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BUILDING ENERGY AND SYSTEMS SIMULATION PROGRAMS: MODEL DEVELOPMENTS AND APPLICATIONS

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ABSTRACT

An overview is given here on different projects which involved a part of the building simulation programs used and developed by the 'Energy Calculation Group' of the Building Equipment Section at EMPA.

Recent work with DOE-2 was mainly related to the topics of cooling load calculation and the task of the prove of the need for cooling in Buildings. For this application, a standard input was developed. Requirements from other users were mainly addressed to the modelling of new system types such as radiative cooling and displacement ventilation, for which procedures have been developed in DOE-2 as in other programs. A current research topic is evaporative cooling, the potential of which is shown under Swiss climate conditions for a variety of system types. some preliminary results are shown

Due to its modular structure, TRNSYS is used for the study of more specific problems which cannot be treated by the standard options available within DOE-2. TRNSYS is also used in the frame of a national project with the title "Energy optimised operation of chilled ceilings in combination with displacement ventilation systems". A main topic of this project is night time cooling with chilled ceilings. Several newly developed TRNSYS components are used for this project, such as

- a new multinode model for the simulation of the characteristic air temperature gradient over the room height for the simulation of a room with a displacement ventilation system;
- a closed cooling tower model which calculates the tower specific parameters from manufacturer provided data for design conditions.

Multizone air infiltration and ventilation programs allow for the determination of air and contaminant transport across the building zones and against the outside environment. In the frame of international projects, the COMERL air flow model was developed at EMPA. Its air flow model part COMVEN has also been adapted as a type for TRNSYS. This integrated use of a multizone air flow model in a building simulation code allows for the treatment of combined heat and air transport problems such as passive building cooling.

Keywords: Building simulation, displacement ventilation, radiative cooling, evaporative cooling, closed cooling tower, natural ventilation, multizone airflow modelling, combined heat and air transport, passive cooling

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INTRODUCTION

The 'Energy Calculation Group' of the Building Equipment Section at EMPA has been involved in building and HVAC simulation for more than a decade. The work covered both the use and the development of programs, for research and consulting. Among the wide range of programs worked with, the most important are DOE-2, TRNSYS, SUPERLITE and COMIS.

DOE-2

For DOE-2 (Birdsall *et al.* 1990), the group has slipped from the former consulting task into the role of a support organisation for the about 50 users in Switzerland, providing Swiss weather data, new program versions etc. A similar development has started for other programs. Recent work with DOE-2 was mainly related to the topics of cooling load calculation, where DOE-2 was used to develop the new Swiss SIA Standard, and the task of the prove of the need for cooling in Buildings (overheating risk assessment), which is required by the authorities in some regions of the country. For this application, a standard input was developed in the context of the IEA project Annex 21, which is addressed to the following aims:

- Unified procedure with easy checking possibilities
- Substantial decrease in the necessary effort
- Minimal error possibilities (quality assurance)

Requirements from other users were mainly addressed to the modelling of new system types such as radiative cooling and displacement ventilation, for which simplified procedures have been developed in DOE-2, but also in other programs (see below, section 'TRNSYS').

A current research topic is evaporative cooling (Zweifel *et al.* 1994), the potential of which in the Swiss climate is estimated. The system under consideration is shown in Figure 1.

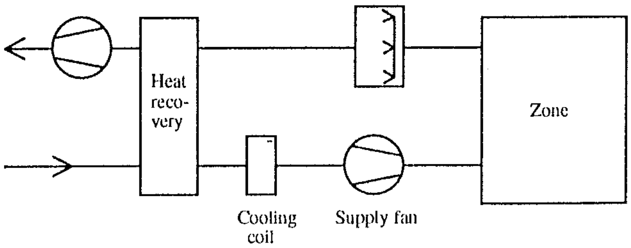

Figure 1: *Simplified schematic of adiabatic cooling system*

Its main features are an adiabatic humidification of the return air and a heat recovery device to remove heat from the fresh air intake to the cool exhaust air stream. The simulation of this system involved the modelling of the two most important components of this system, as well as the proper control strategy. Several component types were investigated and compared to each other:

Humidifiers:	Spray type air washer Wetted-media air humidifier
Recovery devices:	Rotary Flat plate Fluid circuit

Not only the reduction of cooling energy consumption was calculated, but also the water consumption and the additional energy consumption for auxiliary devices such as pumps, oscillators, recovery wheel drives etc. and the fan energy consumption due to additional pressure loss in the system caused by the additional components. This could only be done by using the program's facility of 'functional inputs', a way of defining customised program code via the input file.

