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Research in the frame of Annex 21

BUILDING THERMAL MODELS: AN INTEGRATING CLASSIFICATION APPROACH

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IEA - EXCO Technical Day
Research Presentation

Energy Conservation in Buildings and Community Systems Programme

1. INTRODUCTION

Building thermal analysis by means of simulation models has been the subject of a substantial amount of research in the scientific community in the last twenty years. An impressive number of models have been developed for all building thermal systems. The purpose of the IEA - BCS Annex 21 project is to establish a survey of what has been performed in this area in twenty years of IEA cooperation work. Annex 21 primary objective is to create an easy access to updated knowledge and software for the calculation of buiding energy and environmental performance. It aims at seeking means to transfer calculation procedures into the building and environmental services design profession.

The annex 21 project is divided into 4 subtasks :

- Subtask A : "Documentation of Existing Methods" (leader Belgium)
- Subtask B : "Appropriate Use of Models" (leader UK)
- Subtask C : "Reference Cases and Evaluation Procedures" (leader USA)
- Subtask D : "Design Support Environment" (leader Canada).

This paper relates work performed within the subtask A. The main purpose of subtask A is to establish a standardized method for documenting building thermal models and to use this standardized procedure for the documentation of typical models. The evolution of the subtask has led to the development of the "MIS" ("Management of Information System") program.

MIS is an expert system (written in Prolog) for the documentation of almost anything. It has been designed and will be principally used for the documentation of building thermal models. The heart of the MIS program consists of a double structure : the group structure and the tree structure. In order to make an efficient use of the MIS, a preliminary classification step of building thermal models is required.

An attempt to classify the different building thermal models is proposed in this paper, which starts from the observation of the physical processes occuring in such a system. Physical processes can be separated into "intra-components" processes and "inter-components" processes. For each process, a mathematical model can be built, which is based an appropriate hypotheses.

This paper shows that a strong connexion can be established between the building thermal systems classification and the building thermal models classification. As a conclusion, a classification of the different building thermal models under the form of a tree structure is proposed, which meets the requirements of the MIS structure. The whole procedure will be illustrated for a given class of building thermal systems, the passive solar systems.

2. PRESENTATION OF THE CLASSIFICATION METHODOLOGY: FROM THE SYSTEM TO THE MODEL.

Thermally speaking, a building is made of components which interact between each other. The different components can be classified according to their belonging to the building structure, the heating system, the internal (occupants, internal gains) and external (climate) environments although it is very often difficult to distinguish between these different domains. For example, a passive solar heating system is usually totally integrated within the building : a window, a so-called "direct gain" heating system is entirely part of the building although it can be considered as a heating device, transferring some useful energy from the environment to the building.

In order to classify the building thermal models, the following methodology is proposed :

1. The building thermal system is divided into components : glazing, air spaces, walls, heating systems...

2. Each component in characterized by the occurence of physical processes which are limited to the component itself : "intra-component" processes (ex. conduction through a wall).

3. Some other physical processes are occuring between components : "inter-components" processes (ex. convection between a wall and the room air).

4. Each physical process in described by a mathematical model based upon appropriate hypotheses.

5. The different process models (intra-component and inter-component processes that have to be taken into account) are combined between each other to produce the building thermal model.

The modelling methodology is represented in fig. 1. In this figure, the internal and external environments are considered as boundary conditions with respect to the building thermal system.

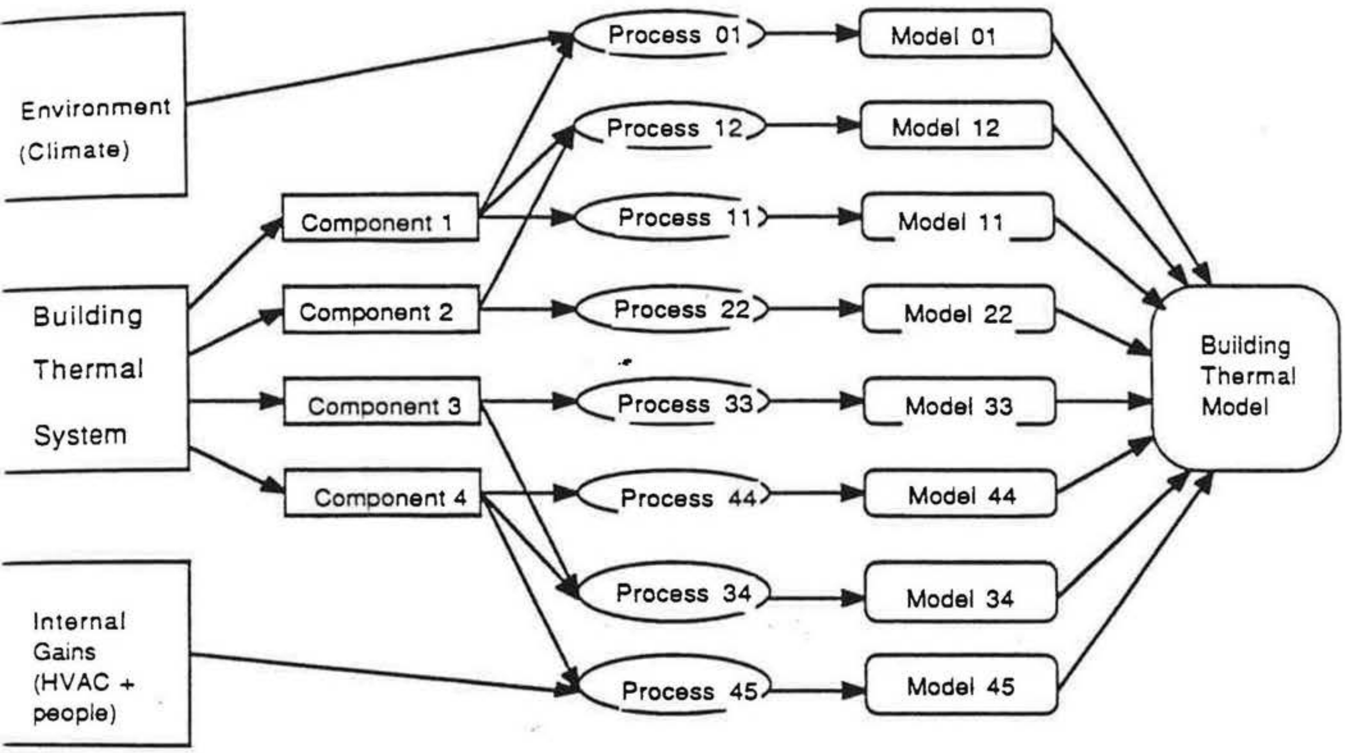

Fig. 1: Modelling methodology in building thermal systems.

