COUPLING EXPERT SYSTEMS TO THERMAL CALCULATION AND SIMULATION COMPUTER CODES

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ABSTRACT

The present paper shows a possible way to make simulation computer codes more easy to use by nonspecialists. The basic idea is to implement a code which translates the building representation into a suitable thermal model. It is a part of a more important project which takes place at the Solar Energy Laboratory (LESO-PB), and which aims at the elaboration of an integrated system to assist building designers (Morel 1989a). That integrated system is organized around a central database to store the current state of building being designed, and includes expert systems in various domains, as well as classical' procedural computer codes to calculate significant quantities (energy indexes, costs, task lists, etc). The paper is focused on the structure of the central database and the interface to a dynamical thermal simulation code.

1. INTRODUCTION

It is now widely recognized that the energy issue cannot be analyzed independently of the other issues with which the designer is faced, and that the tool for thermal analysis and design of a building has to be integrated into a collaborating set of tools connected together. For example, a compromize has to be found between an increased thermal insulation and the corresponding rising of building cost.

Therefore, we need to store somewhere within the tool a global view of the building being designed, with enough characteristics to allow the proper work of all the connected tools. This structure may be compared with a "blackboard" system, where the experts are taking and giving back information and knowledge from and to a central instance.

On the other side, thermal analysis of a building is currently frequently done using monthly energy balance calculations (see for example (LESO 1991)). These simplified methods, although quite enough accurate to give the designer the numbers he needs to qualify the building for heating energy demand, are not adequate to evaluate the thermal comfort. Many tentatives of evaluating the comfort by simplified methods were made (see for example (Claux 1985)), but they generally do not give reliable enough numbers, or they cannot take into account user's behaviour or complex situations.

It could be therefore useful for the designer to be able to use a dynamic thermal model of the building, but without the need of the detailed knowledge which is usually required from the user of such a computer code. The work presented here shows a tentative to allow a more or less automated elaboration of the thermal model corresponding to the designed building. The building is supposed to be represented with enough details in the central database (we will see later which characteristics are needed). Moreover, as we already have a good practical experience with nodal network models, we use such a model in the present work (Morel 1984). An elementary help for analysing the results has been devised, but not yet implemented at all.

In the paper, we will focus on two topics:
- the central instance to store the building representation;
- the implementation of the code to translate the building representation into a thermal model (that part of the tool is not yet completely operational).

2. BUILDING REPRESENTATION IN A DATABASE

The central instance of the integrated design tool has to store a representation of the building in the current design state, being progressively refined by the designer with the help of the various tools used in the process. A more detailed analysis is given in (Morel 1989 b).

This central instance must meet the following criteria:
- it must allow an easy access at various levels of detail (depending on the field and the tool accessing the data);
- it must be evolutive, ie when a new design tool is being added it should not be necessary to re-elaborate the building model from the beginning;

- it should be easy enough to interface to all computer tools used by the practioners, currently or in the future.

In order to fulfill these requirements, an object oriented database is certainly the best solution. We decided to go in that direction, and used the database management system (DBMS) ONTOS (Ontologic 1990), which is based on the object oriented programming language C++. In fact, ONTOS simply brings to C++ objects the 'persistance' property, and maintains on disk a permanent image of the volatile objects defined in C++.

The building is described by objects, which may be either 'constructive' objects such as a wall, a window or a heating radiator, or more abstract objects such as a room, a thermal zone, the building location, or the definition of climatic conditions.

Each object may be defined at a more or less detailed level, depending on the need of the considered connected tool. For example, the description of a whole facade with global Uvalue and other thermal properties may be enough for a simplified monthly heat balance calculation code, but for a detailed dynamic simulation model such as the one which is discussed in that paper a more detailed description of each facade component may be needed (walls, windows, doors, etc). In the first case, the facade itself is considered as an 'elementary object', but in the second case it will be a 'composite object', the elementary objects being the walls, the windows, etc.

