Building Simulation

SISLEY : AN OPEN TOOL FOR TRANSIENT-STATE TWO-DIMENSIONAL HEAT TRANSFER

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ABSTRACT

Sisley is an open software that uses the volume-element method to model two-dimensional heat transfer problems under transient and steady-state conditions. It includes a powerful simulation engine coupled with a simple and interactive interface. It make it possible to generate dynamic equations of both physical and reduced models. This software is used to model conventional thermal bridges, as well as windows frames heat losses or specific walls (heated floor) and foundation. In this article we present Sisley software trough a thermal bridge application.

Keywords : Computer simulation , Energy consumption, Building envelope, thermal bridges

INTRODUCTION

Two-dimensional heat transfers are important in buildings because specific problems like heated floors or thermal bridges have significant effects on energy performance and occupant comfort. The evaluation of these transfers on the overall building performance represents a difficulty frequently encountered by building professionals. Thus numerical simulation provides an efficient response to this problem.

Existing tools [1],[2] are calculation programs specific to the heat transfers in the walls. These types of software are primarily based on entering the geometry in 2 dimensions (2D) or 3 dimensions (3D) of the wall through a graphic interface. Then they calculate the distribution of flows and temperatures under steady-state conditions via a meshing, which may not be automatic. These tools do not, however, provide the possibility of evaluating the effect of local heat transfer (thermal bridges) on the overall building performance.

In order to provide an accurate assessment of the heat transfer effect on the building performance, we have developed Sisley software. This software operates under Windows 95 with 12 MB RAM. This paper will illustrate main features through an example of thermal bridge problems.

USER INTERFACE

Sisley Software allows the users to draw the configuration of the walls using a 2D heat transfer library of graphic components. This library may be shared by several users and enhanced as one wishes. In our case we describe an **L** thermal bridge structure (cf Fig 1)**.**
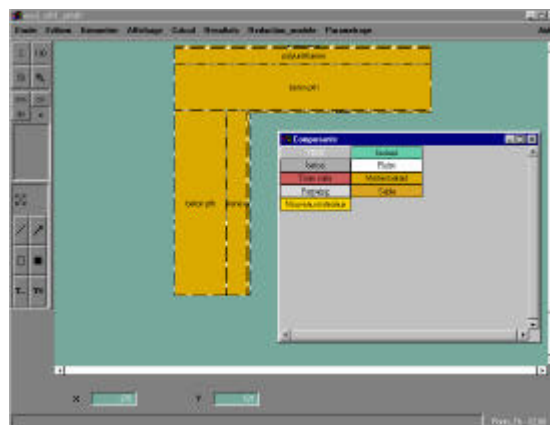

Fig 1 : Choice of materials

After choosing the materials the user defines boundary conditions. The principle of drawing the boundary conditions is simple. The user pastes a magnetic line - representing the boundary conditions - on the surface of the wall (Cf fig 2). Different boundary conditions could be used :

- Imposed temperature.
- Imposed Flux.

- Imposed Convective heat transfer coefficient.
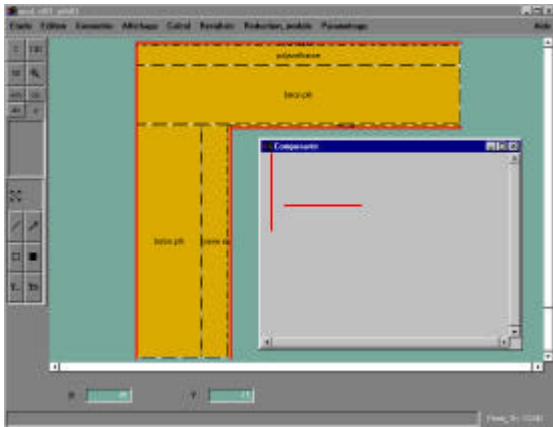- Null Flux (by default).

Fig 2 : Definition of boundary conditions

CALCULATION

- *automatic meshing.*

Using this graphic description, Sisley automatically creates the whole meshing used to model the thermal bridge. The calculation algorithm is based on an irregular meshing of the "Tchebycheff" [3] type. All the meshing points are distributed over a semi circle. The positions of these points are projected onto the segment. The nearer to the surface the denser the meshing is (see fig 3).

