HOW TO OVERCOME THE HVAC SIMULATION OBSTACLES

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Abstract

Examples on application of system simulation in preplanning, sizing and comissioning of HVAC systems are briefly given and typical obstacles for a more broader utilization in engineering offices are introduced. Efforts needed to overcome most of the obstacles are described. It is shown that currently system simulation is a business for experts. To increase the application of simulation in HVAC engineering offices efforts should be made in training and supporting these experts.

1 Introduction

A lot of HVAC system simulation software has been developed in the last years all over the world /1/. But simulation is still not commonly used for HVAC design. As before in the history of science a growing gap between the academic work and the needs of the real world can be observed. Scientists work on comparisons among simulation software, operational monitoring methods and experimental validations of models for building and HVAC components. Engineers in current HVAC design need transparent procedures, default data for the early design stage, easily understandable descriptions for computations to be done and finally, they need software environments which integrate all the necessary tools and which have user friendly man-machine interfaces. Only the integration work has been attacked yet in projects as EKS /2/ in UK, SPANK /3/ in USA and OPTIMA /4/ in Germany. The aim of this paper is to show the problems and to make clear which efforts should be undertaken to establish system simulation as a standard tool in engineering offices. In the following first three sections examples on application of simulation in three stages of a building are given and some obstacles are introduced. Further obstacles are summerized in section 5. Efforts needed to overcome most of them are given in section 6. The paper is based on discussions with people involved in simulation during workshops for IEA /5/. All simulations have been realized with TRNSYS /6/. In agreement with the information policy of our clients and to satisfy the page limits of the conference proceedings only the highlights of the simulation results can be presented in this paper.

2 Preplanning

System simulation helps to reduce investment costs by more accurate sizing of HVAC systems. But most of the national payment orders punish designers: low investment costs mean low planning costs. This is the most important obstacle for system simulation. The only solution is to explain HVAC designers that simulation might also help to show building owners the need for HVAC installations. Building owners are impressed by simulation results which show the consequence of wrong HVAC sizing: the violation of thermal comfort.

In the following example the authors got the simulation contract from the HVAC designers. The goal was to study the natural ventilation concept for an african airport building /7/.

The building consists of two handling levels. The ground floor of approx. $6200m^2$ has a common inbound and outbound public concourse, check-in area and circulation areas for departure. First floor mezzanine level is of $838m^2$ in total. It has a public cafeteria and contains also employee service rooms. Second floor level of $3207m^2$ has a passenger concourse, two separate departure lounges and airline lounges. Third floor level of $984m^2$ has public and transit restaurants and some offices.

Figure 1 shows the modelled airport zones and the expected air flow pattern. The underground service channel (zone 10) is connected to the stairway tower (throu zone 3 and 6). Without any mechanical ventilation a socalled chimney effect is expected, if the entrance doors and dampers are open:

- an average total fresh air massflow rate of 35 kg/s during the day.
- an average total fresh air massflow rate of 105 kg/s during the night.

TYPE 56 /6/ is used to model the building. Figure 2 shows the simulated zone air temperatures for a 16 day summer period. The evolution of the outdoor temperature is the result of an agreement between the authors, the HVAC company and the architects. It is constructed from one single measured day in February. The results given in Figure 2 indicate that the building has a quite heavy construction and it takes about two simulated weeks to bring the building to thermal equilibrium. But the results also show that in all zones the air temperatures exceed thermal comfort limits. The authors recommended additional air-conditioning (cooling and mechanical ventilation).

