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COUPLING AND SOLVING THERMAL AND AIR FLOW PHENOMENA IN PASSIVELY COOLED BUILDINGS

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PASSPORT Plus is a new building thermal simulation tool, developed in the framework of PASCOOL. It incorporates new findings from the experimental and theoretical research activities performed in PASCOOL that have been integrated in an original informatic structure. Overall, the emphasis during the development of the program was given on dealing with problems related to cooling of buildings, especially by natural and passive techniques. Some of the program's features include a detailed treatment of the thermal mass, external remote obstacles, external shading devices like facade obstacles and louvers, improved treatment of natural ventilation phenomena. PASSPORT Plus is a flexible numerical model, in a sense that it can be easily modified in order to adapt and incorporate new findings from ongoing and future research, independently developed modules for treating specific systems or processes, with minimum effort and changes to the program's structure. The tool has been validated against experimental data and various other simulation programs, with very good agreement.

Keywords: Building; Thermal simulation

1 INTRODUCTION

Energy conscious design of buildings for cooling purposes introduces a set of substantial constraints when passively cooled buildings are

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compared with actively cooled buildings, or actively–passively heated buildings. This fact leads to different requirements of the models used to predict their performance. The major differences include:

- A greater emphasis on certain phenomena, such as the influence of the external wind patterns or internal convection in cases of night ventilation strategies, or the significance of heat conduction in heavy walls of the envelope for heat attenuation.
- The need to remove certain common hypotheses, such as the fully mixed treatment of the air of the zones.
- The presence of certain elements that play a dominant role in the design, such as external shading devices for solar control.
- The stronger level of interzonal coupling and the stronger interaction between different building zones and the surroundings. In fact, for buildings in winter-dominated climates or for conventionally cooled buildings, the basic action for energy savings or comfort strategies is always a *component level* action (for instance better glazings). However, in passively cooled buildings, these strategies are taken on the *whole building level* or even very often, related to the adjacent areas (i.e. landscaping) or transitional spaces (i.e. courtyards).
- The different operating conditions, usually a wide band of free-floating conditions for passively cooled buildings, against prescribed indoor temperatures for other buildings.
- A different notion of comfort, which integrates not only air and surface temperatures but also air velocity and the spatial variations of the thermal comfort parameters in contrast with the classical approach of "room average value".

2 WHY A NEW BUILDING ENERGY ANALYSIS TOOL?

Most of the above issues were the object of experimental and theoretical research in PASCOOL. The problem that emerged was the necessity to evaluate their impact on building performance by integrating the resulting models in a building simulation code.

There are several advanced computer codes for simulating the thermal behavior of buildings, like DOE [1], TARP [2] and BLAST [3]. Several European Research programs in the area of energy conservation in buildings have utilized extensively the ESP software [4]. TRNSYS [5] is also a very popular, commercially available, program in the field of solar energy system design.

These thermal building simulation codes, as well as many others, were developed as a result of how different analysts set up the numerous aspects of the thermal building modeling 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 [6].

In general, the applicability of a code depends on the mathematical representation of the basic heat and mass transfer mechanisms when applied to the elements of the building envelope and to the indoor air. All the above mathematical representations are based on simplifying assumptions of the reality. The validity of these assumptions is a function of the characteristics of the building and of the strategies to be used for its optimum performance.

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 the different working subgroups in PASCOOL. For example, the subgroups on ventilation, solar control, thermal mass, carried out their experimental and theoretical work in order to develop models that best describe the phenomena involved and which were then integrated into the program. The fundamental idea is that the development of new models should not impose any constraints on the modeling technique or the programing language in which the algorithms are developed with. This way it is possible to preserve the *parallel and free activity of modeling teams*.

For that purpose, the code 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 modeling technique used. This way, for example, the heat conduction can be modeled by simultaneously using transfer functions for certain elements, finite differences for others and electrical analog methods for the rest. For any element, the modeling 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 sofware 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, which gives the opportunity of using optimized solving techniques by preserving, at the same time, the whole complexity of the unreduced initial simulation problem.

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 modeling 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 certain phenomena, as well as the already mentioned coexistence of different techniques.

Finally, PASSPORT Plus can easily accept new (future) developments on better modeling 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.

3 UNIFIED MODELING OF TRANSFER PHENOMENA

A building can be described as a complex system made up of different elements conforming gaseous enclosures, in which various heat and mass transfer mechanisms take place. This section includes the common formulation adopted for any of them and emphasizes the models developed or refined within the different PASCOOL groups.