Finally, the user can modify an existing automatically generated meshing in order to build a new meshing.
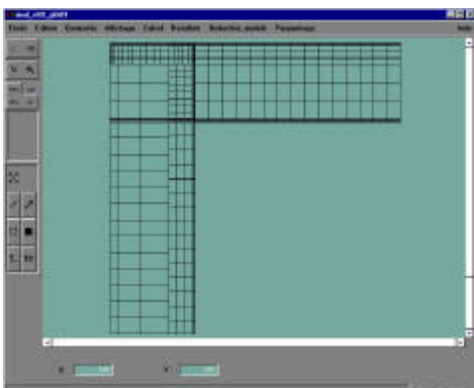

Fig 3 : Automatic meshing

- *The Risk of condensation*

For comfort problems isothermal lines and the risk of condensation are studied. The figure 4 shows the risk of condensation (red point on the corner).

This risk depend on the air temperature and air humidity. When the air is in contact with the surface of the wall, the temperature changes but its specific humidity remained.
Humidity of the wall surface is then calculated [4] – The air humidity in the room is given by the user. Condensation appears if relative humidity on the surface exceeds 100 %.
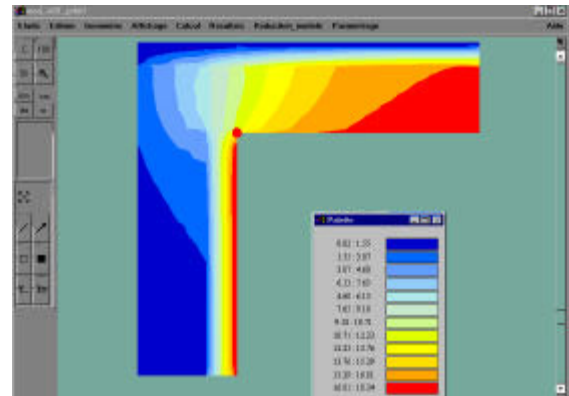

Fig 4 : Evaluation of the risk of condensation

- *Steady state calculation*

As fig 4 shows, Sisley software evaluates isothermal temperature from the boundary conditions. A powerful engine based on Gauss-Seidel iterative method is implemented. The steady state calculation step is used to evaluate temperatures and fluxes and to verify that the model and its data are correctly entered.

- *Automatic generation of the physical model.*

Sisley then generates the equations of the thermal bridge dynamic model in the state space form (see Eq. 1). In our case, the model inputs are the temperatures outside and inside the home and the outputs are the heat flows corresponding to the heat losses. T represents the field of temperatures inside the walls, $Text$ is the outside temperature, $Tint$ is the temperature inside the home and ϕ is the heat losses in the wall.

$$\begin{cases} \dot{T} = A \times T + B1 \times Text + B2 \times T\,\text{int} \\ \phi = H \times T + D1 \times Text + D2 \times T\,\text{int} \end{cases}$$

Equation 1. Representation of the model in the state space form.

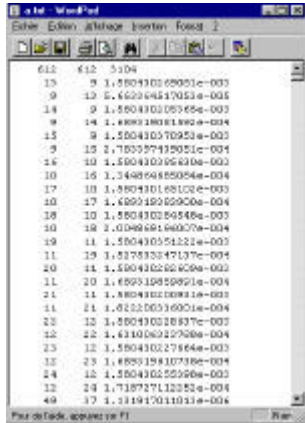As result, the user obtains matrix files of A, B1, B2, H,D1, D2 in sparse format (cf fig 5).

Fig 5 : sparse file of result

In our application, Sisley software generates 612 equations (cf Fig 5). Depending on the applications, the equation number varies from 400 to 1000 equations. Due to this great number of equations we introduce a specific generator to reduce the model size.

- *Automatic generation of the reduced model.*

The reduced model generator is based on Moore's reduction method [5,6]. This is a truncating technique which eliminates a part of the model so that only the dominant components of the model are conserved. These dominant components are enhanced by a base change. The truncation model, already used in building thermal response [7], involves retaining the largest time constants in the reduced model. Small time constants are eliminated. Moore's reduction is similar, in principle, to modal truncation.