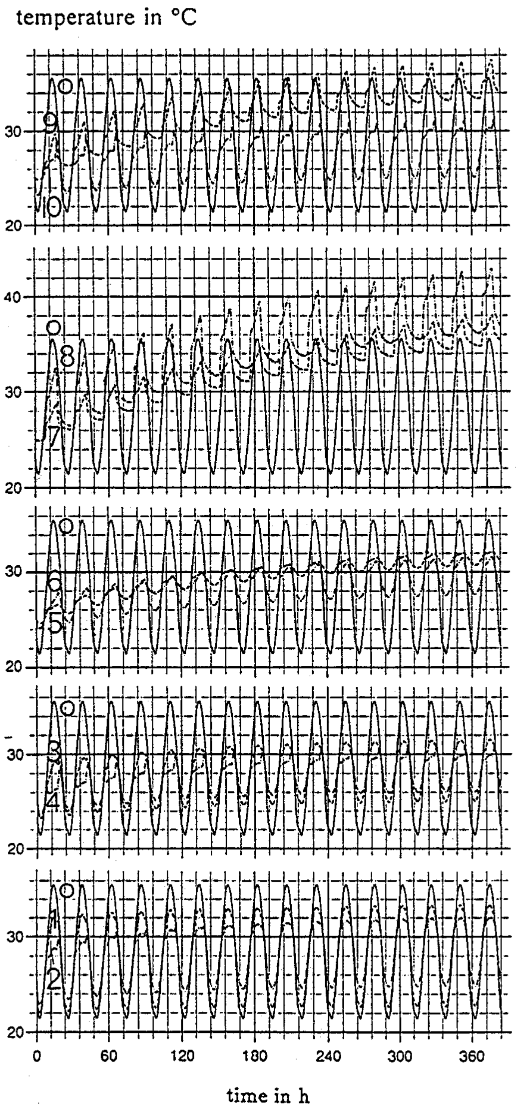

Figure 2: Simulated airport zone temperatures

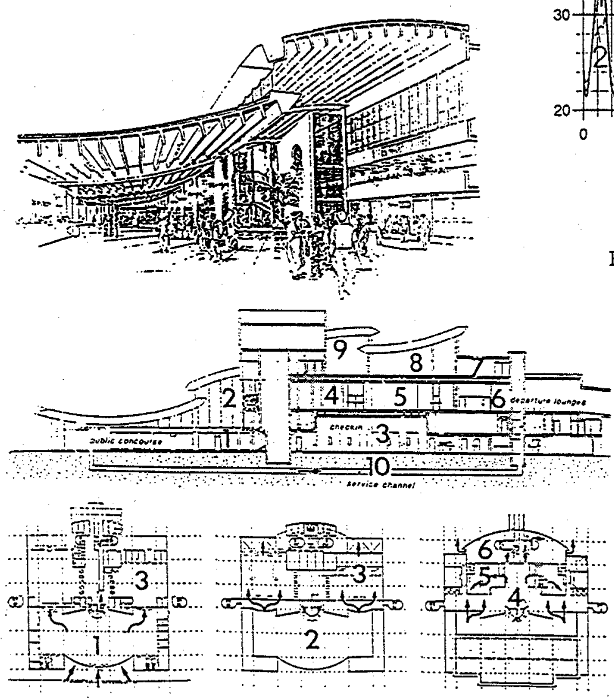

Figure 1: Airport zones and air flow pattern

3 HVAC Sizing

The example given in this section shows another two simulation obstacles: to run integrated building and system simulations huge amount of input data are required and component parameter have to be identified using curve fitting and other identification methods:

- The interconnection between building, HVAC and control system leeds to an energetical complex system. A generic conceptual model for the description of the building and the HVAC system as a composite object is required for system simulation. The decomposition of the problem should be made with consideration of the most important phenomenas from the specific point of view. So, the decomposition is problem driven, even if the subparts are often the same (coil, fan,...). Therefore, most of the simulation packages have a modular structure. This gives the users flexibility, but demands of the user some expert knowledge and adequate discipline. A system is defined to be a set of components, interconnected to accomplish a specific task.

- In most of the cases manufacturers data cannot be used directly to describe the components foreseen in the HVAC system. The suitable type of equation which approximates a special curve has to be derived from the physical model or it has to be selected by considering the shape of the curve. Curve fitting is needed in situations where there are much more data available than parameters, so that exact matching is out of question.

The building modelled is the administration and education center of a computer company near Stuttgart /8/. It has a total area of 74 000 m^2. Figure 3 shows the blueprint of the building and the isometrical view of the selected training rooms. Each room has a ground area of 40 m^2 and a height of 3 m. TYPE 56 /6/ is used to model the building.

Figure 4 shows the scheme of the HVAC system which supplies the teaching rooms. It consists of a single-duct pressure independent VAV system with a central air handling unit and local terminals and an additional hydronic heating system equipped with radiators in each conditioned zone. The VAV-system consists of mixing box, air filter, finned tube preheating and cooling coils, centrifugal supply and extract fans with revolving speed control and finned tube reheating coils and VAV-boxes for each zone.