The relations between the objects are described by 'relational properties', such as 'contains' or 'adjacent to'. They are typically stored in lists of pointers to other objects. The schema of these relationships is represented on figure 1.

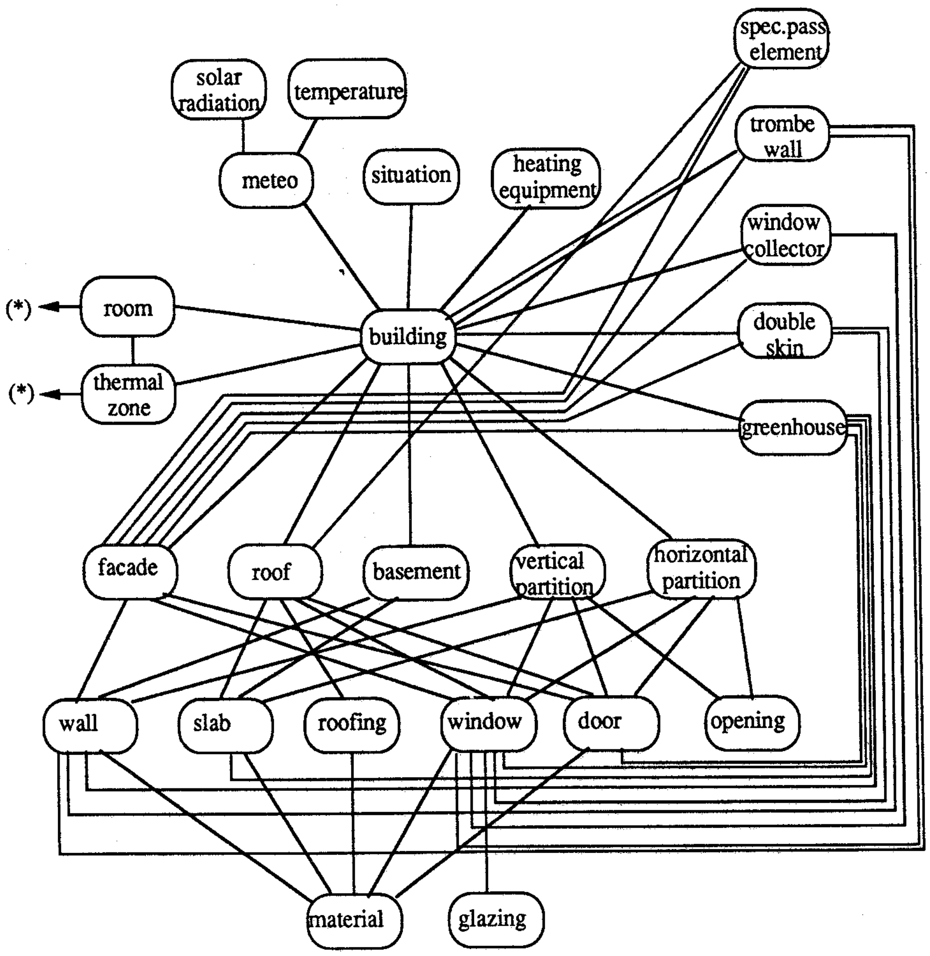

Fig.1: Building representation database schema ((*): the objects belonging to classes 'room' and 'thermal zone' are linked to facade, roof, basement, vertical partition, horizontal partition, wall, slab, roof, window, door, opening, greenhouse, double skin, window collector, trombe wall, special passive element). The links represented on that figure are 'contains', 'adjacent to', or 'in'.

It has to be noted that the current representation of technical equipment is rather global, and that a more detailed model should be elaborated further.

The object representation has many advantages. Among them, it offers the possibility to represent the knowledge associated with building calculations very easily, by the use of 'methods' (functions) attached to class descriptions. For example, the calculation of a wall Uvalue is performed from the description of the wall layers (material code and thickness of each layer), using a method attached to class 'WALL'. Such a calculation may also use property values of connected objects, such as the calculation of the average Uvalue of a facade from the thermal characteristics of each facade component.

