer models for simulating the thermal behaviour of buildings, like DOE (Diamond 1979), TARP (Walton 1983), BLAST (Hittle 1979). Several European Research Programmes in the area of energy conservation in buildings, have utilised extensively the Environmental Systems Performance (ESP) software (Clarke 1985). TRNSYS (Klein 1988) has also been a very popular commercially available programme in the field of solar energy system design, mainly because of its modularity, especially following the release of a version for personal computers. These thermal building simulation codes, as well as many others, were developed as a result of how different analysts setup the numerous aspects of the thermal building modelling processes. Although they appear to be different building models, they are all more-or-less based on the same energy conservation equations, but different approaches and assumptions lead to models with different applications (Alvarez et al 1997).

The origin of the development of PASSPORT Plus was the need to have an informatic structure able to admit a straightforward integration of different models, prepared by different working groups in

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PASCOOL. This way, the development of new models did not impose any constraints on the modelling technique or the programming language in which the algorithms were developed with and thus preserves the parallel and free activity of modelling teams. For that purpose, Passport Plus uses a flexible methodology based on:

a) The mathematical formulations of the different transfer mechanisms or the thermal behavior of elements and components, which are unified by common expressions in terms of the actual coupling variables. The result is a total independence between the final formulation and the modelling technique used. This way, for example, the heat conduction can be modelled by simultaneously using transfer functions for certain elements, finite differences for others and electrical analogue methods for the rest. For any element, the modelling technique can be the most suitable for approaching its specific characteristics.

b) The coupling between all heat and mass transfer mechanisms is treated following a structured process. The different stages are linked in such a way as to allow the use, if necessary, of independent software preprocessors.

The final solution is reached by reducing successively the number of coupling variables involved in each stage of the process. The result is a computationally very efficient final formulation, that gives the opportunity of using optimized solving techniques by preserving, at the same time, the whole complexity of the unreduced initial simulation problem. Detailed information on the solution procedures are presented in (Alvarez et al 1997, Coronel and Alvarez 1995).

A second characteristic of PASSPORT Plus is the availability of a selective level of consistent complexity, so as to avoid the frequent incoherence between the level of detail in modelling certain phenomena. For example, a detailed calculation of the view factors has no use if the solar target is not going to be calculated. In summary, PASSPORT Plus handles (even for the same building) detailed and simplified approaches of a certain phenomena, as well as the already mentioned coexistence of different techniques. Another example with regard to the different levels of desirable complexity that the user has the option to select, is with regard to natural ventilation rates. Preliminary calculations may be handled by setting an assumed hourly value of the number of air changes (ACH) in a zone or alternatively, use a detailed network model developed in PASCOOL for natural ventilation, based on PASSPORT Air (Dascalaki, Santamouris 1995) for calculating a more accurate hourly value of ACH.

PASSPORT Plus can easily accept future developments on better modelling techniques, new components or new strategies, as well as, related building design issues such as daylighting, indoor air quality, passive heating, natural and hybrid cooling techniques or HVAC systems.

PROGRAM DESCRIPTION

The interface of PASSPORT Plus is available in QBasic for DOS and a new version for Windows. The general structure of the program is illustrated in Figure 1. The input is a combination of user specified data and information available in libraries. The main input data include:

- *Component Libraries* : Several libraries for the definition of glazing and opaque materials, wall and window elements, shading devices (including facade obstacles like overhangs and side fins, and external louvers), neighbouring outdoor skyline description and building operation, are available for the user.
- *Building Operation* : Basic operations are controlled by user specified schedules. For weekdays, weekends and holidays, the user can specify a 24-hour schedule, either as on/off or as a specific value, where appropriate. In particular, these operations include internal convective or radiative gains, window and door opening and closing, ventilation mode operation (either calculate natural ventilation during the simulation or use a fixed number of air changes by natural or mechanical means), temperature mode (free floating or fixed temperature), and mechanical equipment operation.
- *General Information* : Location, type of building, outdoor terrain type, period for calculations.
- *Meteorological data :* Hourly values of diffuse on the horizontal and beam normal solar radiation, outdoor air temperature, relative humidity, wind velocity and wind direction.
- *Building Description :* The building is described on a zone by zone basis. Zones are composed of external and internal elements (walls, windows, doors). The user can define specific element constructions using material libraries which provide all necessary properties for a variety of building materials.
- *Zone Description:* Geometry, operating schedules (temperature mode, ventilation, internal gains, mechanical equipment), and occupant related information.
- *Element Description* : Geometric description and type of construction from library defined components, for external and internal zone elements. Use of predefined operating schedules, when appropriate, for windows, doors, shading

devices, and link to the outdoor skyline and indoor building zones. Definition of the preferable heat transfer method to treat the conduction problem through each element.