Moore's truncation initially involves passing from the thermal base (Equation 1) to the "balanced" base. This base is based on the controllability and observability concepts used in Automatic control.
A strict definition of controllability and observability is given in [8], together with a description of the Automatic concepts introduced in this paragraph.
To make it simple, controllability is the possibility, to obtain and vary the model states using the system inputs. Observability is the possibility to determine the model states from the outputs.
The controllable and observable state components are defined by their controllability matrix **Wc** and

observability matrix **Wo**, obtained by a Lyapounov type resolution:

$$(2) \quad \begin{cases} \mathbf{A} \times \mathbf{Wc} + \mathbf{Wc} \times \mathbf{A}^T = -\mathbf{B} \times \mathbf{B}^T \\ \mathbf{A}^T \times \mathbf{Wo} + \mathbf{Wo} \times \mathbf{A} = -\mathbf{H}^T \times \mathbf{H} \end{cases}$$

The "balanced" base, is constructed so that the controllability and observability matrices are identical and equal to a diagonal matrix **W**. The term "balanced" means that the system's controllability and observability have an equally important role in the construction of this base.
Moore's truncation involves retaining the most controllable and observable state components of the system. The most dominant states, in terms of controllability and observability have the index d (3).

$$(3) \quad \begin{pmatrix} \dot{\mathbf{Xd}} \\ \dot{\mathbf{Xf}} \end{pmatrix} = \begin{pmatrix} \mathbf{Abdd} & \mathbf{Abdf} \\ \mathbf{Abfd} & \mathbf{Abff} \end{pmatrix} \times \begin{pmatrix} \mathbf{Xd} \\ \mathbf{Xf} \end{pmatrix} + \begin{pmatrix} \mathbf{Bbd} \\ \mathbf{Bbf} \end{pmatrix} \times \mathbf{U}$$

$$\mathbf{Tair} = \begin{pmatrix} \mathbf{Hbd} & \mathbf{Hbf} \end{pmatrix} \times \begin{pmatrix} \mathbf{Xd} \\ \mathbf{Xf} \end{pmatrix} + \mathbf{Db} \times \mathbf{U}$$

The states retained by the truncation are those which:
- are the easiest to excite for an energy signal at the model's input,
- have the greatest effect on the observed outputs.

The models obtained after reduction are 3rd or 5th order dynamic models (depending from the initial model structure – **L**, **T**, etc..). The reduced model faithfully reproduces the physical model in the stationary and transient state. The parameters of this reduced model lose, however, their physical meaning.

SIMULATION OF REDUCED AND PHYSICAL MODELS IN MATLAB.

In this part we analyse orders of the reduced model - 3rd and 5th orders - and we compare them with the physical model. The frequency response of reduced models (cf fig 6) shows that the 5th order reduced model is available to simulate the behaviour of thermal exchanges with a time step of 1 hour (2.77^{E-4} Hz). For this thermal bridge structure the 3rd order model is eliminated.
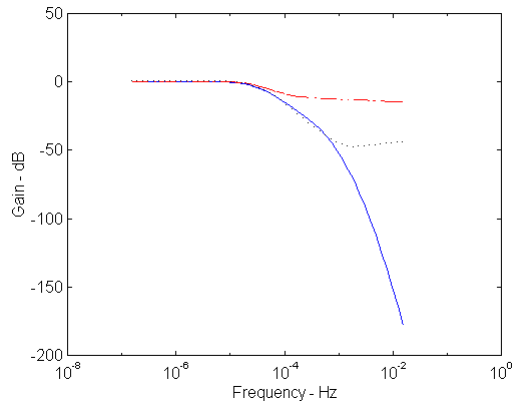
Fig 6 : Model frequency Response
Solid curve – physical model
Dashed curve - 3rd order reduced model
Point curve – 5th order reduced model

We simulate thermal bridge models (reduced and physical) with the external temperature. The meteorological scenario of Paris is chosen. The internal temperature is regulated at 19°C.
We verify - see zoom fig 7 - that the 3rd order reduced model has oscillations. The 5th order reduced model response and physical model response are similar.
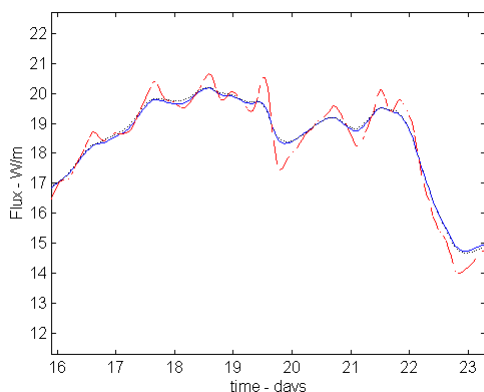

Fig 7: simulation comparison
Solid curve – physical model
Dashed curve - 3rd order reduced model
Point curve – 5th order reduced model

OTHER APPLICATIONS

Sisley allows to represent special frames as steel frames. A 2D model of a roof deck with a steel bulb tee on center, is studied with Sisley. This example is developed in [9]. We verified that a 2 D model is more accurate than a 1 D model to study this type of configuration.
Other applications could be developed with Sisley software. Figure 8 shows the case of a heating floor. The squares represent the heated cable. The reduced model is used to evaluate thermal comfort