Some results are shown in table 1.

Supply air temp. [°C]	Heat recovery type	Humidifier type	Total Cooling Energy kWh
15	Rotary	none	7'757
		Washer	9'191
		Wetted-media	7'401
	Circuit	none	7'380
		Washer	8'561
		Wetted-media	6'765
18	Rotary	none	8'560
		Washer	9'109
		Wetted-media	8'074
	Circuit	none	8'078
		Washer	8'242
		Wetted-media	7'235
	Flat plate	none	7'917
		Washer	7'996
		Wetted-media	7'106

Table 1: *Total energy consumption results for different system types*

From table 1 some conclusions can be drawn:

- For some of the system types, more energy is consumed than without the adiabatic cooling. This is due to the auxiliary consumptions and the higher pressure drop in the air system. This is, in this form, only true for the system parameters considered in this work and cannot be generalised. More parameter variations will be done to show the influence of these.

- The Influence of the operation parameters of the air system is at least as important as the effect of having an adiabatic cooling or not

TRNSYS

In the program TRNSYS (Wisconsin 1990), the individual components of a systems are modelled in a modular way using type routines. This allows for a very flexible definition of any system under investigation. In addition, these component type routines may be changed and improved by the user, even new types can easily be added. Therefore, TRNSYS is used for the study of more specific problems which cannot be treated by the standards options available within DOE-2.

The program TRNSYS is used in frame of a national project with the title 'Energy optimised operation of chilled ceilings in combination with displacement ventilation systems'. Chilled ceilings are increasingly used, especially in office buildings, for heat extraction purposes. Indoor air quality is ensured by an additional ventilation system. A commonly used possibility is a displacement ventilation system. This ventilation system in such combination is only used for air renewal purpose. However, if the chilled ceiling extracts the entire heat, the down draft at the cooler walls becomes high and this contaminated air is mixed with the fresh supply air, so that the indoor air quality in the occupied zone is decreased. The measurements showed that the displacement ventilation system must take over at least 20 % of the total heat load.

Another important aspect of the project was to develop a concept for energy efficient night cooling. The principle approach for night cooling with a chilled ceiling is to transfer heat from the daytime into the night an extract it then because the cooling equipment operates with a higher coefficient of performance (COP), or a cooling tower with lower water temperatures. But in commercial buildings, most of the heat (e.g. from solar radiation, equipment and occupants) appears in the room during the working period. To transfer a part of this heat load to the night time, a proper storage medium is needed. A possible medium is the building itself, if we allow that the wall temperatures can rise during the day. We found as a result of the dynamic simulations that we can transfer 25 to 30 % of the heat load into the night time with an air temperature rise of 3 K over the working period (see Figure 2).

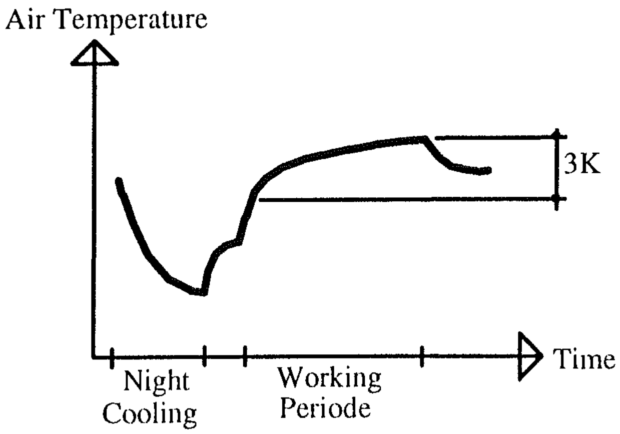

Figure 2: *Room air temperature during a day*

The dynamic simulations were done with the program TRNSYS and with a new room model for the displacement ventilation system (Koschenz 1993). Most of the thermal simulation programs are not able to simulate such a system because of their one node approach. A one node approach means that the room air temperature is represented by only a single value for the zone. But a displacement ventilation system has a characteristic air temperature gradient over the room height. Therefore the new model (see Figure 3) uses three air temperatures.

