EVALUATION OF THE ENERGY USE OF BUILDINGS, SYSTEMS AND PLANTS

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ABSTRACT

The paper presented is based on work done within the IEA ANNEX 10 'system simulation' group.
There, eight research instituts discussed and agreed on simulation models for heating and air conditioning components. The models are documented in so called 'component specifications'. These specifications contain a description how to simulate the steady state and also in a first estimation the dynarnic, hydraulic and aeraulic behaviour.
The computer codes, developed on the base of these models (extension of the TRNSYS code or own programs), allow a comprehensive calculation of the energy consumption, and energy flow, within the building, system and plant.
The simulation work should not stop, when all energies are calculated. A good presentation and an evaluation of the energies has to be done. Tlús necds an **evaluation** method.
Several methods, Eke thermodynan-dc evaluation, comparison with ideal processes or the efficiency theory are discussed. In the fóllowing, additional work is done to improve the efficieney theory.
All theories demand a clear defilútion of the boundaries of each. process within the building, the systems and the plants. If all energies at these boundaries are known the different processes, like hot- and cold-water or steam production, eneray distribution, air-treatment within the air conditiorúng system, heating and cooling in the room and energy use of the building, can be evaluated.
Of course a good graphical representation is necessary to have a better understanding of the results.
The comprehensive simulation work gives much more information than only energy. These can be the frequency of oceurence of eyelin-of components, control behaviour, pressure distribution in networks, conifort conditions in rooms etc. . The evaluation of this values can be done using more general methods Eke cost or penalty functions or knowledge based evaluation methods.
The described methods are used to evaluate the energy use of an office building with two kind of air conditioning systems.

INTRODUCTION

The improvements within the simulation programs, allow nowadays a more comprehensive simulation of the "real world" and there is much more information available as only temperature and global energy consumption; in example energy flows within each system and building component (based on simulation with modular programs), comfort conditions (based on the simulation of the temperature distribution and air flow patterns within a room) or control behaviour (based on detailed simulation of control loops).

All this leads to an huge amount of information, usually not used. But also the information usually presented, like energy consumptions and temperatures can only be interpreted by experts. Seldom a comparison with other well known systems or "ideal systems" is done or efficiencies for the whole system are calculated. No general method exists to do this evaluation work.

Of course there are a lot of good graphic tools. But these do not replace the need of an evaluation of all the values calculated during a simulation process.

This article mainly deals with a proposal how to present and evaluate the **energy** values calculated for buildings with air conditioning systems and plants. Other evaluation methods are discussed shortly.

SIMULATION PROGRAMS

Within the IEA-ANNEX-10[ref1] and 17[ref2] great effort had been spent to improve component based simulation programs. For every important HVAC component a detailed specification exists. These so called "component specifications" contain a description how to simulate the steady state and in a first aproximation the non steady state and mass flow characteristic of each component.

The results presented below are produced with a comprehensive simulation program, developed at the University of Stuttgart (GERALT) [ref3]. Most of the IEA-ANNEX-10 "Component Specifications" are included in this program. The features of this program are similiar to the TRNSYS program [ref4]. In addition to TRNSYS it covers detailed building simulation types, based on the Finite Difference Method, and the capability of calculating water and air mass flow rates in large networks, considering the flow resistance characteristic of each component. Also a postprocessing of the results is carried out, using the evaluation method, described below.

EVALUATION METHODS

The methods for a better evaluation and enhancement of simulation results can be divided up into three parts

- Direct Presentation
- Thermodynamic Evaluation
- Cost Penalty Functions

Here, a proposal how to improve the energy related performance evaluation and enhancement, is presented.

The examples refer to an office building with two kinds of air conditioning systems, described in table 1.

1 Direct Presentation

Before starting with a proposal how the energies within a building and air conditiong system can be presented, the most important energy flows within the building and system should be defined.

A building with an usual HVAC-system can be divided in several subsystems as shown in figure 1. These subsystems are
- energy production,
- energy distribution,
- thermodynamic processes within the air handling units,
- building, and
- building gains

Figure 2 shows for the single duct air conditioning system the energy flow between the subsystems. This energy flow diagram presentation is usable for visualizing the size of the different energy flows within a building. Especially the energy losses, in example the heat rejected in the cooling tower, or the heat losses of the boiler or the additional energy needed within the air handling units are shown.

As the flow diagrams are only a good tool to get an overview on the whole system, it is necessary to give the energy rates seperately. This is done in a bar-chart, see figure 3. Here also a comparison with an ideal system (discribed in chapter 2) is done.