(limited temperature of floor surface). A library of reduced order models of building components such as "conventional thermal bridges" or heating floor can be constitued and then used in modelling environments like Clim 2000 [10].
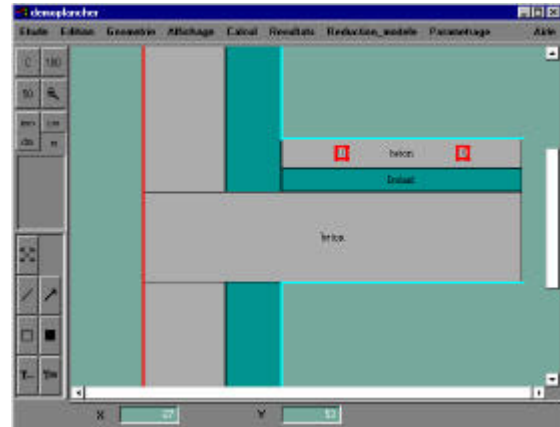

Fig 8 : heated floor model

VALIDATION

In order to validate Sisley we developed two types of comparison :
- Comparison with analytic solutions. We compared 2 D models with simple frames whose solution is given by 1 D analytic calculation or analytic cases coming from [11].
- Code Comparisons. We validated different configurations of thermal bridges with KOBRU [12].

CONCLUSION.

This article presents the Sisley tool used to accurately model 2D heat losses in buildings by thermal bridges. First, Sisley software has numerous advantages as a tool for analysing general 2D heat transfer problems. It is an user-friendly software and its engine can solve complex transfer geometry structures (limited to rectangular shapes) more precisely than models obtained from thermal regulation values [13]. Then the graphic capabilities make it possible for the user to evaluate new materials by enhancing the library as one wishes. Finally the two generators of physical and reduced models are the main advantage of Sisley tool. Reduced models can be integrated into the other components of the envelope to be simulated in the overall energy performance tool of building. A coupled approach with Sisley and a general simulation environment will provide essential supports for evaluating complex configurations of heat transfer problems.

REFERENCES

[1] C. Huizenga, D. Arasteh and al., Therm 2.0 : a building component model for steady-state two-dimensional heat transfer, *Proc. IBPSA 6rd Int. Conf. Building Simulation '99, University of Kyoto, Japan* ,Sep.,1999, pp. 337-341.

[2] H. Nimiya and al., Thermal analysys of 3-Dimentional heat bridges included in steel framed houses - Method of making models and analysis examples, *Proc. IBPSA 6rd Int. Conf. Building Simulation '99, University of Kyoto, Japan* ,Sep.,1999, pp. 747-753.

[3] Francis ALLARD, Contribution à l'étude des transferts de chaleur dans les cavités thermiquement entraînées à grand nombre de Rayleigh, *Thèse d'Etat*, Insa de Lyon 1987.

[4] K. Speidel, Diffusion et condensation de vapeur d'eau dans le bâtiment ,PYC édition, 1983

[5] B.C. Moore, Principal component analysis in linear system : controllability, observability, and model reduction; *IEE Trans Automatic Control AC-26,17-32*, 1981.

[6] S. Dautin, F. Déqué, D. Petit, J.P. Gaillard, Comparison of Model Reduction Methods in Buildings' Thermics - Application to an experimental Building, *Proc.CLIMA 2000*, Brussels 1997.

[7] S.A. Marshall, An approximate method for reducing the order of linear system. *Control 10, 642-643*, 1966.

[8] T. Kailath, Linear systems, *Prentice-Hall* 1980.

[9] J.E. Seem, S.A. Klein, W.A. Beckman, J.W. Mitchell, Transfer Functions for Efficient calculation of multimensional Transient Heat Transfer, Journal of Heat Transfert, Vol 111, Feb. 1999.

[10] D. Bonneau, FX.Rongere, D.Covalet, and B. Gautier, CLIM 2000 : Modular software for energy simulation in buildings, *Proc. IBPSA 3rd Int. Conf. Building Simulation '93,* University of Adelaide, Australia, Aug.,1993, pp. 85-91.

[11] "Heat Conduction" de Necati OZISIK , John WILEY and Sons, New york 1980.

[12] http://www.physibel.be

[13] Th- K77 - Règles de calcul des caractéristiques thermiques utiles des parois de construction - CSTB.