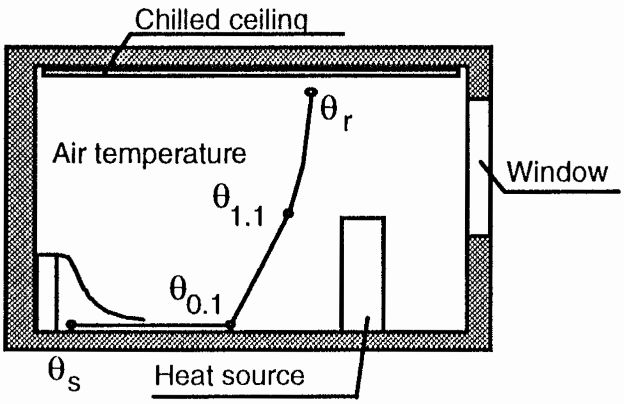

Figure 3: *3-Node room model*

During the night-time, when the outside air temperature is lower, the building mass is cooled back to the temperature where we want it to be in the morning for working start. In this case the wall temperature is the important magnitude for the state of the building. But in a real building, only the room air temperature is measured and not the wall temperature. Hence a simple physical model was developed, which can easily be integrated into a real controller, to predict the wall temperature from the known room air temperature. This simple controller model was tested with dynamic simulations and will also be verified by monitoring in a real building.

The improvement of the COP as a function of the outside air temperature, as shown in Figure 4, was determined by a new TRNSYS-Type for an air cooled water chiller. This type was developed in co-operation with manufactures and compared against their measurements.

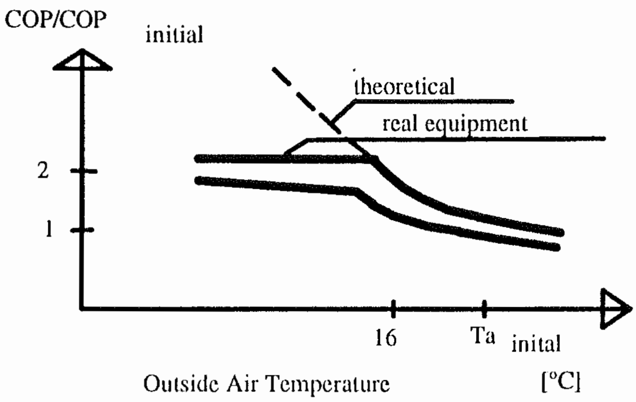

Figure 4: *Improvement of the COP as a function of the outside air temperature*

As shown in Figure 4 the improvement of the COP is limited because the expansion valve needs a minimal pressure difference between the evaporation and the condensation pressure.

Further work, which is still in progress, investigates the operation of a chilled ceiling without a cooling machine. For this purpose a model for a closed cooling tower was developed. It calculates, after a setup procedure with the initial conditions, the water outlet temperature of the cooling tower as a function of the water inlet temperature and the wet bulb temperature. This model was also developed in co-operation with manufactures and compared against measurements.

At the end of the project all the important results will be comprehend in a brochure to be handed out to the engineers as a design guide.

MULTIZONE AIR FLOW MODELLING

Multizone Models

In multizone models (MZM) the building is characterised by a network of nodes representing a volume of homogeneously mixed air, interconnected by air flow components such as cracks, large openings, ducts or fans. Air and contaminant transport across the building zones and against the outside environment can be determined. Natural ventilation due to stack and wind as well as mechanical systems can be modelled.

Multizone models are presently used for a variety of problems. Steady state as well as time dependant cases may be treated. The basic application is the determination of infiltration and interzonal air flows due to natural and mechanically induced driving forces and the consecutive determination of air change rate and room mean age values. Design applications include the sizing of air flow inlets and outlets and HVAC components and the determination of the influence of the building fabric leakage on the system performance.

Energy aspects like the determination of seasonal ventilation heat losses can also be covered. Multizone models can also be used for the design of passive and active solar air heating systems.