As shown in fig. 1, the key operation, when modelling a building thermal system is to identify the physical processes governing the system and then to select appropriate models for each process. Furthermore, the picture shows that the integrated nature of a building thermal system (the device actually often performs several thermal functions) appears in the building thermal model formulation as well. This identification of physical processes is performed for a specific class of building thermal systems in the next paragraph.

3. ANALYSIS OF BUILDING THERMAL SYSTEMS AND IDENTIFICATION OF RELATED PHYSICAL PROCESSES.

The methodology will now be illustrated for a specific class of building thermal systems : the passive solar strategies. By their integrated nature, these systems cover most of the physical processes occuring in a building. First of all, the different strategies will be presented.

3.1. The "direct gain" system (DG).

This is simply a south facing window which collects solar energy through the glazing. Depending upon the glazing characteristics (transparent or translucent), the direct gain is classifed as diffusing or non-diffusing. Different aperture positions yield clerestories or direct gain roof systems. A special type of diffusing direct gain system is the transwall concept in which a thin absorber plate (usually tinted glass) is placed within the double glazing system and immersed in water. This system is more appropriately referred to as a "dual" gain system as it combines both direct and indirect gain principles.
(fig. 2)

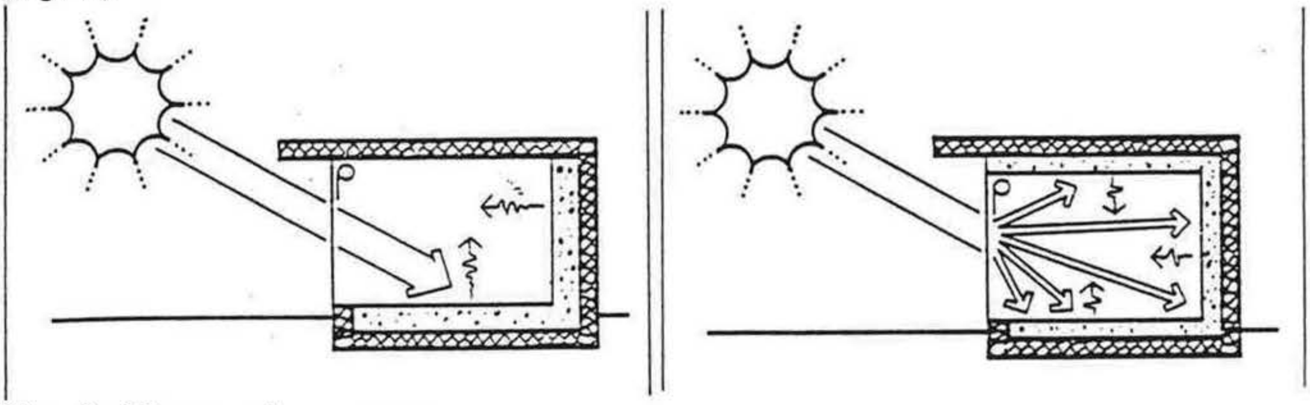

Fig. 2: Direct gain systems

3.2. The mass wall system (MW).

An accumulator wall is situated behind the glazing in order to store solar energy. Usually, the wall is painted black. The discharge is performed after conduction of heat through the wall.

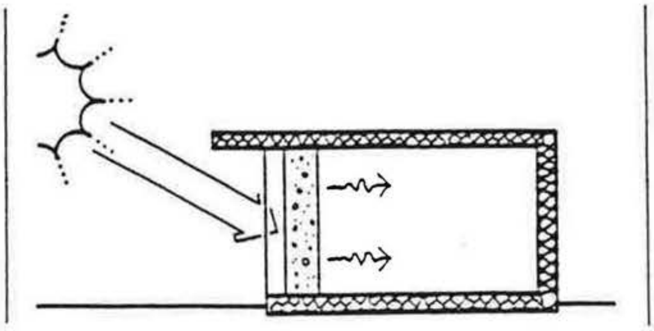

Fig. 3: Mass wall system.

3.3. The "Trombe" wall system. (TW)

Ventilation openings are located in the wall in order to establish a direct connexion between the buffer space and the room situated behind the wall. These openings are closed at night in order to avoid reverse discharge of the wall. Storage material include concrete and water. In that case, the storage medium can be considered as isothermal.

