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Simulation of Passive Cooling and Natural Facade Driven Ventilation

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Synopsis

In many design cases, energy as well as occupant comfort are the relevant criteria which are studied using computer simulation programs. Comfort evaluations cover air quality, thermal, visual and acoustical comfort. For all these individual aspects, specific simulation programs are available today, but very few programs allow for the integrated evaluation of several or all relevant parameters. The more, heat transport, ventilation as well as lighting are physically coupled and therefore must be integrally modelled in the simulation process.
This paper gives a short description of the concept used for the coupling of the air flow simulation code COMVEN with the building and systems simulation code TRNSYS. Then, two application examples typical for a building design study situation are presented.
The first example shows a multi-storey school building which is passively cooled at night-time due to natural stack airflow. The influence of the operation of the openings on the maximum room temperatures is discussed for a hot summer period case.
The façade of the building of example 1 shall be retrofitted with a glazed outer façade. In example 2 the natural ventilation of this building is studied. Ventilation is provided by naturally driven shaft ventilation through the façade spaces. Control strategies for the openings and the blinds are discussed in respect to overheating risk and minimum air flow rates.

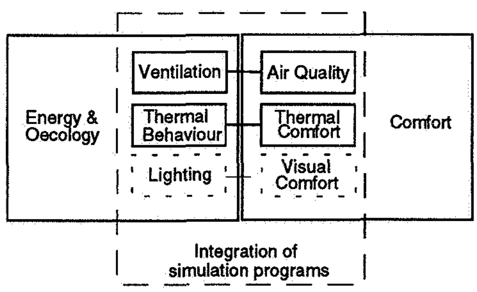

Figure 1: Evaluation of energy and comfort aspects

Keywords: Multizone air flow modelling, building simulation, coupling, COMIS, TRNSYS, passive cooling, façade driven ventilation

1 COMV-TRNS: Integration of COMVEN as a TRNSYS Type

1.1 Combined modelling of heat, air and contaminant transport

Many building simulation models are not very well adapted to the simulation of natural ventilation. On the other hand, multizone air flow models normally require the room air temperatures as input values. Therefore the modelling of thermally induced driving forces is limited because in many applications the room air temperatures are not known a priori. In such cases, the coupling of a thermal and an air flow model is needed. This can be established according to

several different concepts, ranging from user directed parameter transfer to a complete merging of the two model codes.
Quite a few attempts to integrate an air flow model into a thermal model have already been made [1]. This paper describes the integration of the multizone air flow and contaminant transport model COMIS into the building and systems simulation code TRNSYS [2].

1.2 The multizone air flow simulation code COMIS

COMIS is a multizone air flow and contaminant transport simulation code which development started in the frame of the one-year COMIS workshop and presently is continued in the frame of the IEA-ECB Annex 23 'Multizone Air Flow Modelling' [3]. COMERL, an user interface with an integrated database is available for PC. A graphical, more sophisticated user interface is developed in the frame of Annex 23. The actual simulation code, written in Fortran77, is named COMVEN.

1.3 Integration of COMVEN into TRNSYS

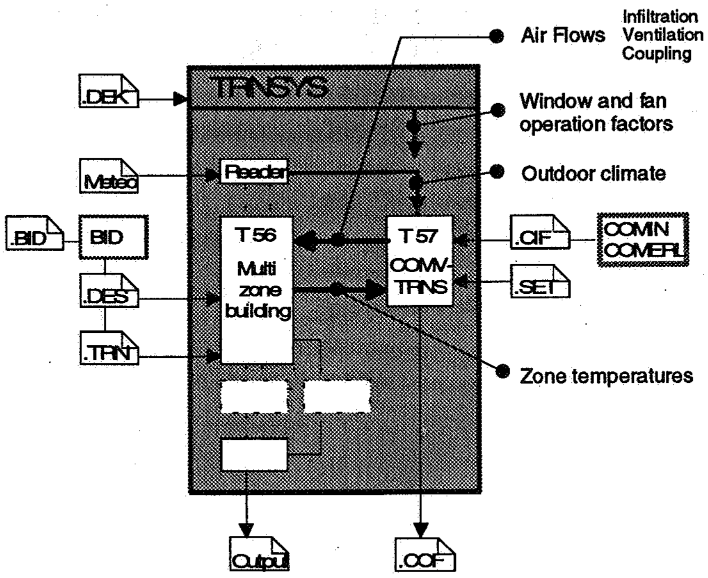

Figure 2: Integration of COMVEN as Type 57 into TRNSYS, data transfer, related files and pre-processor programs

The simulation program COMVEN has been adapted as Type 57 COMV-TRNS for the building systems simulation code TRNSYS, to be used in combination with the TRNSYS multizone building Type 56 [4]. This allows for the integral determination of the heat fluxes due to transmission, radiation and convection. Interactions between the building masses, the plants and the air flows due to natural and mechanical ventilation can be studied.

