TRNFLOW, A NEW TOOL FOR THE MODELLING OF HEAT, AIR AND POLLUTANT TRANSPORT IN BUILDINGS WITHIN TRNSYS

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ABSTRACT

Modelling of buildings with natural or hybrid ventilation systems requires the coupling of a thermal and an air flow model because of the strong mutual impact of the thermal and the air flow behaviour. The newly developed tool TRNFlow is the complete integration of the multizone air flow and pollutant transport model COMIS [Dorer 2001] into the thermal multizone building module of the building and system simulation program TRNSYS [Klein 2000]. An internal solver algorithm using successive substitution with automatic adapted relaxation finds consistent solutions of the two models. The existing TRNSYS user interface for the building module has been updated for the easy and user friendly input of the additional air flow and pollutant transport model data.

INTRODUCTION

Meeting summer comfort criteria is one of the crucial elements in sustainable buildings. Rising internal heat loads especially in office buildings increase the cooling demand. Passive cooling by night time ventilation is a promising possibility to dissipate heat without a high energy demand. With a natural or a hybrid ventilation system electric fan energy use can be minimized by utilizing air temperature differences and wind pressures. Dimensioning of such a system means to define the size and the distribution of the ventilation openings and the size of the ventilation ducts.

The air flows in a building can be calculated with a multizone air flow model. Such a model idealizes the building as a network of nodes and air flow links between them (Fig. 1). The nodes represent the rooms and the building surrounding. The links depict windows, doors, cracks, and shafts as well as ventilation components like air inlets, outlets, ducts and fans. The wind pressures on the facade and the indoor and outdoor air temperatures are the important boundary conditions.

On the other hand the room temperatures can be calculated with a dynamic thermal building model. The construction and the materials of the building envelope determine the character of the thermal behaviour (Fig. 1). In this case the thermal loads (e.g. from persons or office equipment or solar gains), the outdoor temperature and the air flows in the building are the boundary conditions.
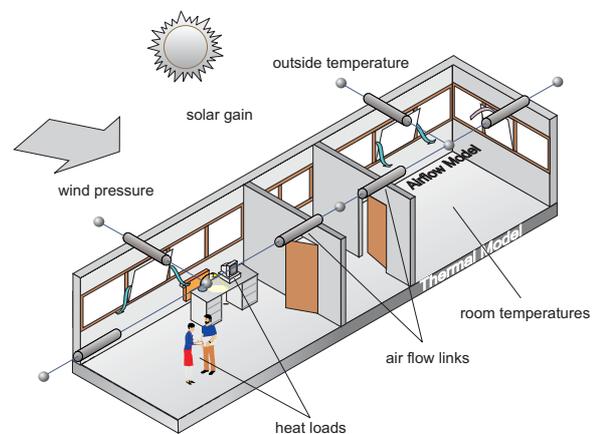
Fig. 1: Thermal and airflow model of a naturally ventilated office building

Only with simultaneous simulation of heat and air flow can this mutual dependence be taken into account and the system design can be done satisfactorily. Therefore in the last years several thermal building simulation programs such as ESP-r [Hensen 1991], TRNSYS [Dorer 1993] or EnergyPlus [Crawley 1999] has been enhanced with a multizone air flow model.

CURRENT SOLUTION IN TRNSYS

Already in 1993, in the frame of the IEA project Annex 23, a coupling of the multizone air flow model COMIS with the thermal building and system simulation program TRNSYS has been developed. The stand alone Program COMIS was then modified to a TRNSYS module which can be linked to the thermal building module by the user. Fig. 2 shows this approach which is described in detail in [Dorer 1993, 1999]

The ordinary TRNSYS solver was used to realize the so called "onions" approach [Hensen 1995], where the two models are iteratively called using the results from the other one as inputs until convergence is

achieved within each time step. This approach reflects exactly the method of the TNSYS solver also known as "successive substitution method".
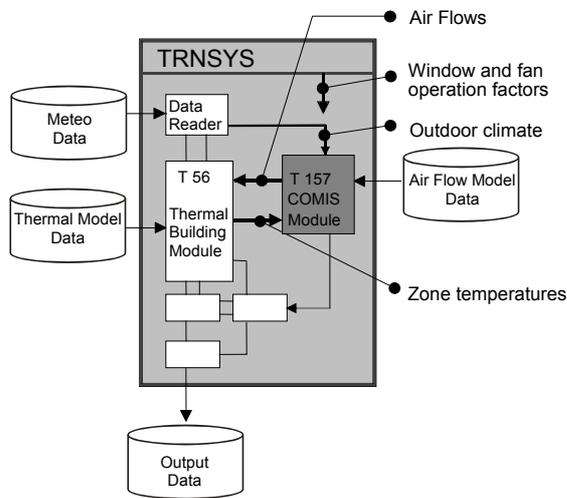

Fig. 2: Coupling of a thermal and an air flow building model with two separate modules.