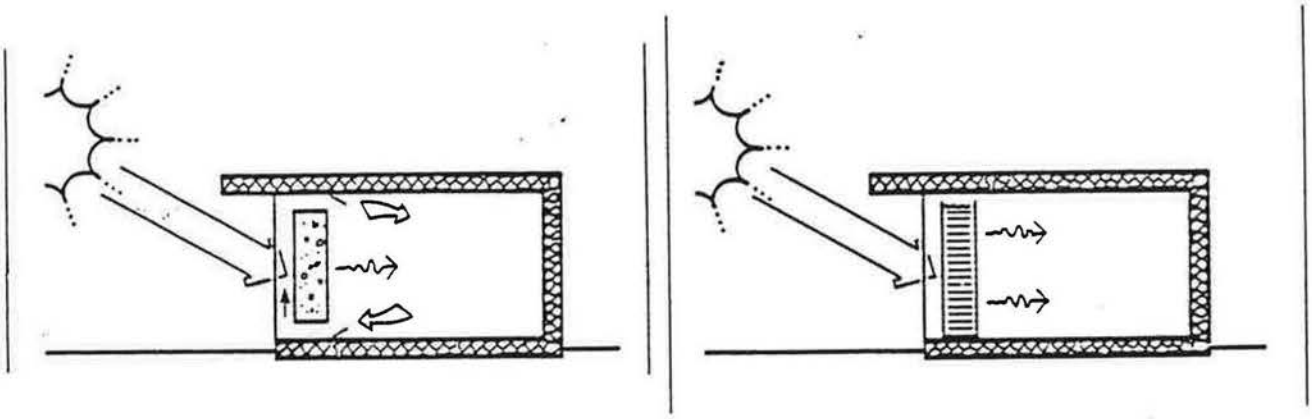

Fig. 4: "Trombe" wall systems.

3.4 The isolated wall collector system. (IW)

This is a Trombe wall which is thermally insulated. This reduces or even cancels the conductive discharge of the wall but reduces the heat losses of the device as well.

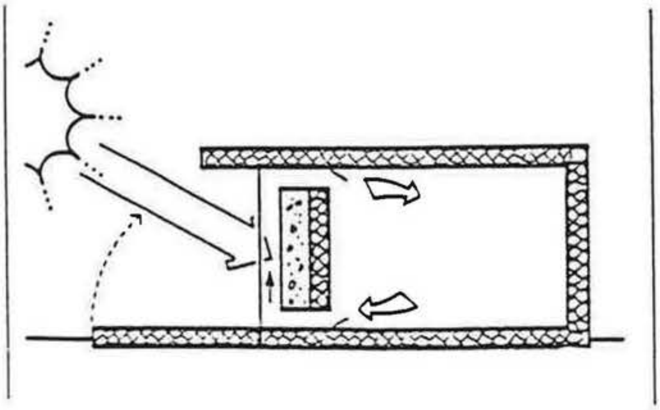

Fig. 5: Isolated Trombe wall system.

3.5. The remote storage wall system. (RS)

The Trombe wall is only made of an insulation layer and the storage device is situated in an other part of the building.

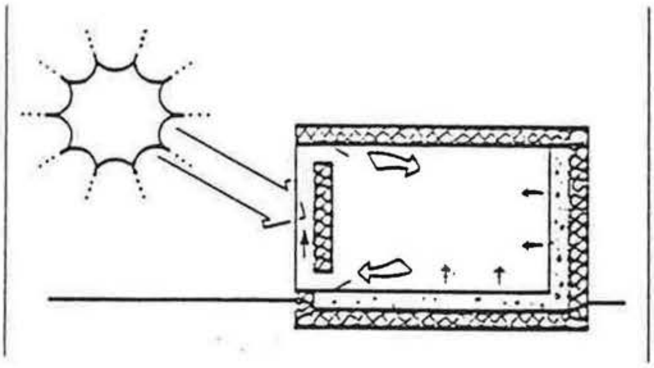

Fig. 6: Remote storage wall system.

3.6. The air collector system. (AC)

The wall is replaced by a metallic absorber cover over which air is blown. Heated air is pushed into a storage or directly vented to the room or in the building structure.

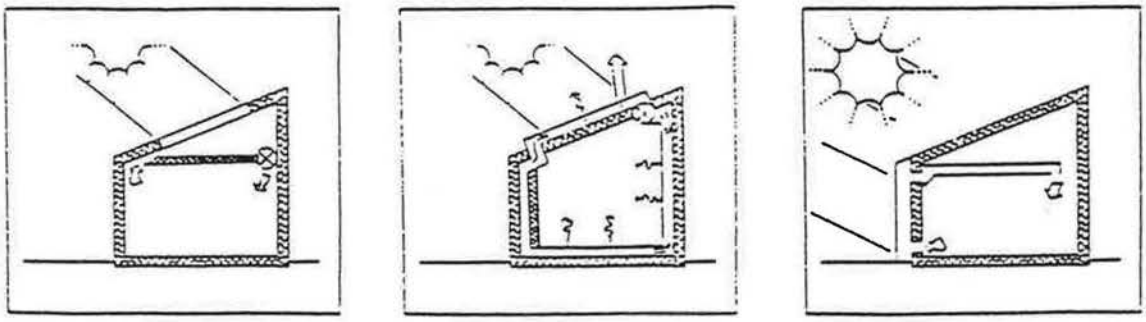

Fig. 7: Air collector systems.

3.7. The window collector system. (WC)

In this system the window is made of two double glazings (or one double glazing and one single glazing) separated by an air layer. It works either as an air collector (air is blown within the double window and solar heat is absorbed by removable blinds) or as a normal direct gain window (the internal blinds are opened).

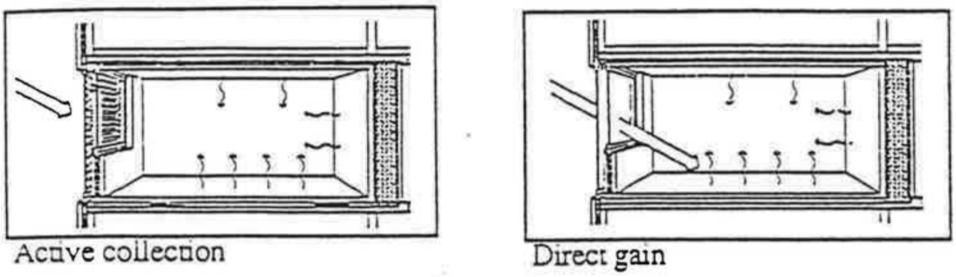

Fig. 8: Window collector systems in collector and window modes.

3.8. The transparent insulation system. (TI)

A transparent but insulating layer is placed between the glazing and the wall. This allows an optimization of the solar gains/heat losses balance. New building material such as polycarbonate honeycombs, capillary structures, aerogels, glass fibers are used as transparent layer.