3.1 Surface Balances

Each internal or external isothermal surface temperature is defined by the thermodynamic equilibrium of surface (i) submitted to conduction, convection and radiation heat transfer (long- and short-wave radiation):

Conduction = Convection − Short-wave radiation emitted
+ Long-wave radiation,

$$-k_i \left.\frac{\partial T}{\partial x}\right|_i = h_i(T_i - T_{\text{air}}) - \alpha_i E_i + \sum_{j=1}^{N_i} C^{\text{R}}_{i,j}(T_i^4 - T_j^4), \tag{1}$$

where for each element (i), k_i is the thermal conductivity, T_i is the surface temperature, x is the dimension perpendicular to the surface element, h_i is the convective surface film coefficient, T_{air} is the air temperature near the element surface, α_i is the radiant absorptivity of the surface element, E_i is the irradiation over the surface element, C^{R} is the long-wave radiant exchange factor between surfaces (i) and (j), N_i is the number of surfaces in the enclosure of the element (i).

3.1.1 Conduction

Modeling conduction heat transfer problems in buildings is usually handled by splitting the boundary of a building element in a finite number of N surfaces, at uniform temperature and uniform heat flow. The accuracy of this approach is improved by increasing the discretization of the boundary although, in most cases, it is necessary to simplify the modeling approach while preserving the total rigor (i.e. one-dimensional conduction through walls).

The boundary surface of the element is the coupling between the element and its environment and so the N surface temperatures are identified as the coupling variables.

The proposed common formulation, incorporated in PASSPORT Plus, relates the surface conduction heat fluxes in the boundary with the corresponding surface temperatures as follows:

$$\vec{q}(t) = [A(t)]\vec{T}_{\text{S}} + \vec{P}(t), \tag{2}$$

where the matrix $[A(t)]$ and the vector $\vec{P}(t)$ are directly related to the modeling technique used to describe this mechanism and are calculated at each simulation step. For constant material properties $[A(t)]$ is invariant.

All modeling techniques available in literature can be finally put in the common form of Eq. (2). This methodology allows modelers to use the most suitable way to represent the conduction problem for each element and does not restrict them to the use of a unique modeling technique. For one-dimensional conduction PASSPORT Plus incorporates transfer functions from Laplace transform and Duhamel integration as well as implicit (Crank–Nicholson) finite differences. For multidimensional conduction it uses transfer functions obtained from a numerical solution of the equations based on a finite differences Alternating Direction Explicit method.

3.1.2 Convection

This transfer mechanism is driven by pressure differences between indoor air and the boundary wind conditions. The convective heat transfer (q_{cv}) is expressed as a function of the temperature difference between the surface (T_s) and the air near the surface (T_{air}):

$$q_{cv} = h_{cv}(T_s - T_{air}). \tag{3}$$

The proportionality constant h_{cv} is the convective heat transfer coefficient or film coefficient. This well-known formulation is used by the majority of the modelers. The main problems that one usually faces is the precise calculation of convective heat transfer coefficients, for each specific application. In PASSPORT Plus, the convective heat transfer coefficients can be user-defined or recalculated at each time step.

3.1.3 Radiative Exchanges

All the radiant exchanges in enclosures defined with opaque, semi-transparent or completely transparent elements can be formulated as:

$$\vec{q}_{rad} = [K]\vec{T} + [C_1]\vec{E}_{ext} + [C_2]\vec{\phi}, \tag{4}$$

where q_{rad} is the vector with the absorbed radiant heat flow for every surface of the enclosure, T is the vector with the temperatures for every surface of the enclosure, E_{ext} is the vector with the exterior irradiation for every surface of the enclosure (only affects (semi-)transparent elements). ϕ is the vector with incident irradiation (solar radiation, internal gains, etc.) for every surface of the enclosure, K, C_1 and C_2 are matrices for the radiant redistribution calculated depending on the method used.

In principle, PASSPORT Plus incorporates the net radiation method, with detailed or approximate (based on the areas) view factors. The primary incidence of the solar radiation can be user-defined or calculated using a detailed solar-target method [7]. The routines for solar control evaluation, including the effect of remote and facade obstacles, as well as shading devices, have been obtained from the extensive research performed in this area within PASCOOL [8].