Experiences with coupled heat and air flow modelling have often shown convergence problems, especially with this successive substitution [Smith Schneider 1995]. Therefore a relaxation of the solving process is necessary. In TRNSYS this can only be realized with an additional relaxation module connected between the two models. To find a relaxation factor which guarantees convergence in each time step during the whole simulation period might be impossible in some cases. This fact and also the laborious handling to link the two modules in each individual simulation case made a further integration of the two models necessary.

METHODOLOGY

To overcome the convergence problems and to automate the linkage of the two models, the air flow model has been fully integrated into the thermal building module (Fig 3). One and the same user interface produces consistent input files for the thermal and the air flow model.

The two models COMIS and TRNSYS are linked as black boxes. For simplification, in Fig. 3 the information flow between the models is represented by one room air temperature node and one air flow variable. In fact there are as many air temperature nodes as there are rooms in the building and each room has at least one air flow. All these different parallel information flows influence each other. In the solution process, the air flow model starts with the input room temperatures $\vartheta_{in,1}$ and calculates the corresponding air flows of each room. These flows

are used in the thermal model, which calculates the output room temperatures $\vartheta_{out,1}$. With an iterative solver algorithm the input temperatures set is found which matches the output temperatures set. Using the successive substitution method, the output temperatures from one iteration step $\vartheta_{out,i}$ are used as input for the next step $\vartheta_{in,i+1}$. The disadvantage of this method is, that it converges only if the derivatives of the functions $\vartheta_{out,i}=f(\vartheta_{in,i})$ at the solution point are in the range $-1< d\vartheta_{out,i}/d\vartheta_{in,i} <1$. But depending on the boundary conditions, the solution might be in a region where the derivatives are outside this range. In such a case, the successive substitution method diverges (dashed line in Fig. 4).
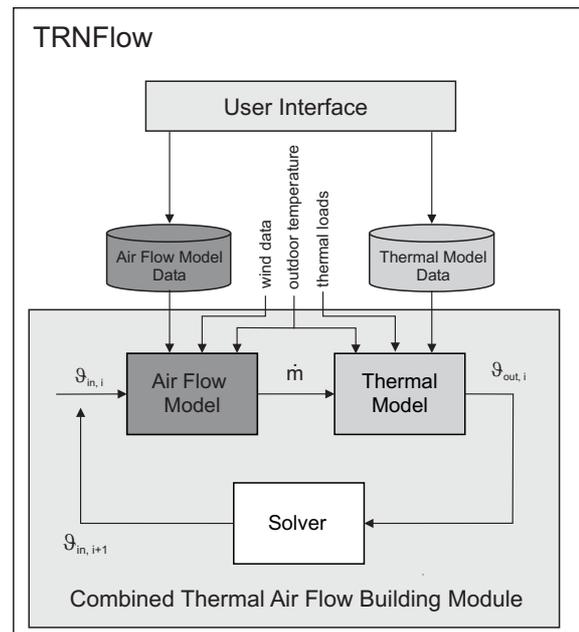

Fig. 3: Information flow of the combined thermal air flow building module and the user interface for building data input

To ensure convergence in each time step, it is necessary to introduce a relaxation factor ζ which reduces the alteration to the input temperatures. As the dotted line in Fig. 4 shows, the iteration will now converge to the solution. Unfortunately, a fixed relaxation factor which guarantees convergence in each time step during the whole simulation period makes the iteration process slow in time steps where no relaxation is necessary or is even impossible to find. Therefore, the optimum relaxation factor for each time step has to be found within the iteration. A newly developed solver algorithm adapts the relaxation factor individually for each room temperature depending on the evolution of the solving process. As shown in Fig. 5, with an oscillating evolution, the respective relaxation factor will be halved in the next iteration step and it will be multiplied by 1.5 if the evolution converges steadily.
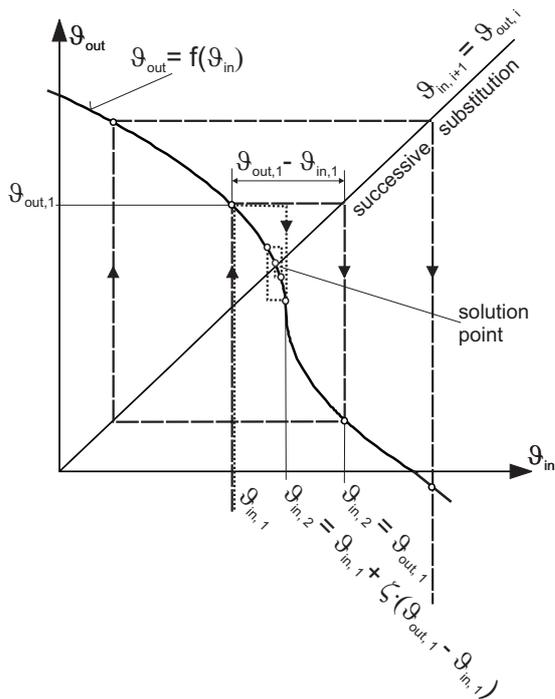
Fig. 4: Evolution of the iterative process using the successive substitution solver method with and without a relaxation factor