The calculations are performed on an hourly basis using, in this version of the program, transfer functions and 1-D finite differences for treating the heat conduction problem. The program does not treat HVAC systems and equipment simulation. The program outputs are hourly values of: Indoor air temperature; Internal wall surface temperature; Load profiles; Indoor air movement from natural ventilation; and Comfort conditions. Results are presented in either graphical or numerical format.

BUILDING SIMULATIONS

The results of PASSPORT Plus were compared with the values given by other programs, considered well-tested. The results from these reference models do not necessarily represent the "real" conditions, however, they are representative of what is commonly accepted as the current state-of-the-art in whole-building energy simulations.

The framework of the comparison was the BESTEST project (Judkoff and Neymark 1995), conducted by the Model Evaluation and Improvement International Energy agency (IEA) Experts Group. The method consists of a series of carefully specified test case buildings, that progress systematically from the extremely simple to the relative realistic cases. Output values for each case, such as annual loads, annual maximum and minimum temperatures, annual peak loads and some hourly data, are compared and used in conjunction with diagnostic tools to determine the algorithms responsible for predictive differences.

For example, Figures 2 and 3 illustrate some of the results obtained. Additional results are available in (Coronel, Alvarez, Rodriguez 1995). The first figure shows the results for the indoor hourly free floating temperature (°C) for a winter day. The second figure illustrates the corresponding calculated hourly heating (+) and cooling (-) loads (kWh) for the same building operating with a mechanical system, under the same conditions. It appears that the results obtained from Passport Plus are in excellent agreement with the other programs, following the overall trend very closely. For all different tests included in the BESTEST protocol, on a daily and annual basis, the results from PASSPORT Plus were within the acceptable range settings.

Additional simulations of two monitored buildings were used as a validation exercise for PASSPORT Plus. Program predictions of indoor air temperatures and element surface temperatures were compared against measured data. The two buildings were monitored within the framework of the PASCOOL project, namely the National Observatory of Athens (NOA) in Hellas and the Mendillorri building in Spain. Available measured data for the outdoor conditions, including ambient air temperature, relative humidity, wind direction, wind velocity, and solar radiation, was used to update the corresponding meteorological files in PASSPORT Plus. The simulations were performed over a summer and winter period, for each building. The results are illustrated in Figures 4 and 5, for the NOA and the Mendillorri building, respectively.

The NOA building is a two level high, heavy mass neo-classic building, made out of 70 cm thick stone, located on a hill near the Acropolis of Athens. Figure 4 presents the calculated and measured indoor air temperature for two zones on the first floor of the NOA building, during a five day period in summer and winter. The results are obtained using PASSPORT Air (Dascalaki, Santamouris 1995) to calculate the hourly number of air changes, under free floating conditions. For the five day summer period the indoor air temperature variation is only a few degrees during the 24-hour period, as a result of the building's heavy structure. The calculated indoor air temperatures are in very good agreement with the measured data, clearly following the overall trend. For the five day winter period the indoor air temperature variation during the first three days is more evident. This is a result of operating the central heating system during the working hours of the day. For the last two days, which correspond to a weekend, the indoor air temperature variation is only a couple of degrees. During the weekend the building operates under free floating conditions and the heating system is not used. Again, the calculated and measured data are in good agreement and clearly follow a common trend.

The Mendillorri building is located in the outskirts of Pamplona city. It is a five level high residential building, made out of insulated brick walls. The corresponding results for two zones are shown in Figure 5, during a three day period in summer and winter. For the summer period the maximum temperature difference is 1 C. For the winter period the maximum measured and calculated indoor air temperature difference is again approximately 1 C.

CONCLUSIONS

The need for the development of PASSPORT Plus originated from the need to have a suitable structure able to admit a straightforward integration of models developed by different research groups. Accordingly, new models do not have any constraints with regard to the Modelling technique or the language in which the algorithms are written.