Air quality problems can be treated in many aspects. MZMs are very well suited to study contaminant spreading within a building. Examples are the risk assessment of counterflows from kitchen or bathrooms back to the living rooms, the ingress of Radon from the ground or of reversed flow in furnace exhausts.

The transient infiltration of outdoor contaminants may be studied. Based on air flow and contaminant concentration results, the overall performance of the ventilation system may be determined using the concepts of multiroom ventilation efficiency.

Finally, health related parameters such as accumulated dose figures for different occupants may be derived.

COMERL

COMERL is a multizone air infiltration and ventilation programme package realised at EMPA in the frame of the international COMIS code development project (Berkeley). COMERL consists of a shell program and the actual simulation program COMVEN. The shell as the user interface is a problem adapted editor developed on the basis of Borland TurboVision. A database for different kind of air flow components such as windows, fans or component and background leakage values is integrated (Dorer *et al.* 1994). Figure 5 shows the structure of the software package with shell and the simulation program COMVEN and the respective interface files.

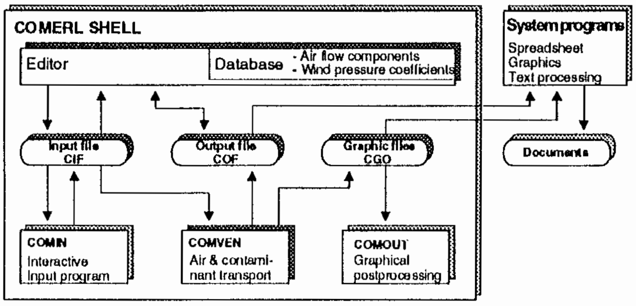

Figure 5: *Structure of the software package COMERL*

Presently the simulation programme COMVEN is further developed in the frame of the IEA-ECB Annex 23 'Multizone air flow modelling'.

Integration of COMVEN into TRNSYS

While for many building simulation codes air infiltration rates are considered as fixed input values, for the multizone model on the other hand, the room temperatures are user input.

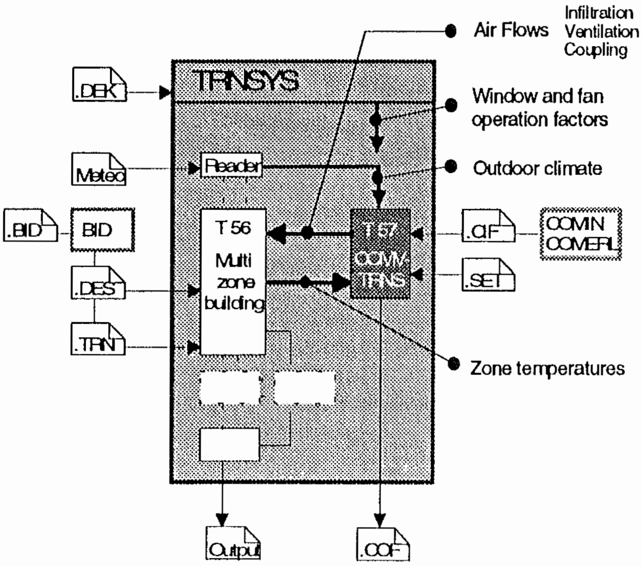

Figure 6: *Integration of COMVEN as Type 57 into TRNSYS, data transfer, related files and pre-processor programs*

Thus, many applications with combined heat and air transport, problems such as passive building cooling or the design of façade systems for naturally ventilated office buildings, require a coupling of the two models or the integration of the multizone air flow model into the building simulation code.

In the frame of the IEA-ECB Annex 23 'Multizone air flow modelling', the simulation program COMVEN has been adapted as a type for the building systems simulation code TRNSYS, to be used in combination with the TRNSYS multizone building type 56 (Dorer, Weber. 1994).

For a four storey school building, the effect of passive cooling by natural night ventilation was studied. Figure 7 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.