3.2 Air Balances

These are the enthalpy balances in each enclosure or zone. The enthalpy balance of each zone equals the time variation of the zone enthalpy, to the total net heat entering the zone, either by surface convection (coming from the internal gains or from the interior surfaces of the enclosure) or by air convection (air movements from/to outdoors or from/to other zones):

Time variation of enthalpy = Internal gains convection
+ Interior surface convection
+ Convected infiltration/ventilation enthalpy $z = 1, \ldots, \mathrm{NZ}$

$$V^z C_p \frac{\mathrm{d}(\rho^z T_a^z)}{\mathrm{d}t} = Q_{ig}^z + \sum_{k=1}^{\mathrm{NS}_z} h_{cvk} S_k (T_{sk} - T_a^z) + \sum_{j=0}^{\mathrm{NZ}} \dot{m}_{jz} C_p T_a^j - \sum_{j=0}^{\mathrm{NZ}} \dot{m}_{zj} C_p T_a^z,$$

where the superscript z denotes the zone index, NZ is the total number of zones of the building, and NS_z is the number of surfaces convecting to zone z.

PASSPORT Plus handles the calculation of single side ventilation, as well as the interzonal air flow due to natural ventilation, using a specific network model included in a subroutine based on PASSPORT Air [9]. This routine incorporates the work and experimental research developed in the framework of PASCOOL, as well as pressure coefficients based on wind-tunnel tests [10].

4 SOLUTION STRATEGY

This section presents the solution strategy implemented in PASSPORT Plus. The connection between the various steps, for the transfer of information and data, is made via computer memory (using default algorithms included in the main program) or via intermediate files (using external algorithms).

4.1 Step 1: External Zone Filter

Modify climatic variables induced by the environment surrounding the building. This step deals with large-scale and small-scale microclimatic variations. Among the small-scale microclimatic variations, it includes the effect of the remote obstacle and the ground, as shown in Fig. 1.

4.2 Step 2: External Shading Devices Filter

Modify external inputs and coefficients calculated in Step 1, as a result of external shading devices, which alter solar and thermal variables over the glazing, walls or openings, depending on what element is affected by the shading device.

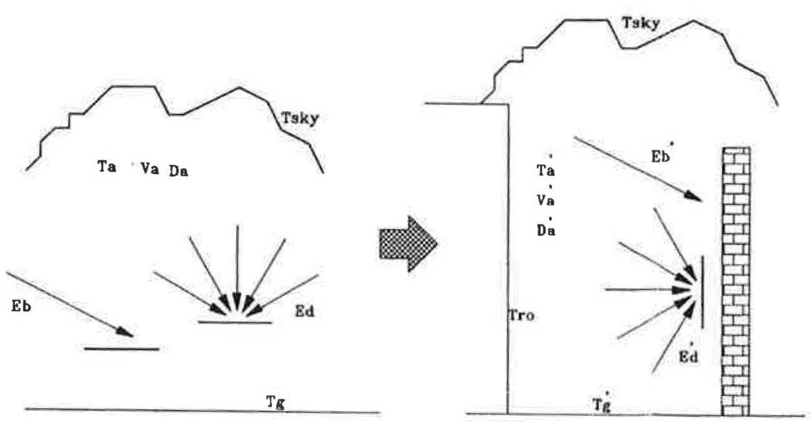

FIGURE 1 Scheme of the calculations included in the Step 1.

For the current version of PASSPORT Plus, there are three different types of external elements that can be treated, including:

Shading 0: no modification.
Shading 1: opaque facade obstacle (overhang, side-fins, set-back, awnings), ("Solar characterization of facade obstacles" library, shown in Fig. 2).
Shading 2: louver's type with vertical or horizontal slats ("Solar and thermal characterization of external louver's type shading devices" library, shown in Fig. 3).

4.3 Step 3: Primary Incidence Over Internal Surfaces

Calculate primary incidence, before radiant redistribution (multiple reflection process), over internal surfaces. This process is completed zone by zone and the primary incidence is calculated for the direct solar radiation, the radiant short-wave fraction from the internal gains and for the radiant long-wave fraction from the internal gains, shown in Fig. 4.