With oscillating evolution of the temperature within the solving process:

$$(\vartheta_{out,i} - \vartheta_{out,i-1}) \cdot (\vartheta_{out,i-1} - \vartheta_{out,i-2}) \leq 0$$

The relaxation in next iteration is:

$$\zeta_{i+1} = \zeta_i / 2$$

With staedy evolution of the temperature within the solving process:

$$(\vartheta_{out,i} - \vartheta_{out,i-1}) \cdot (\vartheta_{out,i-1} - \vartheta_{out,i-2}) \geq 0$$

The relaxation in the next iteration is:
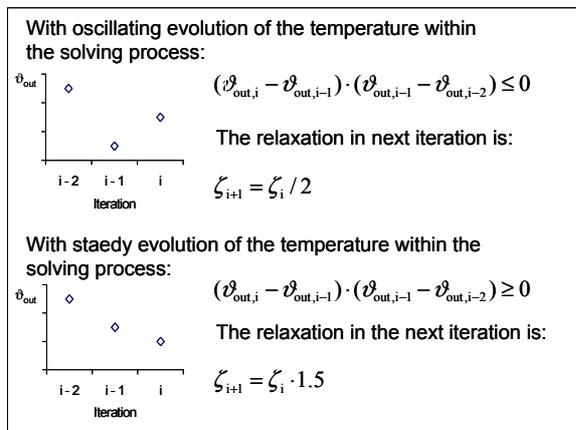
$$\zeta_{i+1} = \zeta_i \cdot 1.5$$

Fig 5: Procedure to find the relaxation factors for the next iteration step

Besides the room nodes (thermal zones) the air flow model needs additional auxiliary nodes for the ventilation duct network as junctions of the individual parts of the duct system. These nodes have no representation in the thermal model in order to keep it as small as possible. The temperatures of the auxiliary nodes are calculated using only the flow rates and temperatures of the joining air flows. Thermal capacitance or other heat gains and losses different to those of the air flows are not considered within these nodes. In the thermal model the air

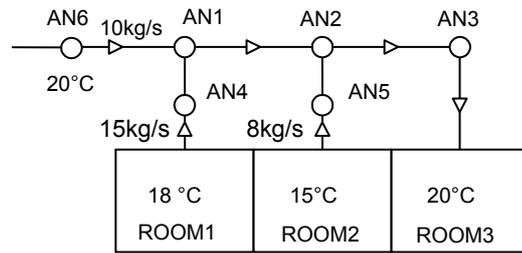flows from auxiliary nodes into the room zones are interpreted as ventilation air flows.

Fig. 6: Example duct network system

To model an air heater or a cooler, respectively a humidifier or a dehumidifier, the set point value of the temperature and the humidity of an auxiliary node can be defined by the means of a constant, an input or a schedule variable. The necessary power to achieve this set point can be obtained by an output.

Fig. 6 shows an illustration example of a duct network. The set point temperature of 20°C is defined for the auxiliary node AN6. For Room3 results a ventilation air flow of 33 kg/s with 17.9°C.

In COMIS a dynamic pollutant transport model is implemented. With this model up to 5 different pollutant concentrations per zone can be calculated. It can be used also within TRNFlow. That means simultaneous simulation of air, heat and pollutant transport is possible with this tool.

Both, the thermal building model of TRNSYS and the air flow model COMIS has been validated within several evaluation exercises [Blair 1997] [Fürbringer 1996]. COMIS-TRNSYS, the former version of the coupling of these two models has been used within an investigation of control strategies for hybrid ventilation systems [Delsante 2002]. The results have been compared with those of three other programs. TRNFlow produces exactly the same results as COMIS-TRNSYS therefore it can be regarded as validated as well.