Another advantage, that will be used in our case, is the ability to use that central instance as a blackboard, where various module write data which may be used further by other modules. For example, from a basic representation of the building, where only the objects 'room' have been defined by the user, a first module may define the thermal zones from the rooms, create the objects 'thermal zone', and another module may take the thermal zones one by one to elaborate a network thermal model of each zone.

3. ELABORATING A NODAL NETWORK MODEL: AVAILABLE KNOWLEDGE AND ITS TYPE

In a previous paper presented at EuropIA90 (Morel 1990), we proposed a classification of knowledge types which are used in building domain. We distinguished "empirical" knowledge (rules of the thumb, practical experience from the specialist, short-circuit of more detailed knowledge), "typological" knowledge (classification of building elements), and "procedural" knowledge (the knowledge that may be easily formalized as algorithms).

In the case of the elaboration of a thermal nodal network model of the considered building, we may distinguish 2 steps: (i) the definition of thermal zones, (ii) the definition of thermal nodes and complete network model (ie. connections between nodes and heat sources applied to nodes).

For the first step, there is no easy way to define an algorithm. Therefore the knowledge may be best formalized as a rule set. For the second step, the knowledge may be partially contained as rules, and a reduction algorithm may be applied in order to reduce the order of the system (ie. the number of nodes which are necessary to have an accurate enough model).

Finally, it has to be noted that in the reality the distinction is not always so clear between the knowledge types, and moreover that the two mentionned steps in the nodal network elaboration are strongly interrelated.

Considering the block diagram of the whole integrated system, the following organization of the thermal dynamic calculation subsystem is therefore proposed (fig.2).

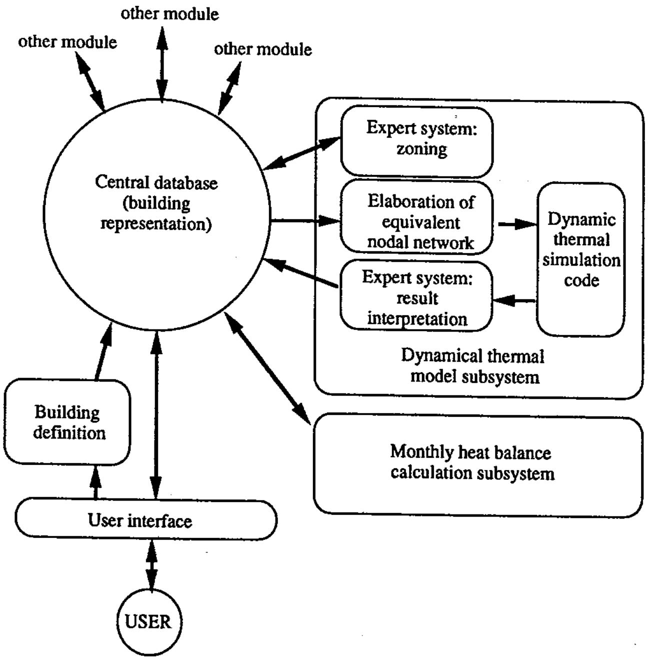

Fig.2: connexion of simulation code to integrated design tool

4. ZONING AND BASIC PROPOSITIONS FOR THERMAL ANALYSIS TO THE DESIGNER

The elaboration of a complete nodal network for a building has to pass through the intermediate step of defining thermal zones in the building. We suppose here that the building is made of rooms, and that a thermal zone may only contain one or more whole room(s) (ie. one room may never be part of more than one thermal zone). Therefore, we have to group the rooms together to compose thermal zones.

The knowledge that will be considered here has been formalized from the experience of the authors and other researchers at LESO-PB for several years of thermal modelling with nodal network computer codes.