The present version of PASSPORT Plus, offered as a Final Product of PASCOOL, even though it is a little more than a prototype, it received and successfully integrated a large quantity of contributions, with variable complexity, from the research carried out in this project. This is a clear demonstration of the suitability of the approach and of the possibilities for expanding the scope to different existing algorithms, more simplified versions, new components etc.

The new approach implemented in PASSPORT Plus for the equation set-up, handling and solving of building heat transfer processes, makes it extremely flexible, accurate and fast. Consequently, PASSPORT Plus becomes an excellent tool, capable of admitting new developments on better modelling techniques, new components or new strategies, as well as other related building design issues such as daylighting, indoor air quality, passive heating, natural and hybrid cooling techniques or HVAC systems. The program has been compared with very good results, against experimental data and other well known simulation tools.

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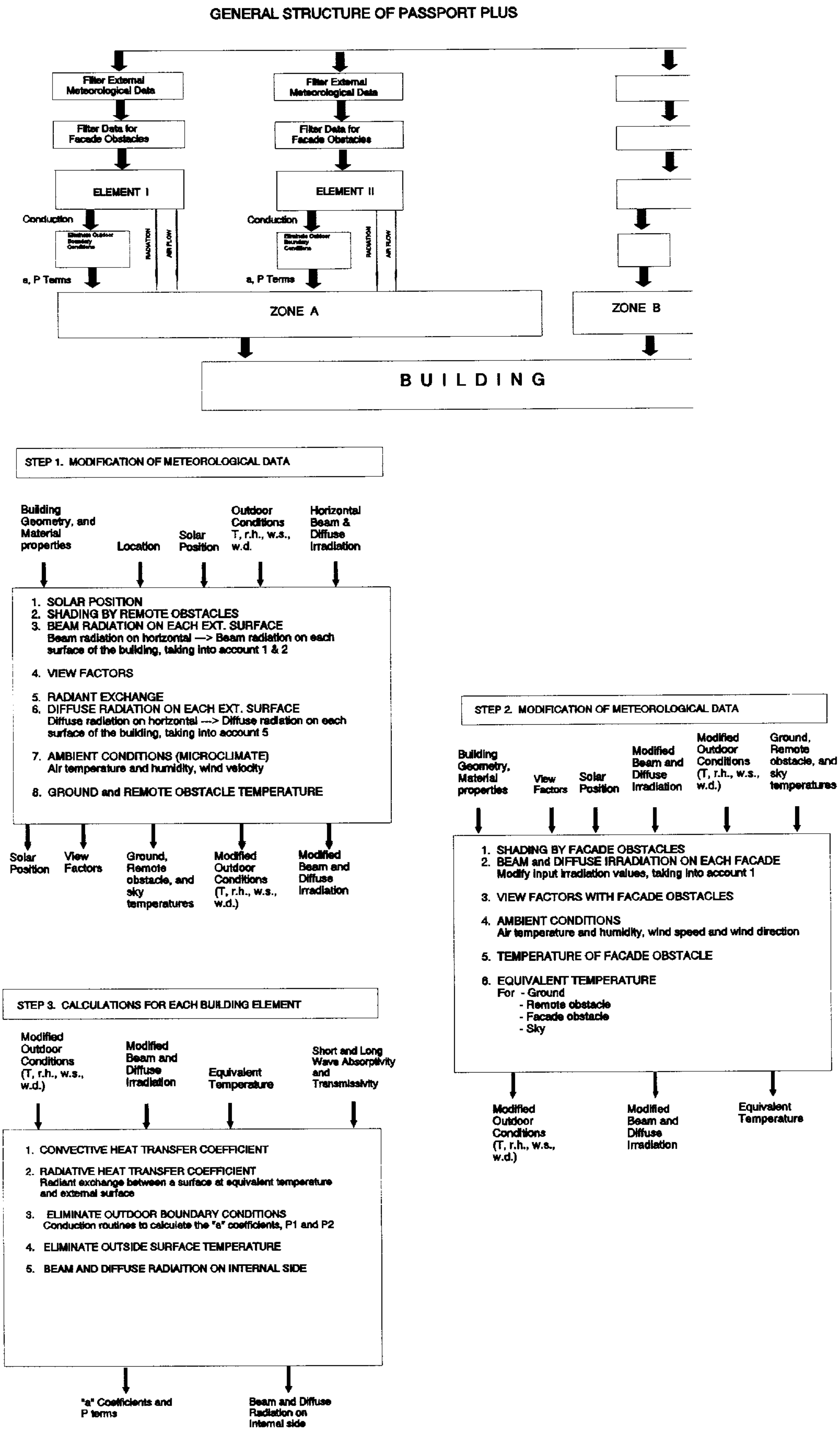


Figure 1. Passport Plus general structure.