Figure 2 shows the TRNSYS program with the two Types mentioned, the parameters of their data connection, as well as the related input and output files and the respective pre-processor programs.

2 Example 1 : Passive night cooling by natural ventilation

2.1 Description of the building and the simulation cases

For a four-storey school building, the effect of passive cooling by natural night ventilation was studied. Figure 3 shows a section of the building with the respective air flow paths through the gap in the always closed internal room door and the bottom hung openable windows to outside.
Two operation modes are compared: In mode 1 the windows are fully opened at night and during the breaks, and in a tilted position during the lessons, in mode 2 the windows are closed at night, tilted during the lessons and fully opened only for one hour before the morning and the afternoon lessons respectively.

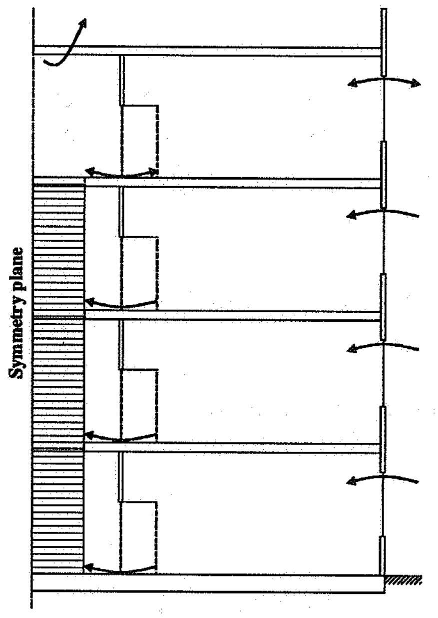

Figure 3: Cross section of the building and the air flow paths for natural ventilation

2.2 Simulation results

For one typical room during a hot summer period in Lucerne, central Switzerland, Figure 4 shows for mode 1 and 2, respectively, the outside and room air temperature as well as the outdoor air exchange together with the window opening schedule.

The full opening of the windows in the morning brings the room temperature rapidly down to the outside temperature, but due to the higher building mass temperature, in mode 2, the room temperature rises quickly again during the lesson, while in mode 1 the temperature remains on a moderate level. Peak room temperatures differ about 4°C from mode 1 (night cooling) to mode 2.