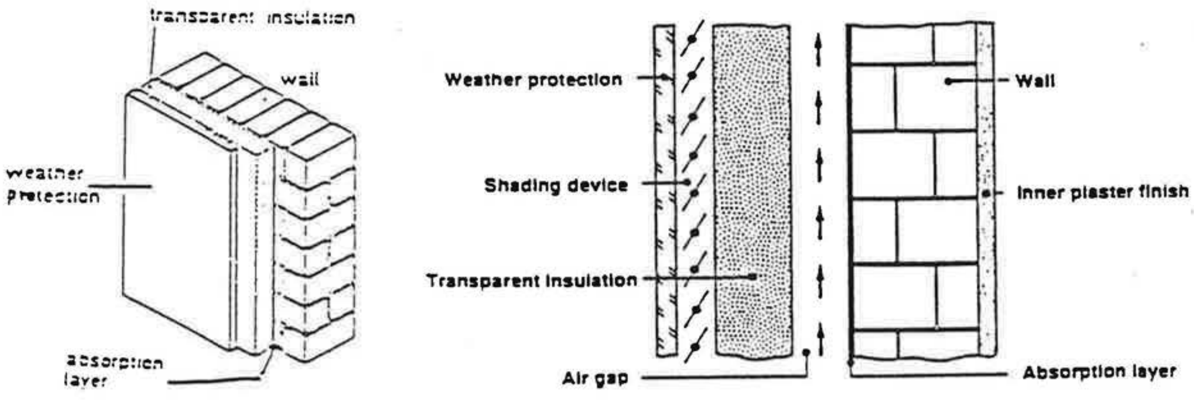

Fig. 9: Transparent insulation system.

3.9. The attached sunspace system. (AS)

The dimensions of the collector buffer space become such that it can be used as a living space. This new room is separated from the building by a wall (isolated sunspace) or is in direct connexion (optionnaly through a glazing) with the room (direct gain sunspace).

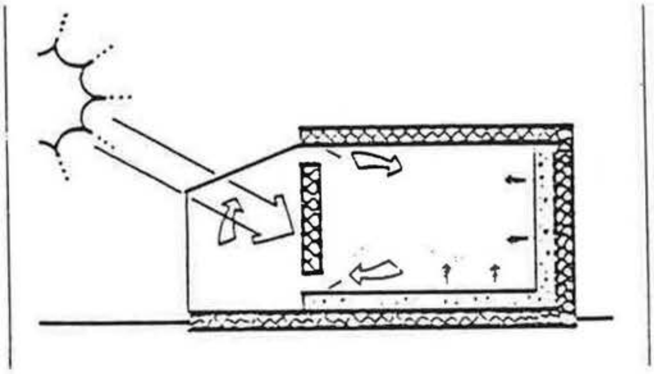

Fig. 8: Attached sunspace system.

3.10. The atrium system. (AT)

The dimensions of the sunspace are in the same order of magnitude as those of the attached building. Several atrium designs are possible, depending upon the relative position of the atrium and the building.

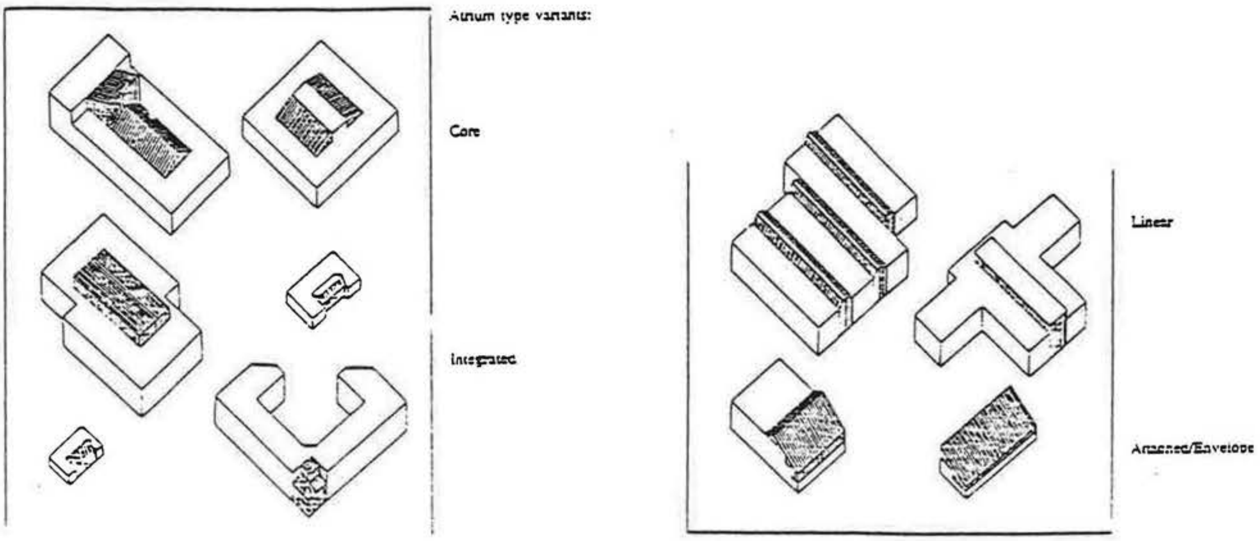

Fig.11: Atrium systems.

3.11. The solar chimney (thermosyphon) or "Barra-Costantini" system. (SC)

Heat is collected by an absorber and air is blown through the building structure (the building itself is used as a storage device). This system is usually used in association with air collectors. But it works entirely passively, without any mechanical assistance.