4.4 Step 4: Short-Wave and Long-Wave Radiation Exchanges

Calculate irradiation and heat fluxes absorbed by all internal surfaces of all building elements. For that purpose, this step performs the

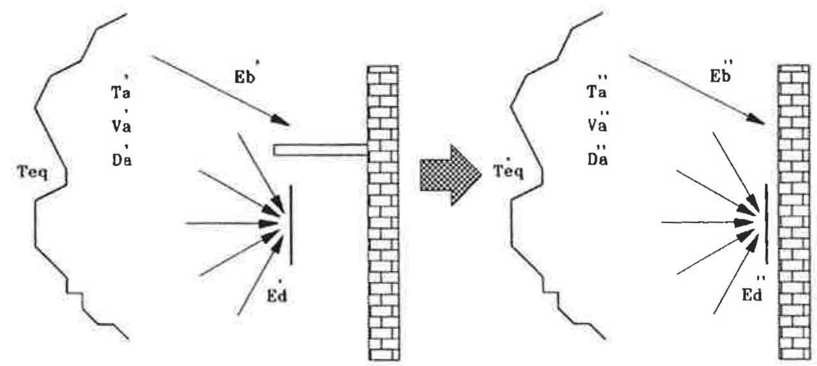

FIGURE 2 Scheme of the calculations included in the Step 2 for Shading 1 type.

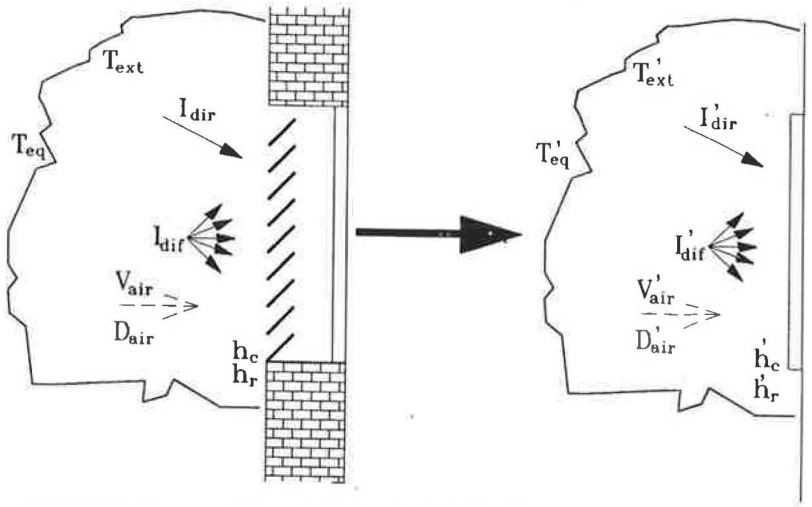

FIGURE 3 Scheme of the calculations included in the Step 2 for Shading 2 type.

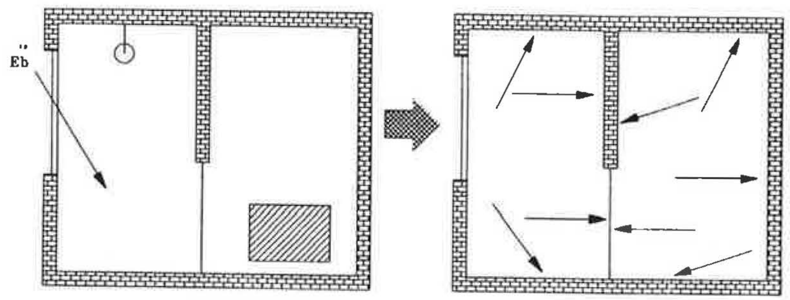

FIGURE 4 Scheme of the calculations included in the Step 3.

redistribution of short-wave radiation from the sun (direct and diffuse) and short-wave radiation from internal gains. It also makes the redistribution of long-wave radiation from internal gains and outdoor long-wave radiation that enters into the building through the external openings, shown in Fig. 5. This step also establishes a linear relation between long-wave flows absorbed by all the building surfaces and the temperature of the internal surfaces for all building elements.

4.5 Step 5: Solving the Exterior Surface Balance

Reduce the final number of surface balance equations by introducing all the external surface balance equations in the internal surface balance equations. This reduction applies to elements with one or more external surfaces, as shown in Fig. 6.

4.6 Step 6: Final Equations Solving

There are two different types of equations:

- Surface heat balance equations for every isothermal internal surface;
- Heat balance equations for the fully mixed air in every zone.