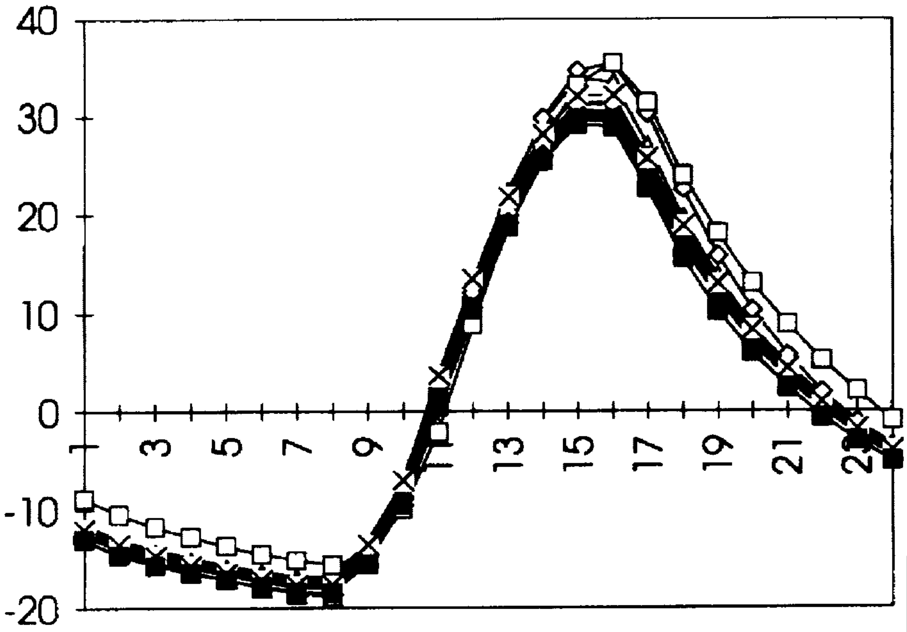
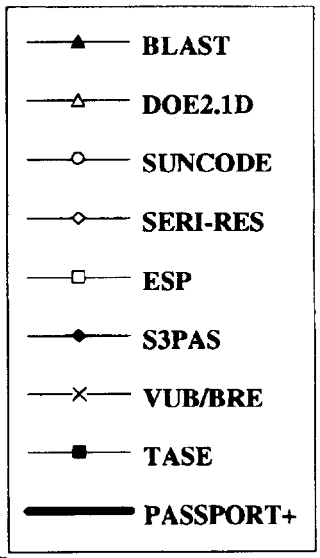


Figure 2. Hourly free float temperature for a winter day.



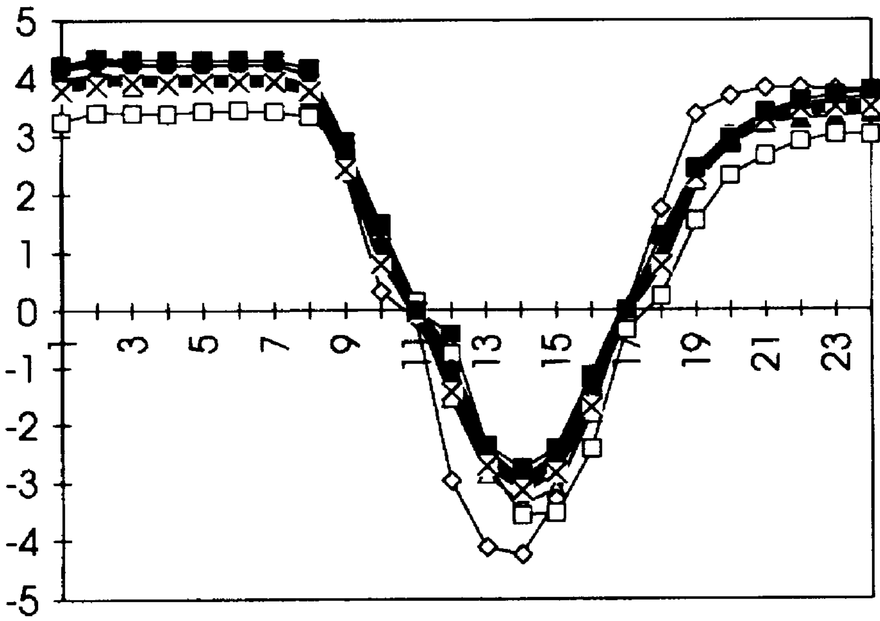


Figure 3. Hourly heating and cooling load for a winter day.