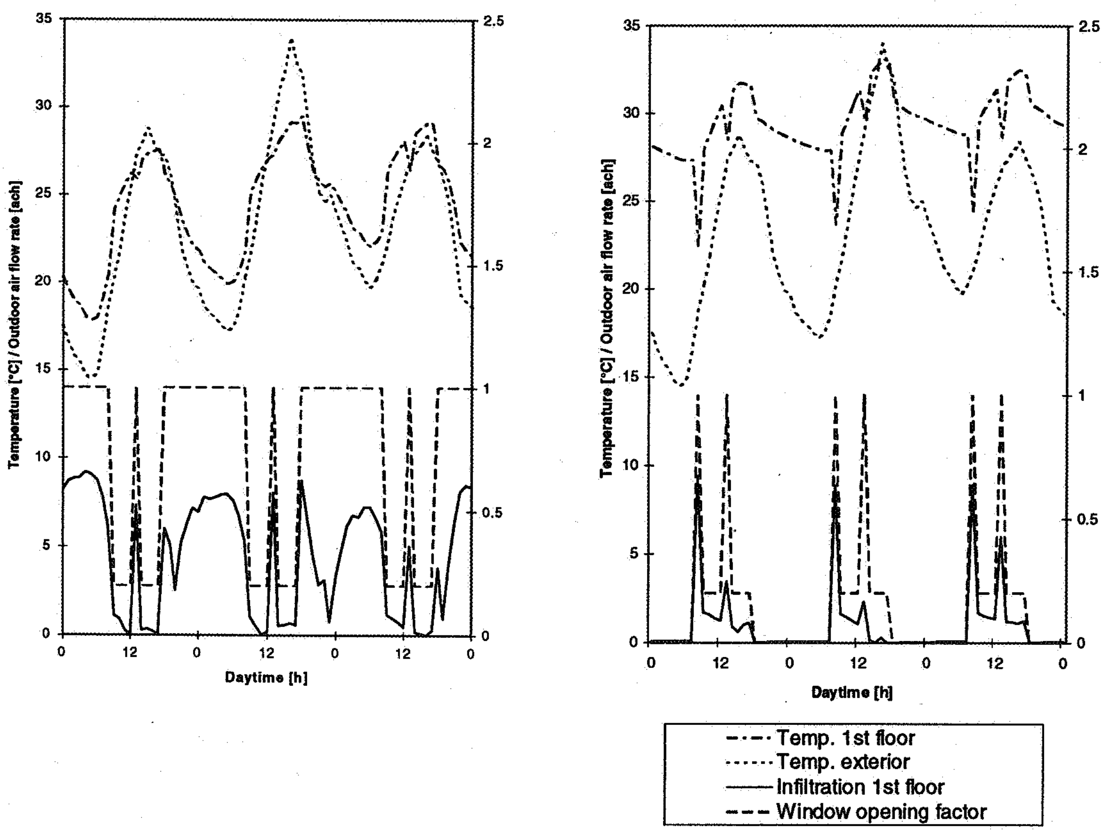

Figure 4: Outside and room air temperature, the outdoor air exchange together and the window opening factor for mode 1 (night ventilation, left) and for mode 2 (no night time ventilation, right)

3 Example 2: Retrofit with a glazed double façade

For the same building, retrofit concepts have been worked out on the basis of a glazed double façade, built up over the original structure which remains practically unchanged. This approach is effective in respect to construction costs and to ecological aspects. Figure 5 shows one of the proposed constructions. On each side of a room, the double façade spaces are open in vertical direction, acting thus as a ventilation shaft. In the middle section, the original window is removed and replaced by a window in the outer façade.
While the potential for reduced transmission losses in winter time is quite obvious, more concern was related to the overheating risk in summer and thus to the possibilities to cool and ventilate the building satisfactorily.

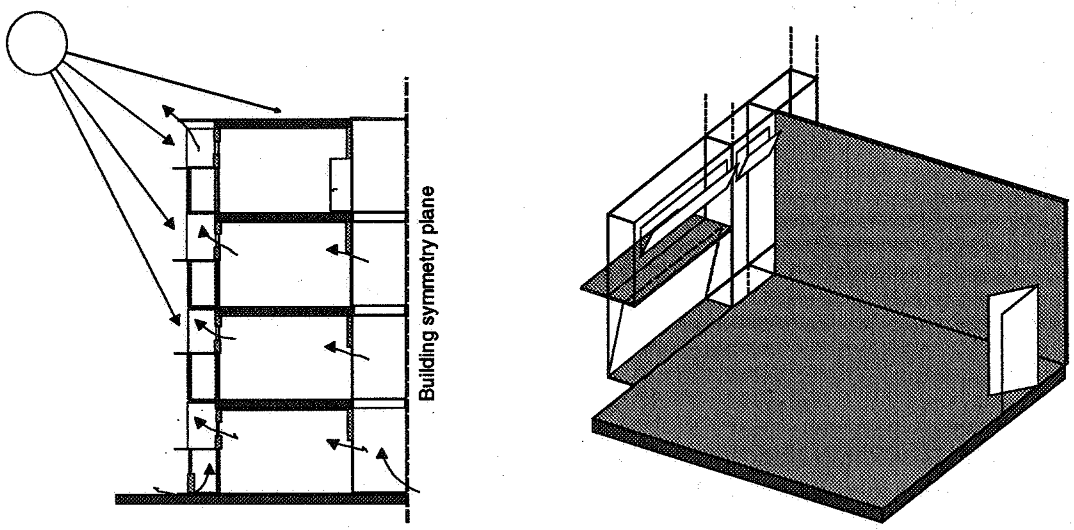

Figure 5: *Cross-section of the building section modelled and isometric drawing of one room with the double façade spaces.*

The aim of the simulation study presented in this paper was to provide data on the thermal comfort and the respective ventilation situation in the different rooms for a typical hot summer period, and to establish strategies for the operation of the different windows and openings for optimum indoor environment.