When elaborating a zone schema, various factors have to be considered:

- the thermal load per m^2 of floor (solar gains and other "free" heat gains);
- the intrinsic thermal characteristics of the rooms (mainly the effective thermal mass per m^2 of floor, and the conduction towards outside and towards the neighbour rooms);
- the operational mode of the rooms (setpoint temperature);
- the room temperatures to which the user is interested;
- the maximum number of zones which are allowable (if we do not define a limit, the best result will certainly be obtained with one thermal zone per room !).

Within the constraint of the maximum number of zones, there should be some way of estimation whether the zone schema is adequate, or whether the maximum number of zones should be increased in order to have a good enough nodal network.

The particular case of one zone model will not be explicitely considered here, as it is rather obvious. In some cases it could be a model good enough to correspond to the reality.

The basic idea is to scan all the rooms one by one, and for each room either to attribute a new zone or to group it with other room(s) in an already defined zone. A new zone will certainly be created if one of the following conditions is met:
- the user is interested in the temperature of the considered room;
- the setpoint temperature is different from the neighbour rooms AND the room has a significant influence on the rest of the building;
- the thermal characteristics are different from the neighbour rooms AND the room has a significant influence on the rest of the building;
- the thermal load are different from the neighbour rooms AND the room has a significant influence on the rest of the building;
- the room is the first one to be scanned.

A new zone will certainly NOT be created if one of the following conditions is met:
- the room has an assigned temperature (in that case, an assigned temperature node will be considered, and not a "floating" node);
- the room has little connexion with the rest of the building AND the user is not interested in its temperature behaviour;
- the room is connected tightly only with other rooms which are in the same situation.

The term "different" has now to be defined more precisely. It is proposed here to express every kind of difference in terms of temperature difference. For the setpoint temperature difference, the correspondance is direct and obvious.

For thermal load, the difference may be expressed by the temperature difference which would be caused, considering the effective thermal mass of the room. If we suppose that we start the day with the same temperature T_0 (for rooms 1 and 2), the temperature reached at the end of the day will be respectively, for the rooms 1 and 2 (neglecting the thermal link with other rooms):

$$T_1 = T_0 + Q_1/M_1$$

$$T_2 = T_0 + Q_2/M_2$$

where Q_1 and Q_2 are the free heat gains integrated during the whole day, in (J), and M_1 and M_2 are the effective thermal capacities, in (J/K).

When the connection between rooms 1 and 2 are rather tight, the approximation made is no more valid, and the heat flow from one room to the other must be taken into account. The expressions for T_1 and T_2 may then be given by:

$$T_1 = T_0 + \frac{1+k_2}{1+k_1+k_2}\,\frac{Q_1}{M_1} + \frac{k_1}{1+k_1+k_2}\,\frac{Q_2}{M_2}$$

$$T_2 = T_0 + \frac{1+k_1}{1+k_1+k_2}\,\frac{Q_2}{M_2} + \frac{k_2}{1+k_1+k_2}\,\frac{Q_1}{M_1}$$

where the factors k_1 and k_2 are defined as:

$$k_1 = \frac{g_{12} \cdot t_{day}}{2 \cdot M_1}$$

$$k_2 = \frac{g_{12} \cdot t_{day}}{2 \cdot M_2}$$

g_{12} being the conductance from room 1 to room 2, and t_{day} the duration of the day (86400 s).

Using these simplified rules, we have elaborated an expert system module, using Nexpert-Object tool coupled with the building representation (currently written with C++ language). The expert system takes the room list as the input, and elaborates a thermal zone list, based on the user's wishes asked at keyboard by expert system. In the practice, it creates objects belonging to class 'THERMAL ZONE', which are then written in the central database.

An additional role of the expert system is to give advise to the user about the conditions in which a thermal simulation should be performed. The factors to consider are:
- the thermal time constant of the whole building;
- the period which has to be studied (winter, summer,

mid-season);
- the situation of the building relative to its environment;
- the available weather files.