The system is controlled by a Direct Digital Control (DDC) unit. Also the incoming daylight is controlled. The setpoint temperatures for zone air and supply air are linear functions of the outdoor temperature. Variable air volume is realized only in the summer mode. In winter the zone temperatures are controlled by variable zone supply temperatures modulated by the reheating coils. The minimum air flow rate for each zone is about 70 % of the maximum. Both fans are fitted with variable frequency control for varying the air flow rate. The static pressure is controlled to be 400 Pa at the measured point indicated in Figure 4.

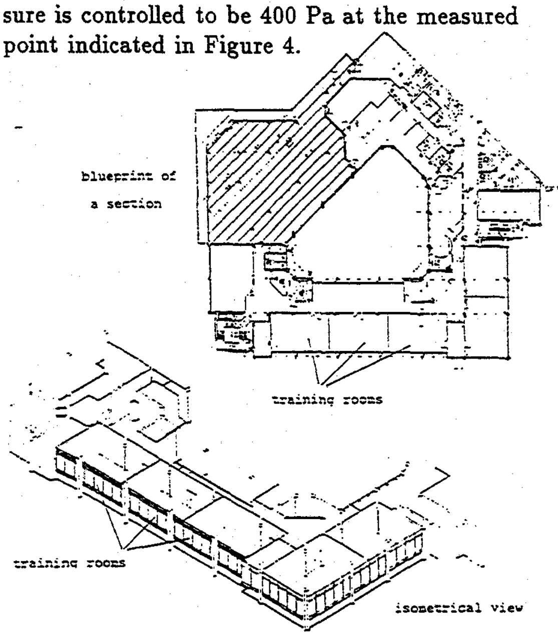

Figure 3: Commercial building

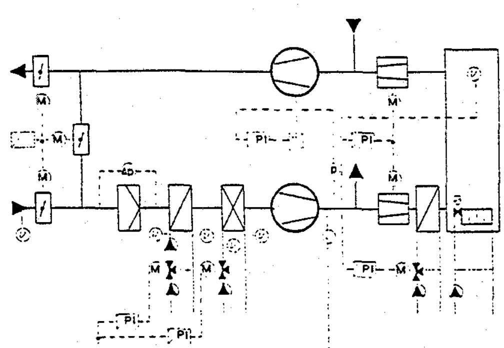

Figure 4: VAV system

To be able to calculate the ventilation costs (electrical power of fans) airflow vs. pressure drop relationships should be also considered in the simulation model of a VAV system.

The performance of the **centrifugal fans** is modelled by a relationship between the fan pressure increase Δp , air volume rate $\dot{V}$ and revolving fan speed n :

$$\begin{aligned}\Delta p \;=\; & c_1 \cdot n^2 \;+\; c_2 \cdot n \\ & + c_3 \cdot n \cdot \dot{V} \;+\; c_4 \cdot \dot{V} \\ & \quad + c_5 \cdot \dot{V}^2 \;+\; c_6\end{aligned}$$

The basic advantage of the approach is that the parameters of the model are the six polynomial coefficients of this equation. In this example manufacturers' measurements (catalogue data) are used for the estimation of the supply and exhaust fan model. The lower part of Figure 5 describes the polynomial curves as a 3D-space-surface.

A simplified way has been chosen to roughly characterize the heat transfer in **dry coils**. The socalled coil effectiveness Φ is defined as the fraction of the total heat transfer to the product of the maximum possible temperature difference and the minimum flow capacity. If measured data are available (catalogue, BEMS) the model of a specific coil can be easily calibrated. The result of a model calibration for dry air conditions could be a relationship between the effectiveness and the air and water flowrates. If such a relationship is available, the outlet air and water temperature can be computed with the energy balance. Again a square polynomial approach is chosen:

$$\begin{aligned}\Phi \;=\; & c_1 \cdot \dot{m}^2_{Air} + c_2 \cdot \dot{m}_{Air} \\ + c_3 \cdot \dot{m}_{Air} \cdot \dot{m}_{Wat} & + c_4 \cdot \dot{m}_{Wat} \\ & + c_5 \cdot \dot{m}^2_{Wat} + c_6\end{aligned}$$

The upper part of Figure 5 shows the result. The correlation shown in the graph violates the classical laws of heat exchanger theory. The effectiveness increases asymtotically with increasing flow rate on both water side and the air side. Even if the measurements also include the effect of temperature increase provided by the fan power, the result remains an example of the accuracy to be expected from real measured data and curve fitting procedures.