3.1 Modelling of the building

A section over the entire building height of the southern half of the building is modelled with its double façade and the adjacent rooms using the TRNSYS Type 56 multizone building.

Type 56 (TRNSYS version 13.1) is not very well suited to model this specific building configuration due the following limitations:

- Solar radiation is considered only for windows and external walls. This means that radiation through the double façade zone into the rooms behind cannot be modelled without applying some modelling tricks.
- The model for windows in Type 56 is quite limited as it does not allow for specific glazing types with specific spectral characteristics. The more, blinds are only considered as a geometrical aperture factor. Thus the energy transport aspects must be modelled by the user.

The double facade and the adjacent room are modelled as follows:

- The energy flows into the double facade space and the room are modelled by equations which are set up specifically for this case. The type 56 model is used only for the calculation of the radiative and convective energy distribution within the two zones.
- The outer glazing and the blind are considered as a wall (TRNSYS wall with known boundary condition), with a very low resistance in order to get literally the same surface temperature on both sides of this wall. The optical properties according to the glazing and the blind are considered in specifically set up energy flux equations.
- Also the inner double glazing is modelled as a wall (TRNSYS wall between zones).

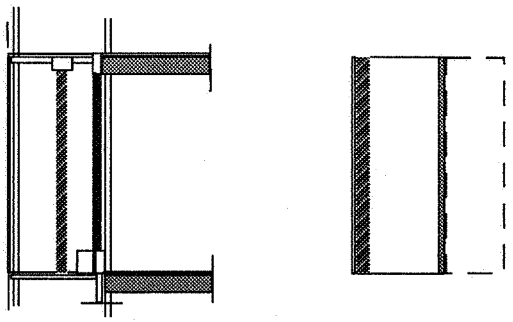

Figure 6: A section of the double façade zone with the blind, left, and the respective model with the outer wall and the inner wall, right.

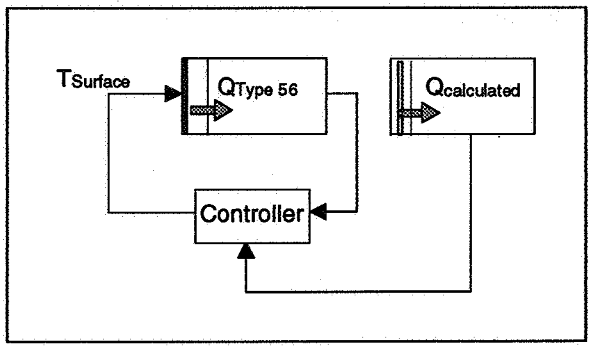

Figure 7: The control loop for the surface temperature of the outer wall.

The correct heat flux into the double façade zone due to solar radiation, radiative and convective emission from the blind and the heat transfer through the external wall cannot be determined explicitly but has to be determined iteratively by balancing out

a) the energy flux $\dot{Q}_{Calculated}$ as determined explicitly as the difference between the incoming radiation energy and the heat exchange from the blind to the outside surface
b) the energy flux $\dot{Q}_{Type56}$ as determined by the room star network model in type 56

The free parameter for this iteration is the surface temperature of the outer (external) wall. The iteration is realized by a control loop (see Figure 7). This approach has to be made due to the fact that no direct gains to walls can be defined in Type 56. The modelling of the glazed double façade is described in more detail in [5].

It has to be mentioned however that in the new release TRNSYS 14.1, Type 56 has been improved and individual wall gains can now be defined, making the above described modelling approach obsolete in some parts.

3.2 Simulations

Simulations have been made for the same hot summer period as used in example 1. The result parameters are the air flows per opening in the room as well as the temperatures in the individual zones. Thermal comfort parameters can be checked taking into account also the wall surface temperatures. The air quality aspects are covered by mean age of air values per room or by defining CO_2 sources according to the occupant presence and checking the resulting concentrations. Wind effects as well as the influence of the second, north oriented building half have not been considered in the simulations.

Within the iterative solution process, oscillations may occur in stack (boyancy) dominated driving force conditions. In such cases, changes in the air temperatures and thus in the stack pressures lead to reversed flow directions in a critical zone and in consequence the room temperatures change again significantly. These oscillations from one iteration step to the next may lead to numerical convergence problems, which can be overcome by introducing an element which numerically damps the air flow data connection between Type 56 and Type 57 (COMV-TRNS).