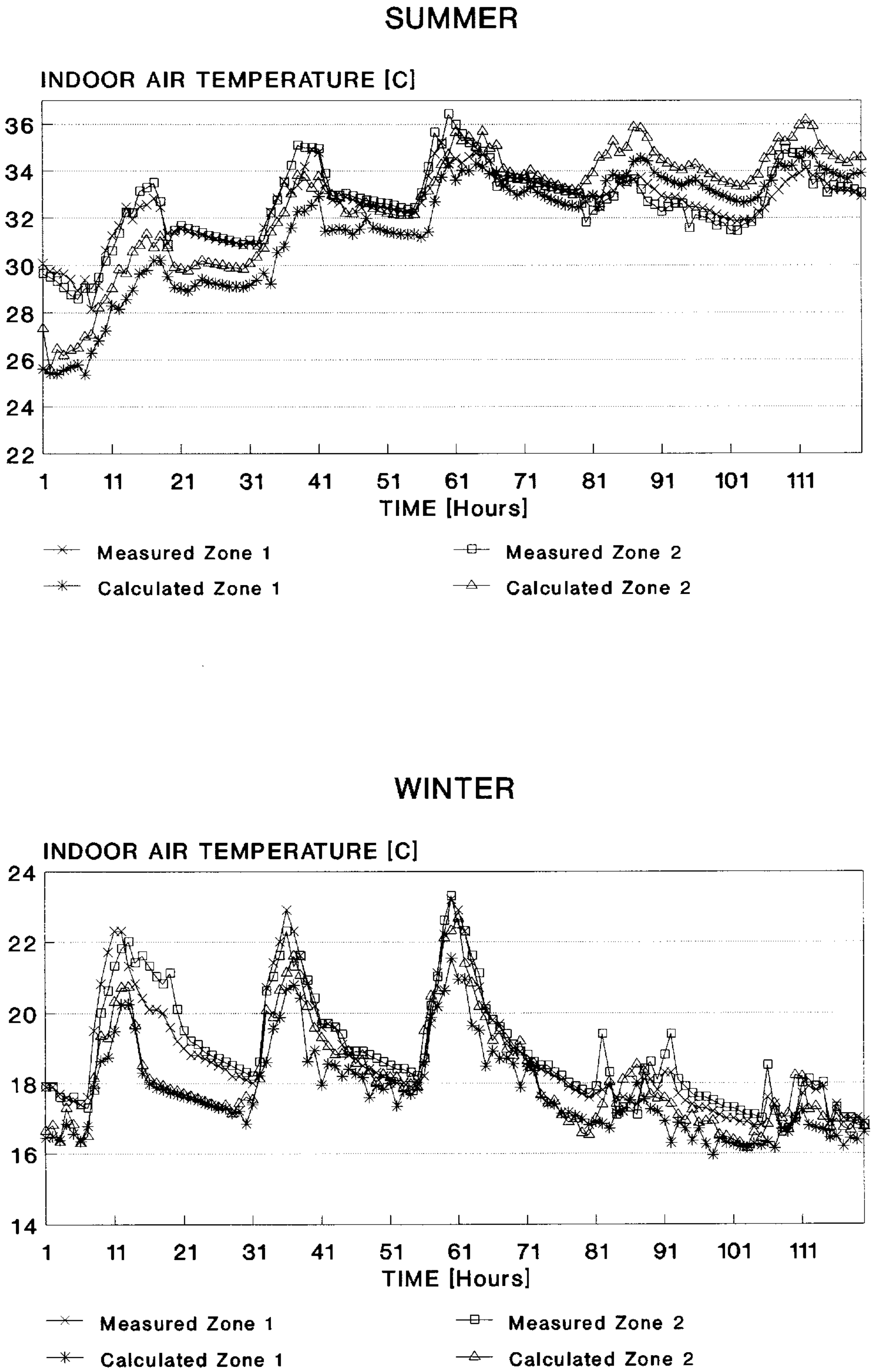
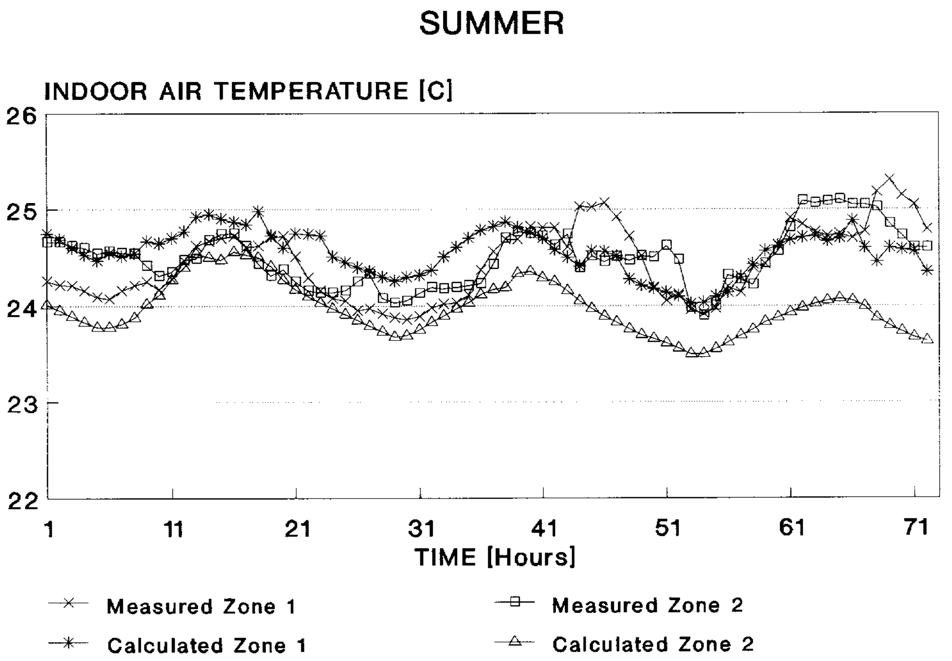