The coil pressure drop is modelled by using the following equation

$$\Delta p_{coil} \;=\; R_{coil} \;\cdot\; \dot{m}^n_{air} \;.$$

The air flow resistances are determined by using the manufacturers values of pressure drop and air flowrate under nominal conditions.

The characteristic of an **air filter** is given by the following equation

$$\Delta p_{filter} \;=\; R_{filter} \;\cdot\; \dot{m}^n_{air} \;.$$

For calculating heat transmission through the **duct** walls and insulation an overall heat transfer coefficient $U \cdot A$ is used.

The exponential relationship between heat emission and temperature difference of **radiator** and zone is implemented /1/. The characteristic curve of a radiator is related to nominal values on a radiator test bench. Hereby a logarithmic temperature difference is considered:

$$\dot{Q} \;=\; \dot{Q}_{nom} \;\cdot (\frac{\Delta\vartheta_{ln}}{\Delta\vartheta_{ln,nom}})^n .$$

The simulation results given in Figure 6 demonstrate the applicability of system simulation as a HVAC design tool. Due to small sizing the presented VAV system runs only on few weeks of the year with variable air flow rates. In summer most of the time maximum available airflow rates are needed to export the cooling loads from the zones. Further results are given in /8/.

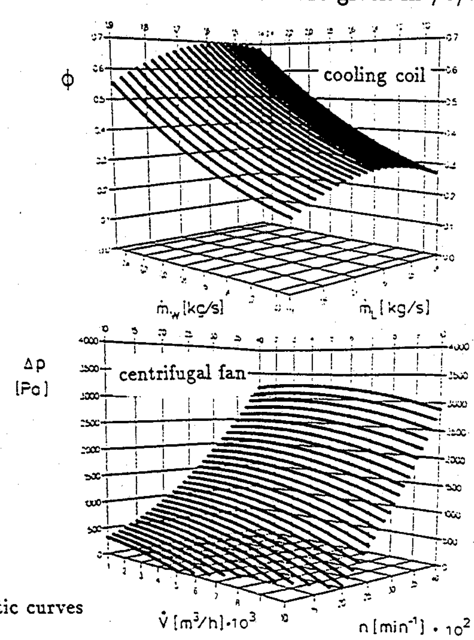

Figure 5: Characteristic curves

4 Comissioning

This third example shows that sometimes additional measurements are required for a simulation study. In such cases an engineering office can hardly compete with a research institute.

The building owner and the HVAC designers of a commercial building had a dispute on the cooling capacity of an already installed cooling panel system /9/. Figure 7 shows the cooling panels in the office rooms. The panels are controlled by thermostatic valves at the inlet of the cooling panels. In addition to the cooling panels the rooms are cooled and dehumidified by a single duct air handling unit. It supplies the rooms with a minimum outdoor air change 50 m^3/h per room. The windows are special, including a metal sun reflector. They reflect sun radiation at high sun positions and transmit sun radition at low sun positions.

The most important information is the cooling power of the panels. Therefore, new measurements were executed. Air temperatures, surface temperatures, water supply and exhaust temperatures and water and air flow rates were measured. As a result of these measurements Figure 8 shows the characteristic curve of the cooling panels. The results show that the cooling power is even higher than given in catalogue.

TYPE 56 /6/ is used to model the building. Figures 9 shows the evolution of the simulated temperatures and humidities. When varying the water inlet temperatures it was important to watch the possibility of condensation at the cooling panels. The calculations show, that when the water inlet temperature is less than $17,5° C$ and night cooling is on, the room air temperatures can be held at $26° C$. But when the water inlet temperature is less then $16,5° C$ condensation is possible. So, the water inlet temperature of $17,5° C$ and for very hot days additional night cooling was recommeded.