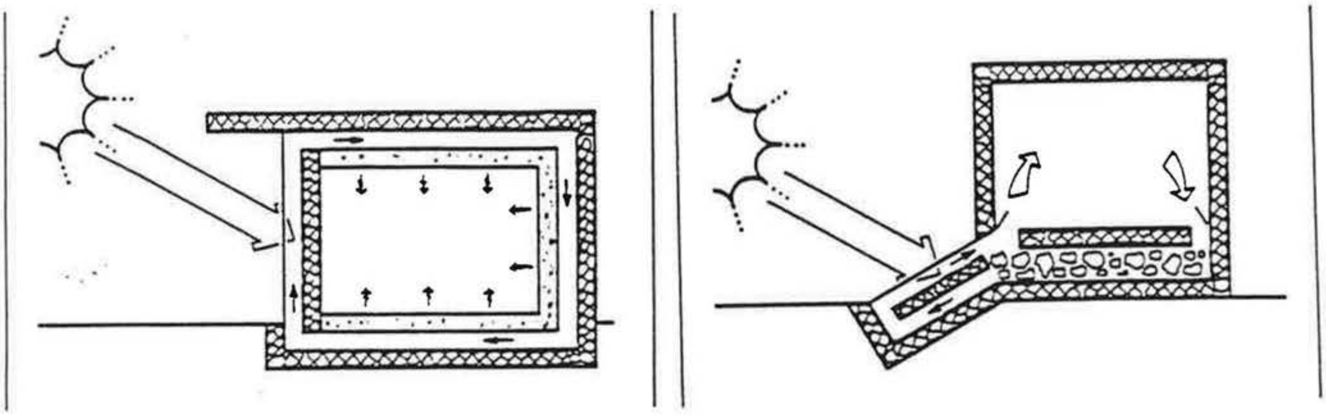

Fig. 12: Solar chimney and Barra-Costantini systems.

3.12. The dynamic insulation system. (DI)

This is not a passive solar system properly said. But it can be considered as a system very similar to the Barra-Costantini system or the window-collector system but without solar collector. The concept of the dynamic insulation is simply to blow air within the walls in order to reduce the heat losses.

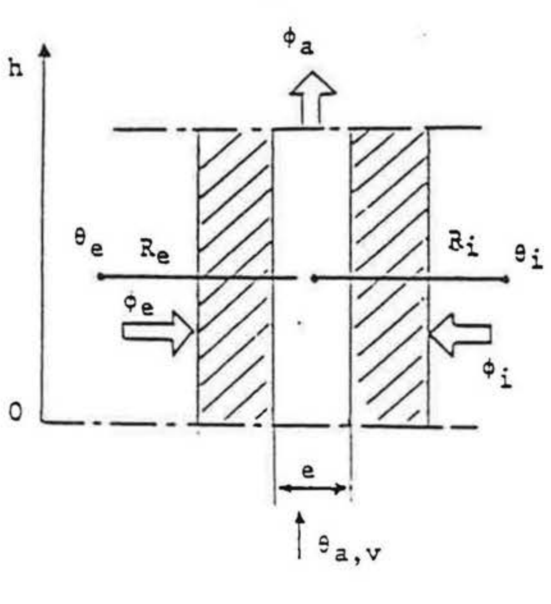

Fig. 13: Dynamic insulation system.

3.13. The classical opaque wall system. (OW)

This is neither a solar device but it is included in order to present the whole range of variation of the passive solar system. Indeed, a passive solar device can be considered as something between the wall and the window with an optional air flow in the wall, in the window or both. Starting with the window, this non exhaustive enumeration of passive solar devices logically finishes with the wall.

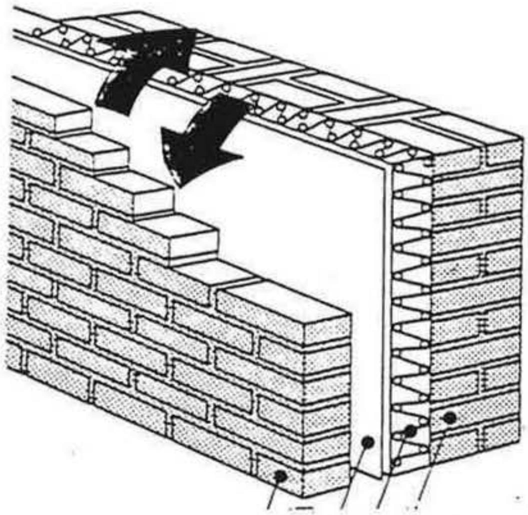

Fig. 14: Opaque wall system.

This survey shows that most of the passive solar heating devices are made of the following components:

- A glazing or transparent element, optionnaly associated with shading devices (overhangs, sidefins, external shutters, internal blinds, plants,...)

- An air space layer

- An accumulator wall.

Furthermore, the device interacts with:

- the external environment

- the building

- the internal casual gains (example: people in a sunspace)

- the auxiliary HVAC system

For all passive solar systems, and considering successively intra-component processes and inter-components processes, the following physical processes can be identified:

A. Intra component processes.

A1. Glazing.

A11. Transmission of solar radiation through the glazing.
A12. Absorption of solar radiation inside the glazing.
A13. Conduction of heat through glazing layers.
A14. Infrared radiation between glazing layers.
A15. Convection between glazing layers and filling gas/air inside the glazing.
A16. Air movement inside the glazing system.

A2. Air space.

A21. Internal conduction through the air space layer.
A22. Internal convection through the air space layer.
A23. Air movement inside the air space layer.
A24. Transmission of solar radiation through the air space layer.
A25. Absorption of solar radiation inside the air space layer.

A3. Accumulator wall.

A31. Conduction of heat through the accumulator wall.
A32. Transmission of solar radiation through transparent parts of the wall.
A33. Absorption of solar radiation inside the transparent part of the wall.
A34. Internal air movement inside the wall.
A35. Internal convection within the wall.
A36. Internal infrared radiation within the wall.

B. Inter-components processes.

First of all, the fig. 15 shows the different interactions that can occur between the different components, including the "boundary" components, in a passive solar heating system.