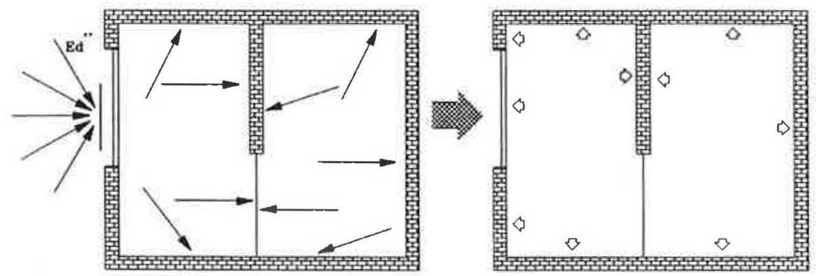

FIGURE 5 Scheme of the calculations included in the Step 4.

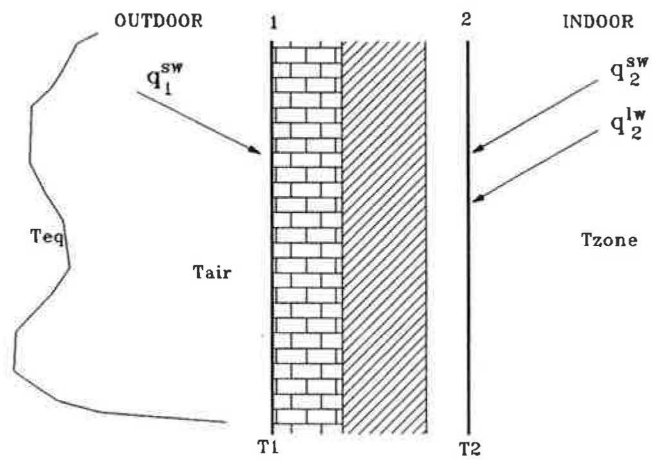

FIGURE 6 Scheme of the fluxes over an external wall.

The unknowns in this system of equations are the internal surface temperatures and the air temperature in every zone. The solving strategy has two main objectives, namely to:

- Obtain full matrices (without many zeros) for solving them with a more efficient algorithm that takes less time and memory;
- Avoid having to resolve the system when there are only changes in the independent terms of the system. The goal is to only recalculate and solve the system when there are changes in the A matrix of Eq. (2).

The solving strategy has two steps:

- First, eliminate all surface temperatures from the initial system and obtain a final system with the only unknowns limited to the air zone temperatures;
- Then solve the final system and obtain the air zone temperatures.

The general first matrix can be divided into different submatrices, as shown below:

$$\left[\begin{array}{c|c} A & B \\ \hline C & D \end{array}\right] \times \left[\begin{array}{c} T_{sur} \\ \hline T_{zone} \end{array}\right] = \left[\begin{array}{c} P_{sur} \\ \hline P_{zone} \end{array}\right], \quad (6)$$

where T_{sur} is a vector with all the internal surface temperatures of the building and T_{zone} is another vector with all the air temperatures of the building. All the surface temperatures can be obtained as a function of the air zone temperatures, by calculating the A^{-1} inverse matrix:

$$\{T_{sur}\} = [A^{-1}](\{P_{sur}\} - [B]\{T_{zone}\}). \quad (7)$$

Introducing this expression for the air zone temperatures, in the last air zone equations, we obtain the final system with only the air zone temperatures as unknowns. This full system can then be solved, for example, using a Gauss algorithm. For a two-zone building this

becomes:

$$\begin{bmatrix} * & * \\ * & * \end{bmatrix} \begin{bmatrix} T^1_{zone} \\ T^2_{zone} \end{bmatrix} = \begin{bmatrix} P^1_{final} \\ P^2_{final} \end{bmatrix}.$$

4.6.1 *Updating Matrices for Each Time Step*

The most common hour-by-hour changes, apart from the independent terms, are the air flows between zones. These changes affect only the final system and the A^{-1} inverse matrix and they do not need to be recalculated. When the matrix A is slightly modified during a given time step, for example when a window or a door is opened or closed, the Sherman–Morrison algorithm [11] can be used to update the inverse matrix A^{-1}.

5 USER INTERFACE

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 Fig. 7. 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), neighboring 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-h 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.