5. NODAL NETWORK DECOMPOSITION ALGORITHM

The basic proposition is to start from a very detailed thermal network (for each thermal zone), and to reduce it afterwards, using an aggregation algorithm. Originally, we intented to use a linear aggregation algorithm such as the one explained in reference (Neirac 1987). Temporary, we used a much simpler algorithm,based partly on the same basic assumptions as the linear aggregation method, and partly on the experience accumulated through years of simulation practice.

The linear aggregation method is based on the following principles: several nodes may be aggregated if the conductance between them is much greater than the conductances towards other nodes; moreover, the time constant associated to the thermal capacities of the aggregated nodes and the conductances between them should be smaller than the significant time interval (which may be considered as the simulation timestep). On the contrary of the modal decomposition, the linear aggregation method has the advantage of keeping a physical significance to the reduced state variables.

In our case, we used a much simpler algorithm. We need to define a characteristic thermal capacity per unit area, C_{max}. When two adjacent nodes have a total superficial thermal capacity lower than C_{max}, they will be aggregated, under the following conditions:
- only one of the nodes should receive heat flow (solar radiation, auxiliary heating, etc);
- the thermal conductance between the nodes should be greater than a lower limit G_{min}, calculated in function of the total thermal capacities C_{agg} of the aggregated nodes an the simulation timestep Δt: $G_{min} = C_{agg} / \Delta t$.

Moreover, the nodes with a thermal capacity (per unit area) lower than an absolute minimum C_{min} will be ignored as a thermal mass (typically, it concerns the insulation material).

This simple algorithm has been implemented as a C code, taking its input data in the central database, and producing an output file for the nodal network simulation code we use at LESO-PB (Morel 1984).

6. SIMULATION RESULTS ANALYSIS

A very important part of the work has not yet been tackled now: in order to be of practical use, a complete energy analyzer should also contain knowledge to interpret the simulation results. As for the simulation input, the interface towards user (and central database if the user wants to store the results) may be composed of two parts:
- a purely algorithmic part, which calculates significant quantities from the behaviour of the various building state variables (minimum and maximum temperatures, number of hours over a predetermined value, comfort characteristics from Fanger's theory, maximum peak heat demand for heating equipment dimensioning, etc);
- an expert system part, which contains the rules that the experienced practitioner uses when he/she analyzes the results of the simulation; these rules are based on the quantities calculated in the previous step.

7. CONCLUSION: TOWARDS A DESIGN TOOL WITH A COMPLETE ENERGY ANALYZER

In order to be widely accepted by building designers who are not experts in computer use (architects or engineers), a tool to analyze the dynamical thermal behaviour of a building has to include enough knowledge concerning the way to simulate the building. On the other hand, the simplified heat balance calculation methods, which normally might be easy enough to be used in the practice, do not currently give all the necessary information to design a good building on the point of view of thermal behaviour, particularly concerning the overheating risk and the thermal comfort issue.

It is therefore necessary to add, to a classical dynamical simulation computer code (nodal network equivalent, response factors, harmonic decomposition, etc), an interface which contains the knowledge the experts in thermal simulation use when they build a model from the building characteristics.

In our case, such a proceeding is made easier through the use of a building representation, in the frame of our research around an integrated design tool. Therefore, the user should not have to enter more information on the building structure than what is already in the central database. We are currently investigating possible ways to enter the building characteristics into the central database (coupling with a conventional CAD system, specialized building definition language, etc); that topic will not be treated here.

The system we expose here is based on the use of a small expert system as an interface between building representation and a nodal network simulation code, in conjunction with a simple interface in order to reduce somehow the order of the system and produce the input configuration file for the simulation code. The reduction algorithm is currently very crude, and should be refined in the future.

Such a design tool could be improved, by the use of a simulation code including equipment simulation. Currently, the code used does not simulate equipment behaviour, but only calculates dynamical evolution of the temperatures and heat flows everywhere in the building. Although the user has the possibility to define thermostats or "regulated nodes", the equipment itself is not modelized. In the future, such a modelization has to be included, in order to fulfill the requirements of the practicioners.

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