EXAMPLE

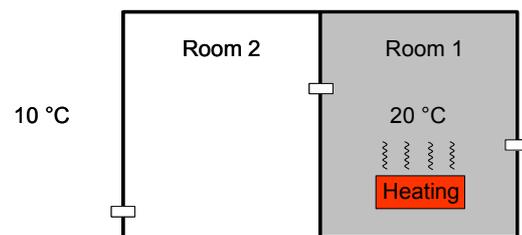With a simple example the effect of the automatic adapted relaxation shall be illustrated:

Fig 7: Two zone model as illustration example

Room 1 in fig. 7 is heated with a set point temperature of 20°C. Room 2 has a free floating temperature with an initial value of 20°C. The outside climate is constant without wind and with an air temperature of 10°C. The two rooms are connected to each other and to the outside with links in three different heights. The lowest one is the link from room 2 to the outside and the highest is the link between the rooms. At the beginning, the stack effect drives cold outside air into the free floating room 2 and cools it down. At a certain room temperature the stack effect turns to the opposite direction and warm air from room 1 flows into room 2. At this critical temperature a solver without relaxation will oscillate between these two situations and no solution can be found. Fig. 8 shows the evolution of the temperature and the air change rate in room 2 and the number of iterations with a fixed and with an automatic adapted relaxation factor. Without or with an inappropriate relaxation factor the maximum number of iterations is reached and the solution cannot be found at the critical point. With a fixed relaxation factor of 0.1 the number of iterations is higher at the first time step, when the temperature changes the most. With the adaptation algorithm a suitable relaxation is found in each time step.

CONLUSIONS

TRNFLow is a new tool which allows a user friendly simulation of natural ventilation systems, e.g. passive night cooling, double facades or exhaust air shafts with a coupled heat and air flow model. The multizone air flow model COMIS has been completely integrated into the thermal building module of TRNSYS. The coupling of the two models has been realized within one module. Therefore the user has no longer to perform a laborious linkage of two modules in each individual simulation case. The existing user interface of the thermal model has been enhanced with new features to be used for the data input of the air flow model. An air flow model input file is generated which is in any case consistent to the thermal model input files. Data redundancy in the input files is covered by the user interface. Thus, compared to the old version of the air and heat flow model coupling in TRNSYS, with TRNFlow many possibilities for erroneous data input have been eliminated. The internal solver algorithm is featured with a high stability. Due to the automatic adapted relaxation for each temperature variable in each time step, the user is no longer bothered with numerical questions. Ventilation duct systems and air handling units can easy be modelled using auxiliary nodes which have no representation in the thermal model.
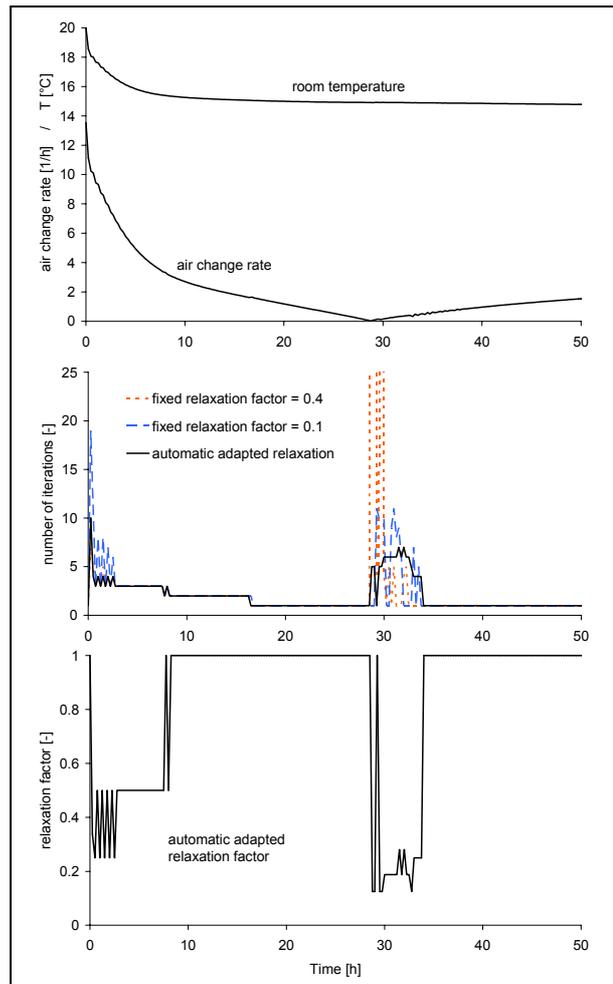

Fig 8:
Upper diagramm:
Temperature and air change rate in room 2

Middle diagramm:
Necessary number of iterations with two fixed and with the automatic adapted relaxation

Lower diagramm:
The relaxation factor found with the adaptation algorithm

ACKNOWLEDGEMENTS

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