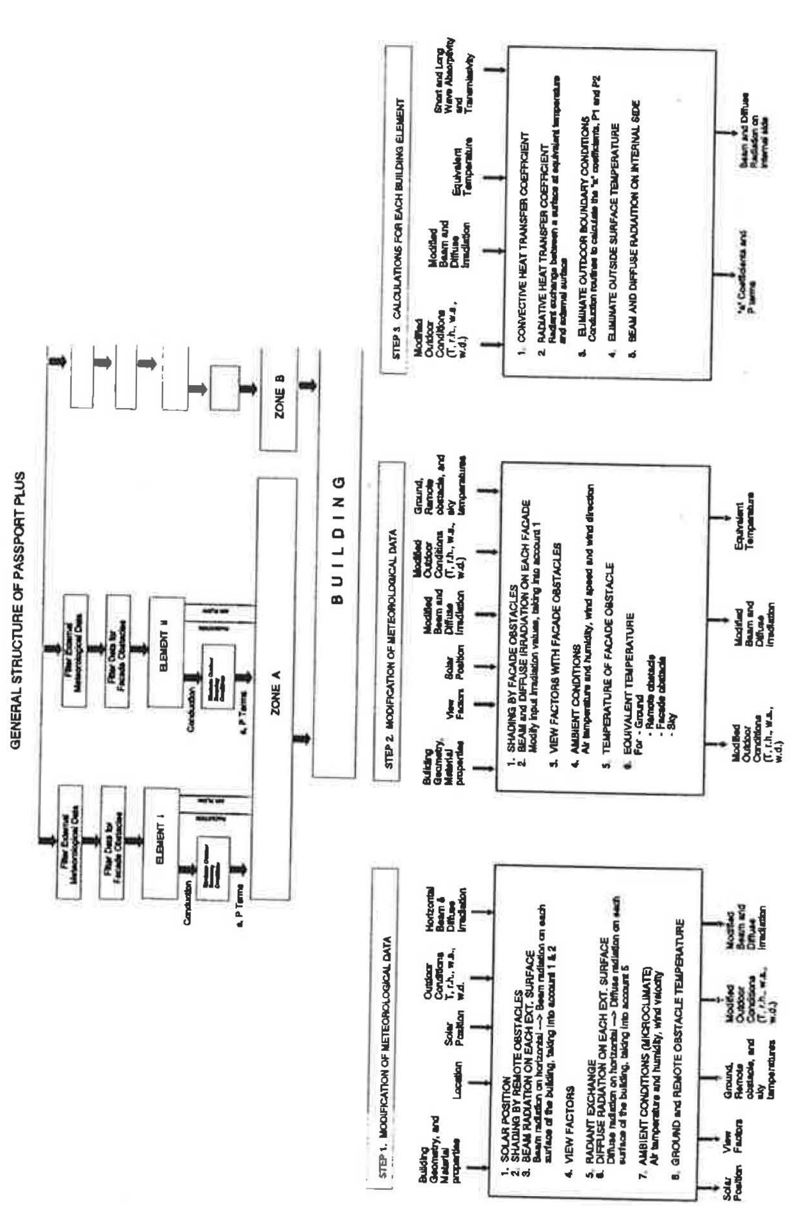

FIGURE 7 PASSPORT Plus general structure.

- *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 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.

6 INFORMATION FLOW

Figure 8 shows the general information flow between all the components included in PASSPORT Plus. Four different groups of routines are incorporated, namely:

- User interface;
- Algorithms for generating the components library;
- Algorithms for generating the building's specific library;
- Simulation modules (Steps 1–4, previously described).

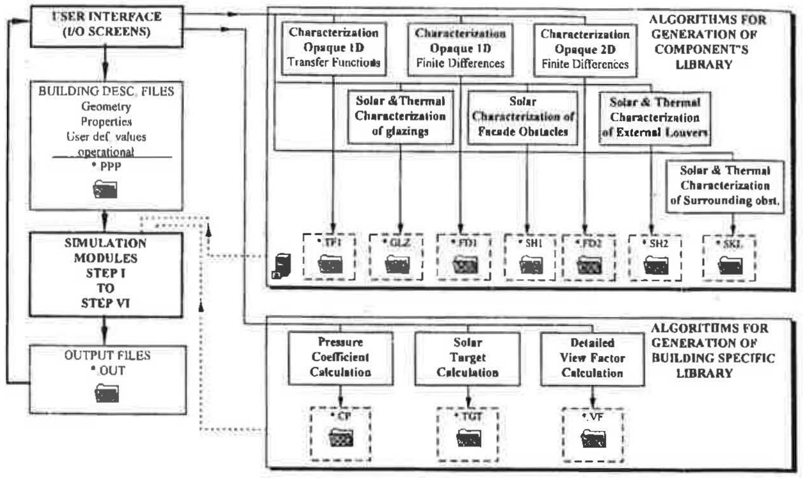

FIGURE 8 Information flow.