3.3 Simulation results

Figure 8 shows for the same three-day period as in Figure 4 the calculated temperatures and air flows for the room and the double façade space of the second floor as well as for the staircase, together with the opening schedules for the windows, the openings to the double façade space and the openings in the staircase to outside.

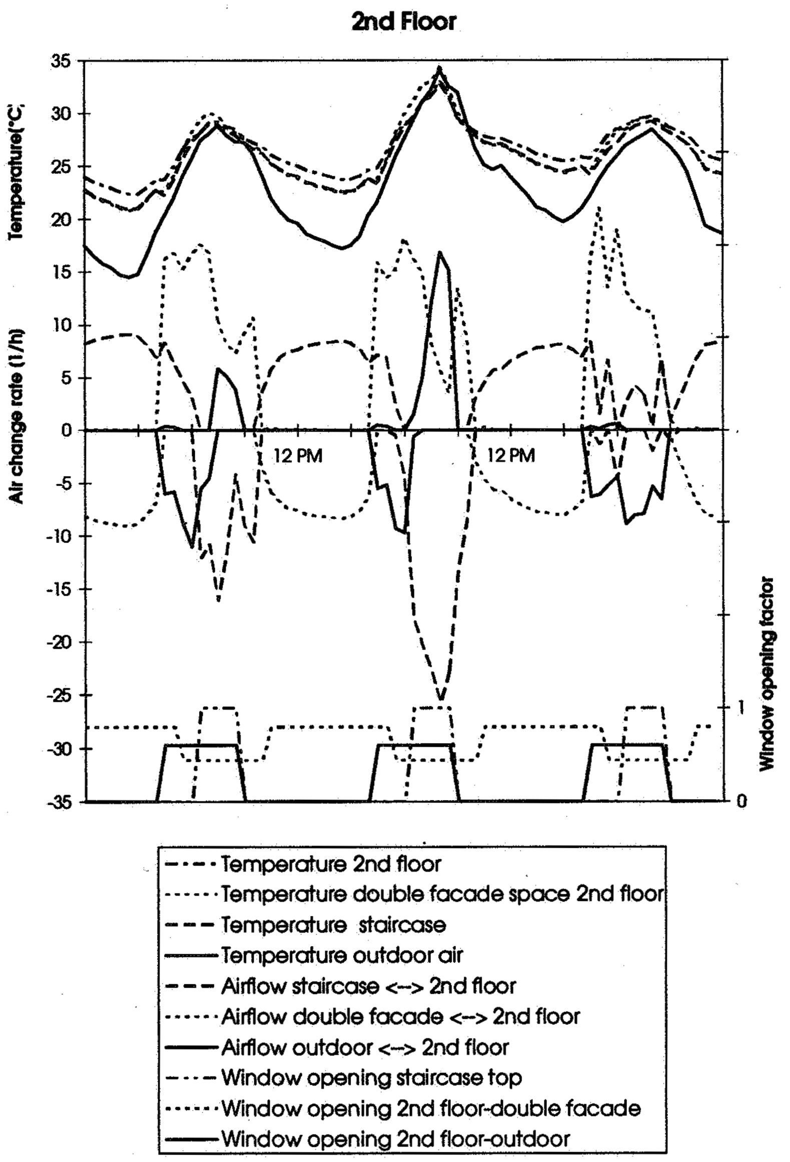

Figure 8: *Temperatures and air flows to and from the 2nd floor room and opening schedules for the different openings. The bottom staircase opening is opended as soon as the top opening is closed (and vice-versa).*

Figure 9 shows the air temperatures and the air flows of the individual openings in the section of the building modelled for two typical daytimes during the second day: Early in the morning at 6 AM when the windows to outside in the room are closed and at 4 PM (at peak outside temperature) when the room windows to outside are opened.