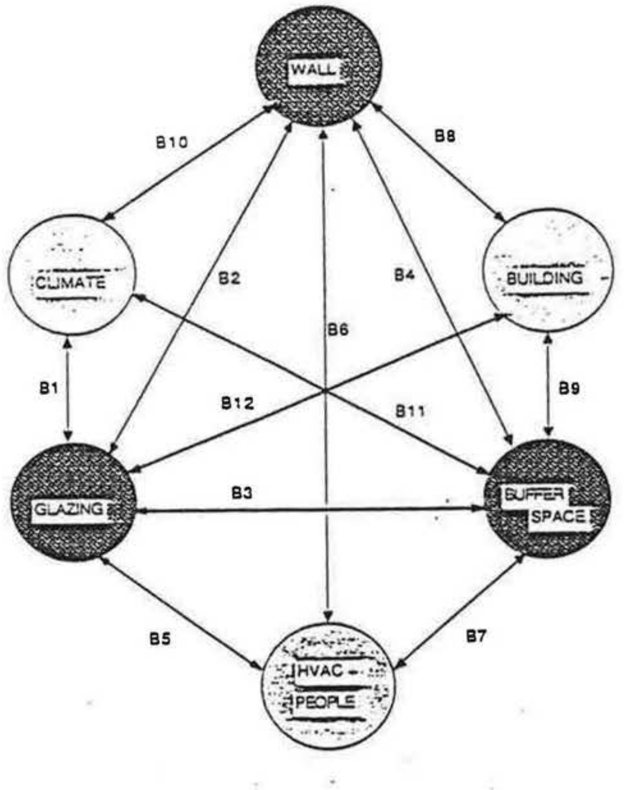

Fig. 15: The thermal interactions in a passive solar heating system.

B1. Interaction climate-glazing.

B11. Convection ambient air-external surface of the glazing.
B12. Infrared radiation between sky and external surface of the glazing.
B13. Absorption of solar radiation at the external surface of the glazing.
B14. Shading effect of overhangs, sidefins and surroundings.

B2. Interaction wall-glazing.

B21. Infrared radiation between wall and glazing.

B3. Interaction glazing-air space.

B31. Convection between internal surface of glazing and air.

B4. Interaction air space-wall.

B41. Convection betwen wall and air space.

B5. Interaction between glazing and internal/auxiliary gains.

B51. Radiative exchange between glazing and occupants/lights.
B52. Radiative exchange between glazing and auxiliary system.

B6. Interaction between wall and internal/auxiliary gains.

B61. Radiative exchange between wall and occupants/lights.
B62. Radiative exchange between wall and auxiliary system.

B7. Interaction between air space and internal gains.

B71. Convective exchange betwen occupants/lights and air space.
B72. Convective exchange between auxiliary system and air space.

B8. Interaction between wall and room (building).

B81. Convection between wall internal surface and room.
B82. Infrared radiation between wall internal surface and other surfaces of the room.
B83. Air movement betwen wall inner channel and rooms.

B9. Interaction between air space and room (building).

B91. Air movement (natural or forced) between air space and room.

B10. Interaction between climate and wall.

B101. Absorption of solar radiation at the external surface of the wall.
B102. Shading effect of overhangs, sidefins and/or surroundings.

B11. Interaction between climate and air space.

B111. Air infiltration between ambient and buffer space.

B12. Interaction between glazing and room.

B121. Air movement between glazing (inside) and room or building structure.
B122. Convection between glazing and room air.
B123. Infrared radiation between glazing and the other surfaces of the room.

The different passive solar systems can be classified according to the occurence of all those physical processes. The following table lists the different passive solar systems and the physical processes occuring for each system.

A. Intra-component processes.

		DG	MW	TW	AC	WC	TI	AS	AT	SC	IW	DI	OW
A1	1	x	x	x	x	x	x	x	x	x	x		
A1	2	(x)	(x)	(x)	(x)	x	x	(x)	(x)	(x)	(x)		
A1	3	x	x	x	x	x	x	x	x	x	x		
A1	4	x	x	x	(x)	x	x	x	x	(x)	x		
A1	5	x	x	x	(x)	x	x	x	x	(x)	x		
A1	6					x							
A2	1		(x)	(x)	(x)	(x)		(x)	(x)	(x)	(x)		
A2	2		x	x	x	x		x	x	x	x		
A2	3					x							
A2	4		x	x	x	x		x	x	x	x		
A2	5		(x)	(x)	(x)	(x)		(x)	(x)	(x)	(x)		
A3	1		x	x	(x)		x	x	x	x	(x)	x	x
A3	2		x	x									
A3	3		(x)	(x)		x							
A3	4											x	
A3	5											x	

B. Inter-components processes.

		DG	MW	TW	AC	WC	TI	AS	AT	SC	IW	DI	OW
B1	1	x	x	x	x	x	x	x	x	x	x		
B1	2	x	x	x	x	x	x	x	x	x	x		
B1	3	(x)	(x)	(x)	(x)	(x)	x	(x)	(x)	(x)	(x)		
B1	4	x	x	x	x	x	x	x	x	x	x		
B2	1		x	x	x	x		x	x	x	x		
B3	1		x	x	x	x		x	x	x	x		
B4	1		x	x	x	x		x	x	x	x		
B5	1		x	x				x	x		x		
B5	2		x	x				x	x		x		
B6	1		x	x				x	x		x		
B6	2		x	x				x	x		x		
B7	1		x	x				x	x		x		
B7	2		x	x				x	x		x		
B8	1		x	x			x	x	x	x	x	x	x
B8	2		x	x			x	x	x	x	x	x	x
B8	3					(x)						x	
B9	1			x	x	x				x	x		
B10	1		x	x	x	(x)	x	x	x	x	x	x	x
B10	2		x	x	x	(x)	x	x	x	x	x	x	x
B11	1		x	x	x	x		x	x	x	x		
B12	1					x							
B12	2	x											
B12	3	x											

Table 2: Classification of passive solar heating systems with respect to intra-component and inter-components physical processes.