Building Gains

As the same building is considered the building gains are the same in both examples. The greatest building gain is produced by the lights (Q_{BEL}), followed by the gain due to transmission through outside surfaces (Q_T) and equipment (Q_N) and solar gains (Q_S).

The ventilation losses (Q_L) are calculated seperately.

Building

The building load is calculated to maintain ideal the desired room conditions. The big step from the sum of the building gains to the loads is caused by the use of ventilated lights and by thermal storage effects within the building. Due to the non ideal control of the room conditions the heat extraction rate is higher than the building loads.

Air Handling and Heating System

Great "losses" can be found within the air handling units. This is caused by the missing of a heat recovery, a surplus of outside air that leads to a high fan consumption, and by the cooling, dehumidifying and reheating process during summer operation mode. This additional use of heat is greater for the constant volume system than for the variabel volume system.

Energy Distribution

As all pipes and ducts are well insulated there are no significant losses. The heat distributed by the radiator perimeter heating system is directly supplied to the rooms and has to be add to the heat extraction rate of the air conditioning system.

Energy Production

The three important energy flows within the cooling plant are
- electrical energy consumed by the cooling tower and compressor,
- energy absorbed at the evaporator and
- heat rejected at the cooling tower.

The losses of the heat production are caused by the losses of the hot water boiler.

The steam production is done with an electrical device. Therefore no losses are calculated.

Energy Supply

Only two kinds of energy are consumed. Electrical energy for the cooling plant, the fans, pumps and the steam humidifier and fuel for the hot water boilers.

2 Thermodynamic Evaluation

There are several possibilities for a thermodynamic evaluation. A first possibility is the use of **exergetic** values, but the use of these values makes only sense, if there is a conversion from heat to work or visa versa. As in usual HVAC systems this can only be found within the cooling plant and the pumps or fans this method can not be proposed.

The second method is to calculate **efficiencies** for each single process and for the whole system. Efficiency can be generally defined as the relationship between usefull energy and energy consumption.

$$efficiency = \frac{usefull\ energy}{energy\ consumption}$$

Usually efficiencies from 0.0 to 1.0 are calculated. Figure 5 shows all the calculated efficiencies for the two systems. A comprehensive definition of all the efficiencies is in [ref5].

There are also processes with efficiencies greater than 1.0 , in example for the COP for a cooling plant or the efficiency of an air handling unit (if there is free cooling provided by the outside air or heat recovery). For this cases a comparison method is proposed by Esdorn and Jahn [ref6]. They propose to compare the actual energy consumption with the energy consumption of a reference case, usually an ideal process. The reference for a chiller can be the Carnot-Process and for the air handling unit a process with the following issues:
- maximum enthalpy recovery
- ideal processes within the air handling unit - ideal fans and pumps (no energy consumption)
- mass flow rates from 0 to $\dot{m}_{su,max}$
- Carnot process for the chiller
- ideal processes within hot water and steam boilers.

With this definitions the quality of the process or the **"effectiveness"** values can be calculated.

$$Quality\ of\ the\ process =$$
$$effectiveness = \frac{energy\ use\ of\ the\ ideal\ process}{energy\ use\ of\ the\ real\ process}$$

Figure 5 shows for the two systems the effectiveness.

In addition to [ref6] the total efficiencies and effectivenesses includes all the electrical consumption of the building (lights and equipment).

3 Use of Cost or Penalty Functions

Beside energy, there are a lot of other values that should be considered in an overall evaluation of a building performance. (in example temperature, comfort conditions, maintenance, reliability, costs etc).

The common evaluation of all these measures is possible if cost functions or penalty functions are used for each item.

$$Overall\ Costs = \sum_i (value_i \cdot costfunction_i)$$

As the determination of the cost functions is always a subjectiv matter, the user of the building will define other cost functions as the HVAC engineer or the control engineer. A cost-benefit calculation method has been used by Brendel and Güttler [ref7] for the evaluation of different HVAC-Systems.

More work on this subject will be done in the IEA ANNEX 17 working group [ref2], with the aim to find evaluation methods for the performance of Building Energy Management Systems.

SUMMARY

There is a need to have a good presentation and an evaluation of the results out of simulation programs. For the example of two different air conditioning systems the calculated energy values are presented in an energy flow chart and a bar chart. Both kind of presentations are needed. The energy flow diagram presentation to get an overview on all the different energy flows within a building and the system and the bar chart presentation to do the comparison of the two systems.