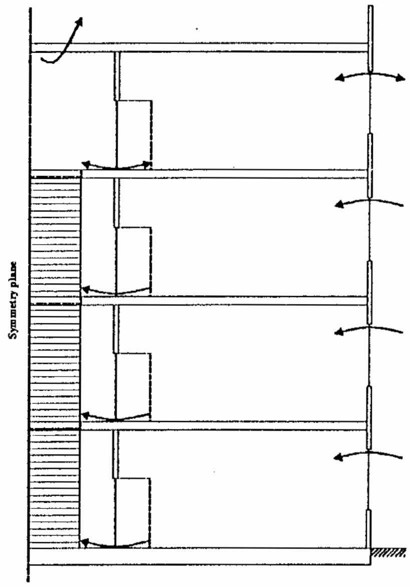

Figure 7: *Cross section of the building and the air flow paths for natural ventilation*

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.

For one typical room during a hot summer period in Lucerne, central Switzerland, figures 8 and 9 show for mode 1 and 2, respectively, the outside and room air temperature as well as the outdoor air exchange together with the window opening factor. 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.

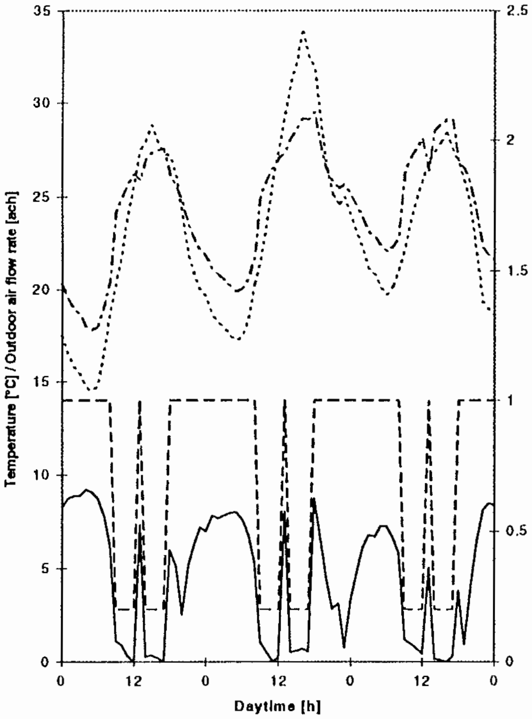

Figure 8: *Outside and room air temperature, the outdoor air exchange together and the window opening factor for mode 1 (night ventilation)*

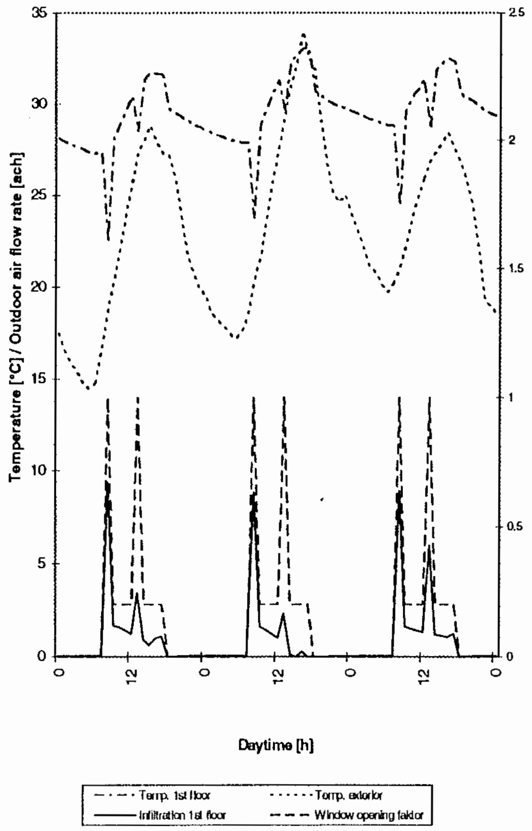

Figure 9: *As figure 8, but for mode 2 (no night time ventilation)*

CONCLUSIONS

Building and Systems simulation programs are powerful tools for a large variety of very different calculation problems. Every program has its skills and weaknesses, and the appropriate use is a key issue.

An experience from the support work is, that enquiries from outside are mainly related to special problems, the treatment of which is usually difficult in one single program and involve different issues. This leads to the need for a combined use of different tools. Therefore future activities will concentrate on the integration of these programs into a comprehensive tool for building energy and systems simulation.

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