4. MODELLING OF PHYSICAL PROCESSES.

The different physical processes that can occur in a building thermal heating system have been identified. When modelling a building thermal system, a survey of the physical processes governing the device has to be performed. For each process, a model has to be selected, based upon appropriate hypotheses. In order to simplify the presentation of the different models, the description will be limited to the different types of interaction, namely:

- Solar radiation transmission
- Solar radiation absorption
- Shading effects
- Conduction
- Infrared radiation exchanges
- Convection
- Air movements

For each interaction, the different models are presented:

4.1 Solar radiation transmission.

- Global calculation of transmitted radiation
- Separate calculation of transmitted radiation
    * Direct component
        - Constant transmittance
        - Sun position dependent transmittance
    * Diffuse component
        - Constant transmittance (at 60° sun height)
        - Non isotropic model

4.2 Solar radiation absorption.

- Constant absorption factor

- Variable absorption factor

4.3 Shading effects.

- Overhang calculations

- Sidefins calculations

- Skyline calculations

4.4 Thermal conduction.

- One-dimensional conduction
    * Constant diffusivity
    * Variable diffusivity
        - Temperature variability
        - Space variability
- Two-dimensional conduction
    * Constant diffusivity
    * Variable diffusivity
        - Temperature variability
        - Space variability
            * Position variability (Homogeneity)
            * Direction variability (Isotropy)
- Phase change calculations
- Water layers calculations

4.5 Surface exchanges.

- Globalized exchanges (radiation + convection)
    * Constant surface coefficient
    * Variable surface coefficient
- Separated exchanges
    * Convection
        - Constant convection coefficient
        - Variable convection coefficient
            * Temperature variability
            * Air velocity variability

* Radiation

- Constant radiation coeffcient

- Variable radiation coefficient

    * Temperature variability
    * Space variability (View factors)

4.6 Air movements.

- Constant flow rate

- Variable flow rate

    * Temperature variability
    * Temperature + pressure variability

5. SYNTHESIS: CLASSIFICATION OF BUILDING THERMAL MODELS.

The classification of building thermal models can easily be obtained by combining the two levels of classification:

1. The level of the process:

Identify the processes occuring in a given system and select those that are relevant to model.

2. The level of the model:

Select an appropriate model for each relevant physical process.

This procedure means that a tree-structure can be obtained for each building thermal heating system by considering succesively:

- the processes involved

- the available models for each process

An example of this tree-structure is given in the next page for the passive solar mass wall system. This kind of representation can be repeated for each building thermal system. The fig. 16 shows the tree structure from the system level to the enumeration of processes involved and relevant to model. The fig. 17 gives, focussing on the "wall" component, the terminal branches of the tree: from the processes to the available models.