7 EVALUATION OF PASSPORT PLUS

7.1 Intermodel Comparison

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 "truth"; 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 [12], conducted by the Model Evaluation and Improvement International Energy Agency (IEA) Experts Group. The group was composed of experts from the Solar Heating and Cooling (SHC) Program, Task 12 subtask B, and the Energy Conservation in Buildings and Community Systems (BCS) Program, Annex 21, subtask C.

The method consists of a series of carefully specified test case buildings, which 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.

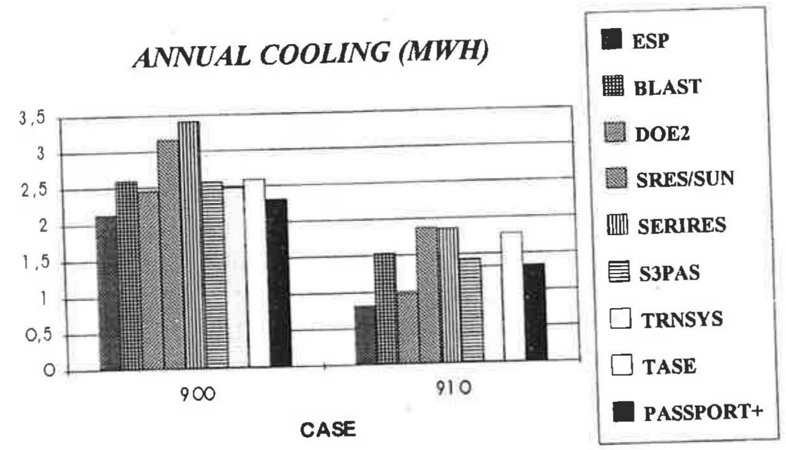

FIGURE 9 Annual cooling (cases 900 and 910).

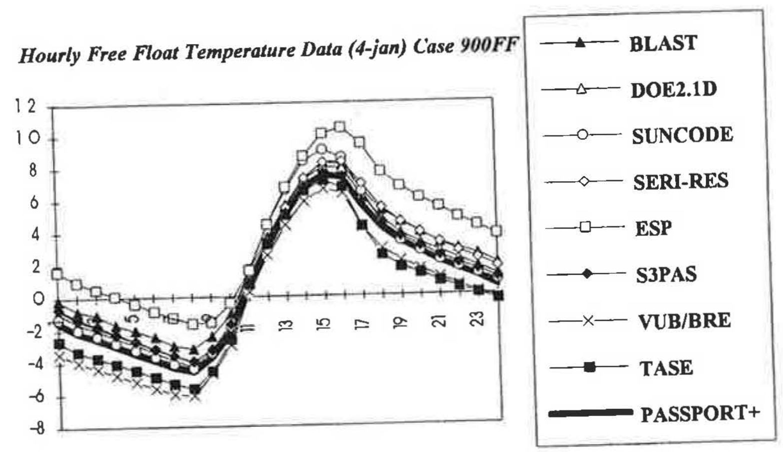

FIGURE 10 Hourly free-float temperature (case 900FF).

For example, Figs. 9 and 10 illustrate some of the results obtained. Additional results are available in [13].

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.

7.2 Comparison with Measured Data

A validation exercise using PASSPORT Plus was carried out in order to simulate two buildings and compare results on indoor air temperatures and element surface temperatures with measured data. The comparison was performed against data from two buildings that 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 Fig. 11.

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. The top part of Fig. 11 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 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-h 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 the bottom part of Fig. 11, during a three-day period in summer and winter. For the summer period the maximum temperature difference is 1°C. For the