Figure 4. Calculated and measured indoor air temperature, for two zones in the NOA building, during a five day period in summer and winter.



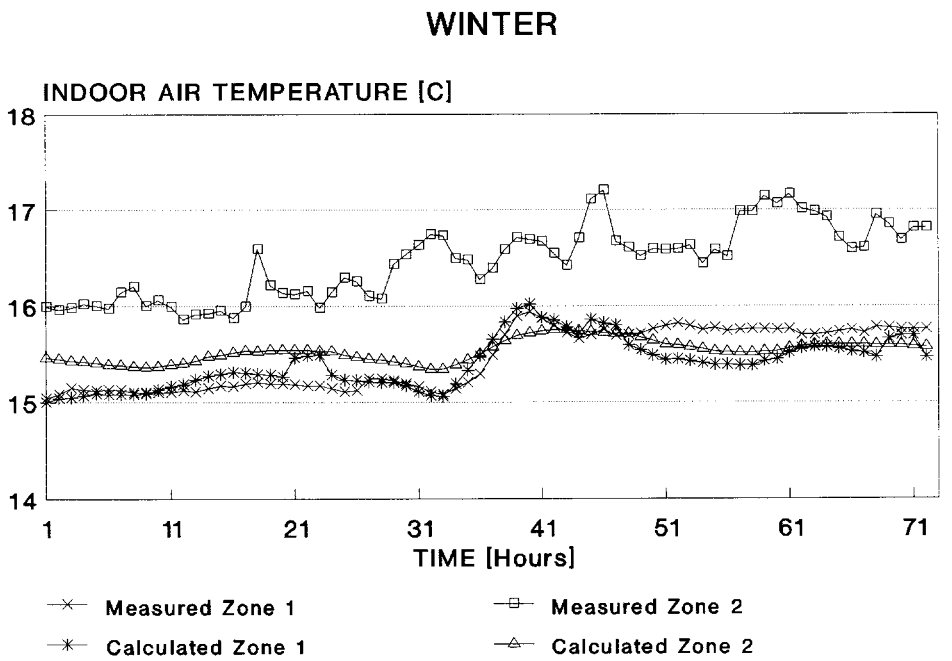


Figure 5. Calculated and measured indoor air temperature, for two zones in the Mendillorri building, during a three day period in summer and winter.