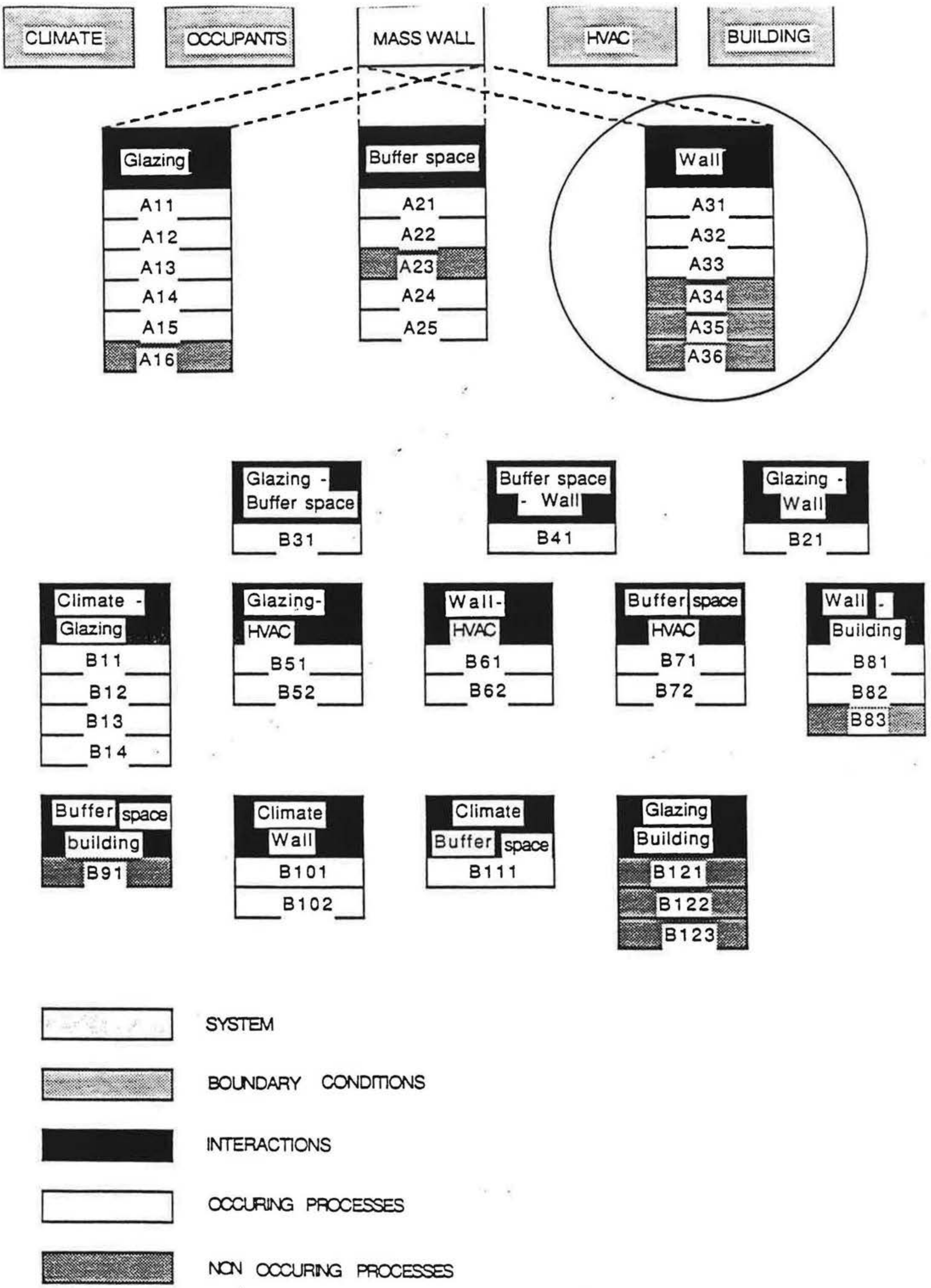

Fig. 16: Tree-structure for the mass wall system: first part

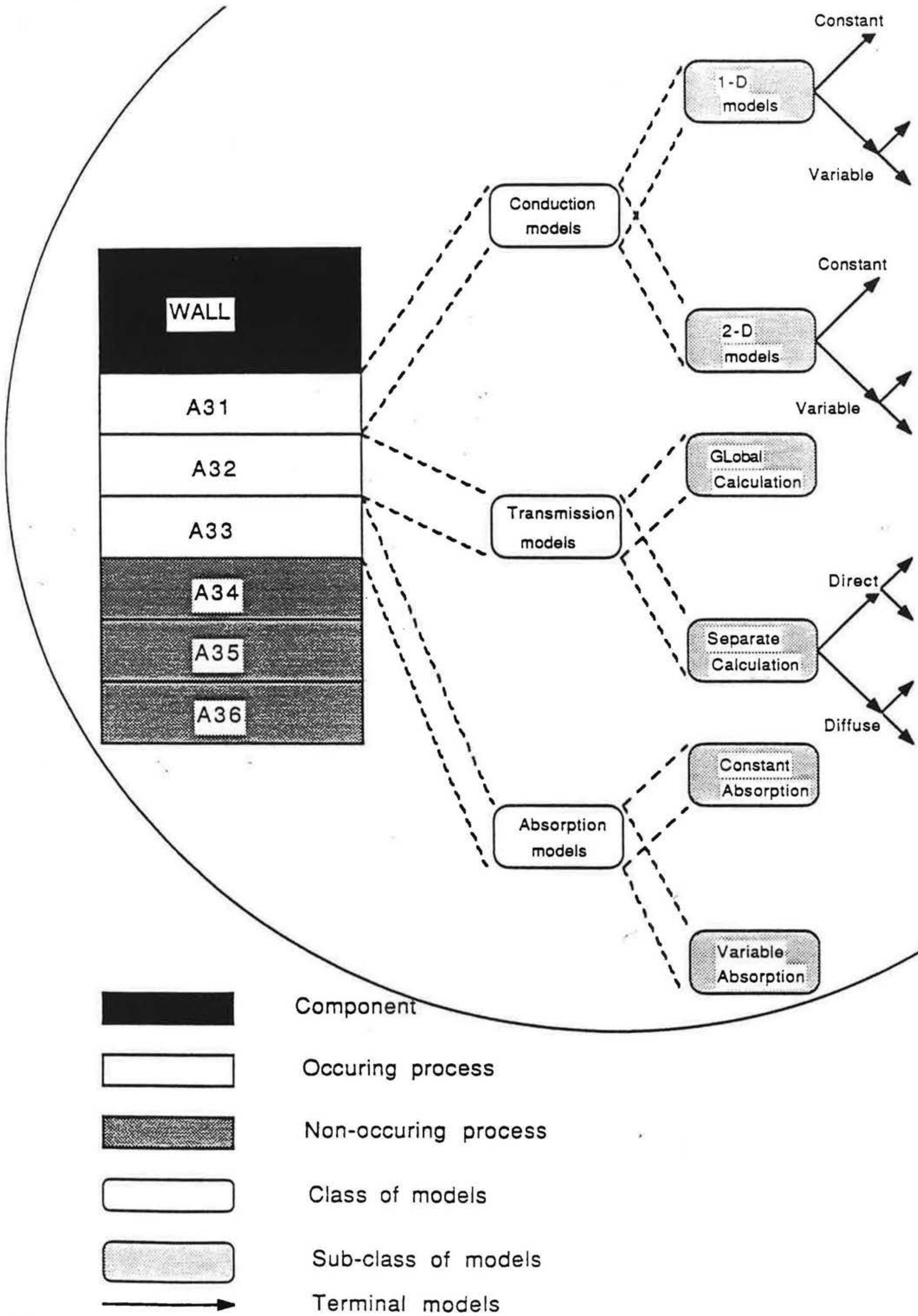

Fig. 17: Tree-structure for the mass wall system: second part.

The tree-structure which is proposed in this paper is not entirely compatible with the MIS structure in that it establishes a difference between the intra-component processes and the inter-component processes. As a consequence, an interaction such as the convection process between a wall and a zone air appears only once in the tree-structure. This is in opposition with MIS philosophy in which the convection exchange between a wall and a zone appears under the "model of zone" (convective gain from wall surfaces) heading as well as under the "wall" heading (internal surface convection).

6. CONCLUSIONS.

In this paper, an attempt has been made to obtain a classification of building thermal models. The methodology involves the division of the building thermal device into individual components. For each component, physical processes entirely limited to this component are identified (intra-component processes). Then, the relations between components are described and the inter-components processes are identified. The different types of physical processes are defined and for each process, the available models, depending upon the basic hypotheses, are presented. The application of the whole procedure yields, for each building thermal system, a tree-structure starting with the physical system and finishing with the models that can be used for representing a given system. The whole procedure is illustrated for a specific class of building thermal systems, the passive solar devices. Their intrinsic integrated and multi-processes nature make them a good example in order to test the methodology. The procedure is well suited for computerization, for instance within the IEA Annex 21 "MIS" expert system.

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