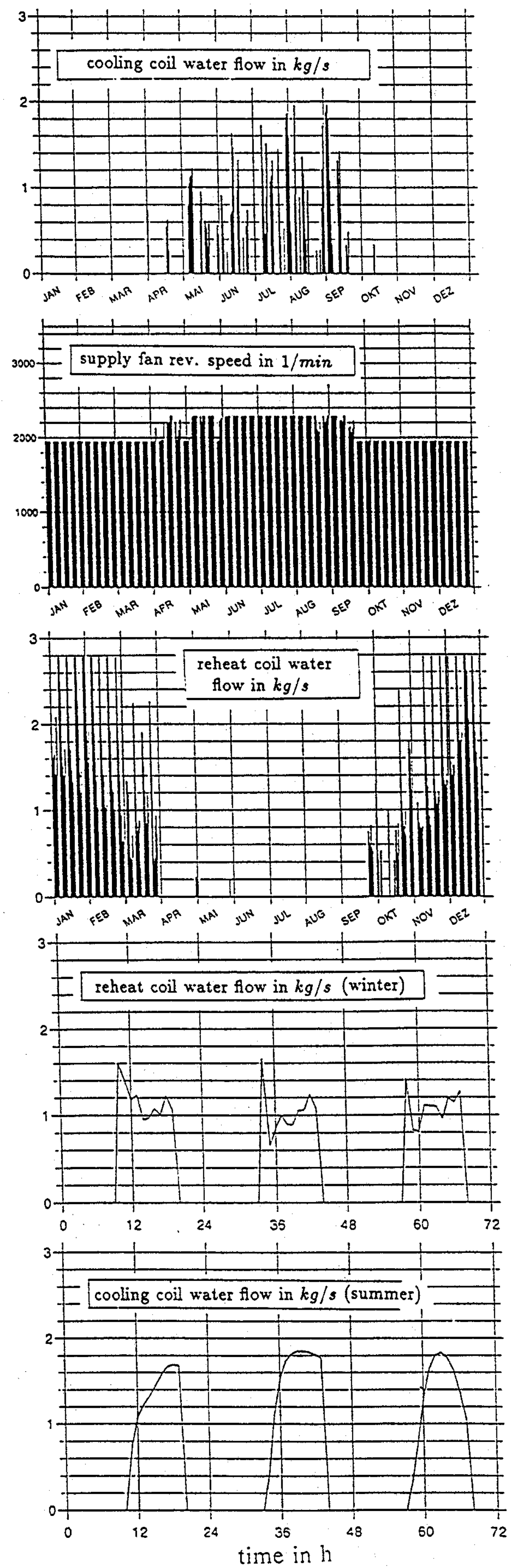

Figure 6: Simulated process variables of VAV system

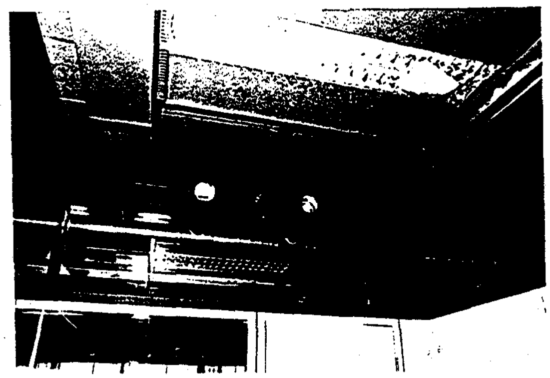

Figure 7: Office room with cooling panels

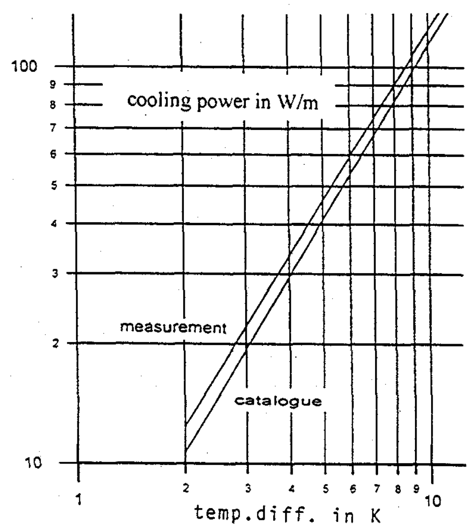

Figure 8: Cooling panel characteristic curves

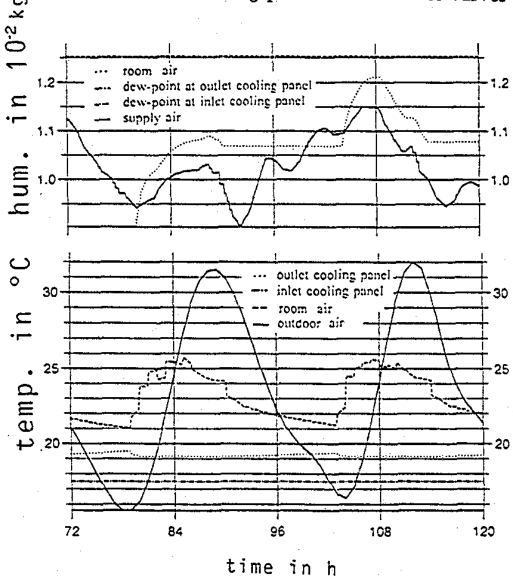

Figure 9: Simulated process variables for cooling panel system

5 Further Obstacles

- The knowledge on simulation of average HVAC design engineers is on a low level. The potential of simulation is still unknown.
- The succesfull execution of system simulation in building applications requires skilled users, having the following four basic qualifications:
  - knowledge on thermodynamic and fluid mechanic fundamentals,
  - knowledge on system and control theory,
  - knowledge on building and HVAC engineering and planning,
  - knowledge on data handling, computational methods and programming languages.

  Usually only young mechanical engineers are educated in all these disciplines. It is always a mistake to assume that such an expert could be replaced by a team of persons where each brings only parts of these qualifications into the group.
- Collecting the huge amount of input data required for integrated building and HVAC simulation is a very time consuming procedure. The following list shows the total expenditure for the examples introduced in the previous sections:
  - example 1 (building simulation): 1 man months,
  - example 2 (building and HVAC simulation): 6 man months,
  - example 3 (measurement and simulation): 2 man months.

  Figure 10 shows the simulation working steps and the average relative time needed for data collection and simulation. The values are based on the experiences of the authors. The most time consuming step is the collection of HVAC data (total 42 %). The collection of the building data is much less time consuming (totel 10 %). Therefore, the automatic data transfer from building CAD to building thermal model won't be a revolution.

6 Conclusions

The given application examples show that system simulation can be very useful in each of the three main stages of a building, which are

- architectural design and HVAC preplanning,
- HVAC planning and component sizing and
- building comissioning.