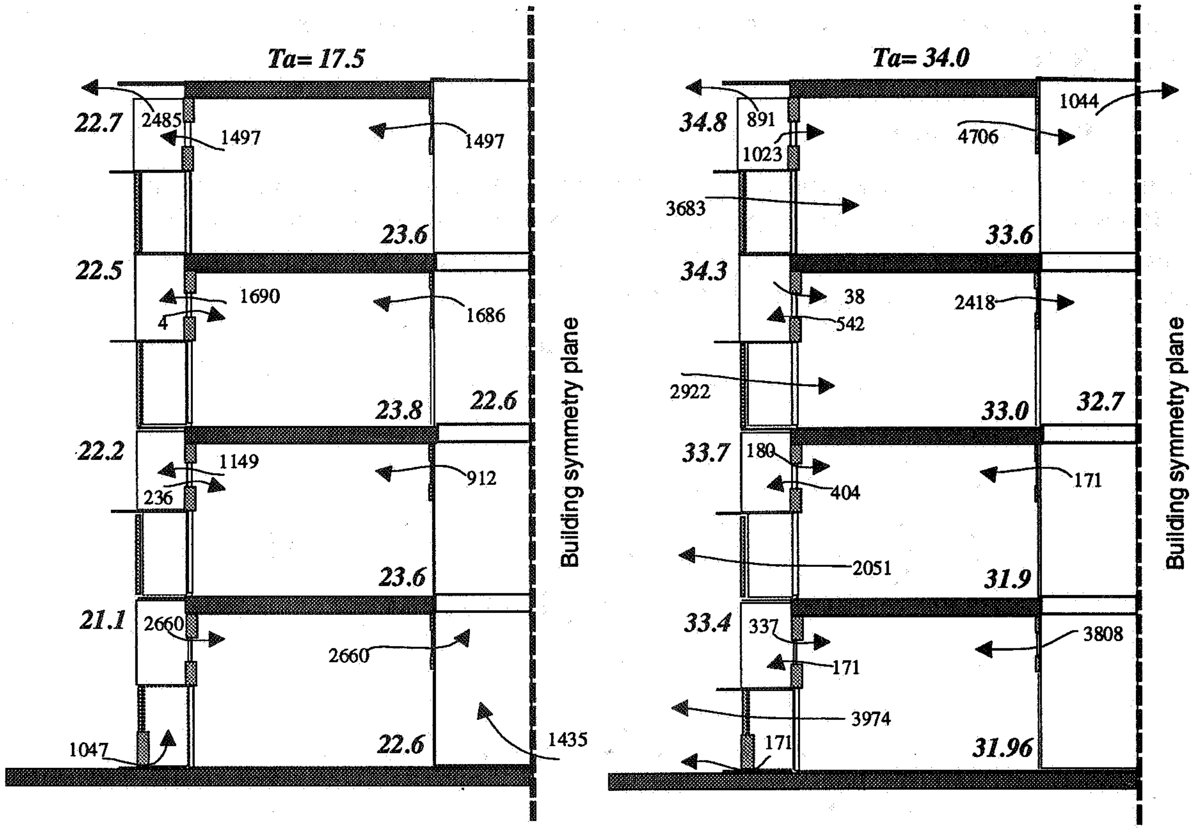

Figure 9*: Outdoor and zone temperatures [°C] (in italics), and the respective air flows per opening [kg/h] at two typical daytimes for the building section modelled*
(left at 6 AM, right at 4 PM corresponding to peak outdoor temperature, see Figure 8)

3.4 Discussion

The room windows are closed during night and the rooms are ventilated only through the façade space. Quite large openings to either the staircase and the double façade space are needed in order to cool the building sufficiently by night-time ventilation. In the rooms, windows openable directly to outside can supply cooler outside air for most of the time during the day and significantly increase the ventilation rate.

Most of the time the air flow pattern for the rooms is quite satisfactorily, only for a short period at peak outside temperatures the supply of the uppermost room is from the façade space, which should be avoided.

Additional simulations were performed in order to study optimum opening control strategies. Simulations showed that there is a potential to use the staircase space as a storage of cool air during peak outside temperatures. In this case all external openings in the staircase and in the upper floors the openings to the façade space must be closed. Consequently, at the upper floors, the doors between the room and the staircase should be open in order to achieve an acceptable ventilation.

4 Conclusions

The evaluation of design concepts for naturally ventilated and cooled buildings can be greatly improved by simulation, considering the coupled effects of the thermal behaviour of the building and the naturally driven air flows.

Numerical problems during the iterative solution process which may occur in stack dominated driving force conditions, may be overcome by numerical damping of the data transfer from the air flow model to the thermal model.

Due to the complex nature of the physical phenomena and the great variety of possible ventilation control strategies, the amount of simulation runs needed to cover a reasonable parametric range may not be underestimated.

5 Acknowledgements

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