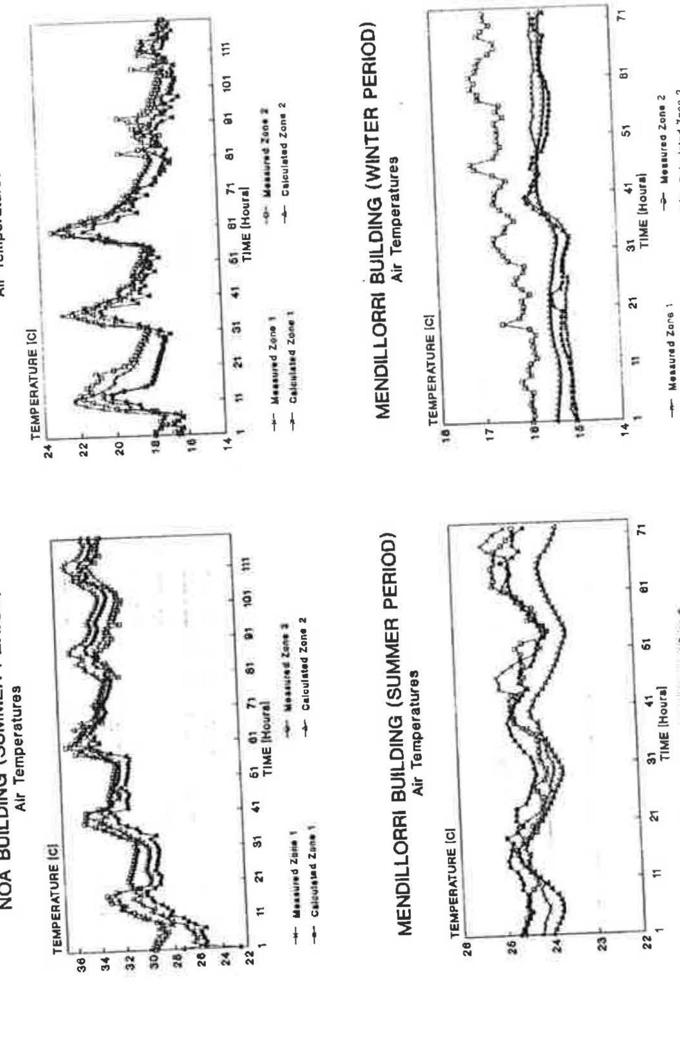

FIGURE 11 Measured and calculated indoor air temperatures, during summer and winter, for two buildings in Athens, Hellas and Pabloma, Spain.

winter period the maximum measured and calculated indoor air temperature difference is again approximately 1°C.

8 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 modeling 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 modeling 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.

LIST OF SYMBOLS

k_i	thermal conductivity of the element i
T_i	temperature of the element (surface) i
x	dimension perpendicular to the surface in the element i
h_i	film coefficient of the face i
T_{air}	air temperature near the element surface
α_i	radiant absorptivity of the element (surface) i

E_i	irradiation over the surface of the element i
$C^R_{i,j}$	long-wave radiant exchange factor between the surface i and the surface j
N_i	number of surfaces in the enclosure of the element i
$\vec{q}_{rad}$	vector with the absorbed radiant heat flow for every surface of the enclosure
$\vec{T}$	vector with the temperatures for every surface of the enclosure
$\vec{E}_{ext}$	vector with the exterior irradiation for every surface of the enclosure (only affects the (semi-)transparent elements)
$\vec{\phi}$	vector with imposed irradiation (solar radiation, internal gains, etc.) for every surface of the enclosure
$[K], [C_1], [C_2]$	matrices for the radiant redistribution calculated depending on the method used
V	volume of the zone
C_P	specific heat of the air
ρ	density of the air
T_a	temperature of the air
T_{sk}	temperature of the surface k in the zone
Q_{ig}	convective energy form the internal gains
h_{cvk}	film coefficient for the surface k in the zone
$\dot{m}_{jz}$	mass flow from the zone j toward the zone z, the zone 0 is the outdoor environment

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NATURAL VENTILATION RESEARCH ACTIVITIES UNDERTAKEN IN THE FRAMEWORK OF PASCOOL

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Natural Ventilation is a widely used passive cooling technique in the countries of southern Europe. Numerous studies have been devoted to the analysis of the physical phenomena related to natural ventilation. These phenomena are very complex and our degree of understanding them often leaves a lot to be desired. Research on this topic within the framework of PASCOOL included experimental and modeling work aiming to fill existing gaps in our knowledge of indoor air conditions in naturally ventilated buildings. An extensive experimental program was carried out in full scale buildings and test cell facilities during the summer period in Greece, Belgium, Spain, Switzerland and Portugal. Existing models were validated and new ones were proposed. This paper gives a brief description of the experimental work and summarizes the results from the data analysis and model development within PASCOOL.

Keywords: Natural ventilation; Passive cooling

1 INTRODUCTION

As revealed by the last ZEPHYR competition [1], natural ventilation is the first design strategy used by architects or designers to reduce building cooling loads and improve indoor comfort in Mediterranean countries where air conditioning systems do not represent a realistic alternative.

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