System simulation might help to reduce investment costs by more accurate sizing of HVAC systems. It also might help to show the need for HVAC installations.

For comissioning purposes measurements are required to calibrate the simulation model. Such a calibrated model allows to investigate the behaviour of the system in critical situations (climatic conditions) which might be not available during the comissioning period.

On the other hand, computers cannot replace human intelligence in the near future and system simulation will remain a business for skilled users.

Collecting the huge amount of input data required for integrated building and HVAC simulation is a very time consuming procedure. In future this task could be managed easier by integrated systems (CAD + database + tools).

But there will be still some large effort needed to increase the application of simulation in HVAC engineering offices. It should be urgently made in training and supporting people involved and people to be involved in simulation studies. Also the understanding of their job in their social environment should be improved:

- A library on simulation models should be available, including **mathematical descriptions, default data, examples** and **HVAC manufacturers' information.**
- Two different kind of **lectures** should be established: lectures for system simulation beginners and lectures for engineering office managers. The first group should get an overview on models and tools available and should start modelling and analyzing typical examples within the course. For the second group the cost benefits of simulation based planning should be demonstrated.
- Teaching and training both request attractive and robust methods. **Demo-versions** but also interactive **tutorial-versions** of simulation packages should be developed.
- Simulation model **comissioning techniques** and **quality insurance procedures** should be also defined and implemented in simulation software.
- A simulation engineer can hardly work without **statistical software.** Statistical tool boxes should support the engineer on the same platform on which the simulation runs.

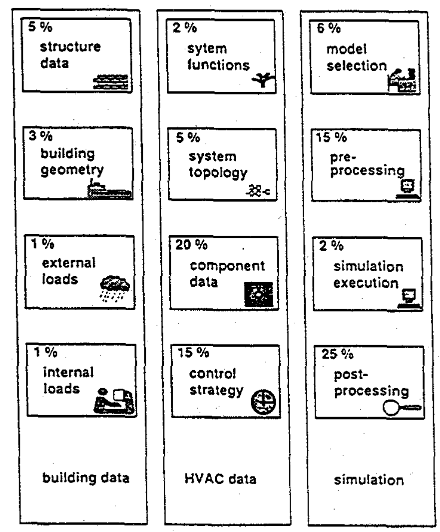

Figure 10: Relative time needed for data collection and simulation

7 References

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