For the evaluation of the energies two methods are proposed. First the use of efficiencies and second the use of effectiveness values. Both methods are supplementary and a clear definition of the boundaries within the system is needed.

If different kind of values should be evaluated cost functions for each value of consideration have to be defined. The result of this method depends strongly on the subjective definition of the cost functions. Here additional work should be done in the future.

Of course the use of the evaluation methods is not restricted to simulation results. Results from audits, information collected in building energy management systems and tests in laboratories can be handled in the same way.

References

[ref1] J. Lebrun: IEA-ANNEX 10 System Simulation, Synthesis Report, ULg., Belgium, 1988.

[ref2] J. Lebrun: IEA-ANNEX 17 BEMS Building Energy Management Systems, Test and Evaluation Methods, Proposal of Work, ULg., Belgium, 1988.

[ref3] Stephan, W.: Modulares Simulationsprogramm für Heiz- und RLT-Anlagen " GERALT " , handbook, internal report, University of Stuttgart, IKE, Abt. HLK, May 1988.

[ref4] TRNSYS: A Transient System Simulation Program, Solar Energy Laboratory, University of Wisconsin, Madison, 1983

[ref5] Ast, H., Bach, H. and W. Stephan: Bestimmung und Bewertung des Energieverbrauchs von Heiz- und RLT-Anlagen durch rechnergestützte Betriebssimulation. Deutscher Beitrag zum IEA-ANNEX 10, final report, University of Stuttgart, IKE, Abt. HLK, November 1988.

[ref6] Esdorn, H. and Jahn.A.: Energy efficiency factors for assessing air conditioning systems. Proceedings of the IEA Conference New Energy Conservation Possibilities and their Commercialisation, Volume 2 p. 1169-1175, Verlag Springer, Berlin, 1981.

[ref7] Brendel, TH. and G. Güttler: Energieverbrauch von Klimaanlagen, Methoden zur Ermittlung von Vergleichszahlen Kosten/Nutzen-Relationen, Verlag C. F. Müller, Karlsruhe, 1981.

Table 1: Description of an office building with two kinds of air conditioning systems

Buiding	Office Building with 5 zones 4 permimeter, 1 internall 1500 m_2 per floor	
System	1	2
System	VAV 2-pipe induction mixing box heating coil steam humidif.	single duct reheat radiator heating mixing box cooling coil steam humidif.
Plant	centrif. chiller oil boiler electr. steam humidifier	centrif. chiller oil boiler electr. steam humidifier

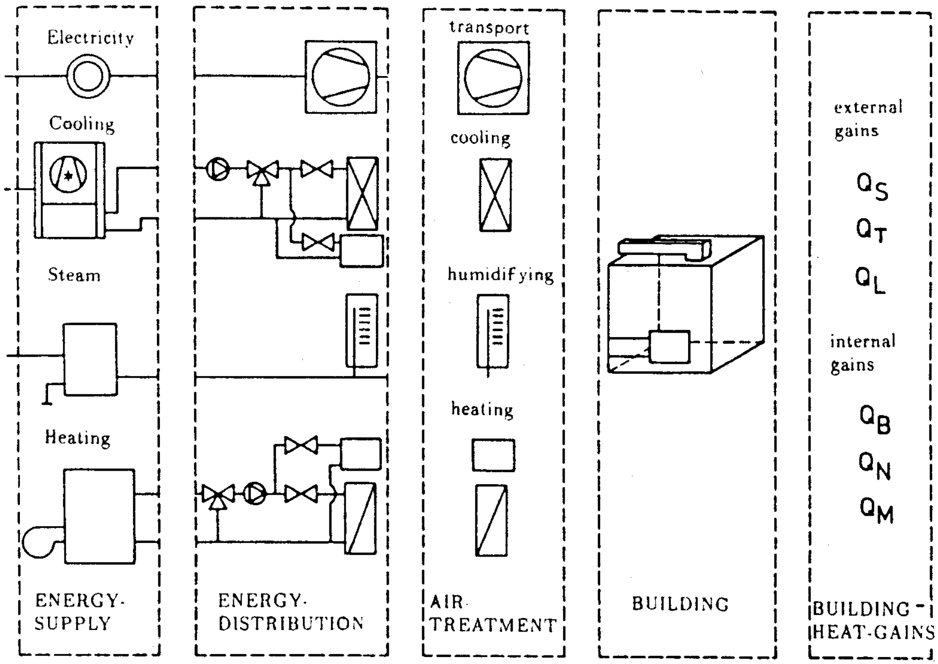


Figure 1: Important Subsystems and Boundaries within a Building and HVAC-System

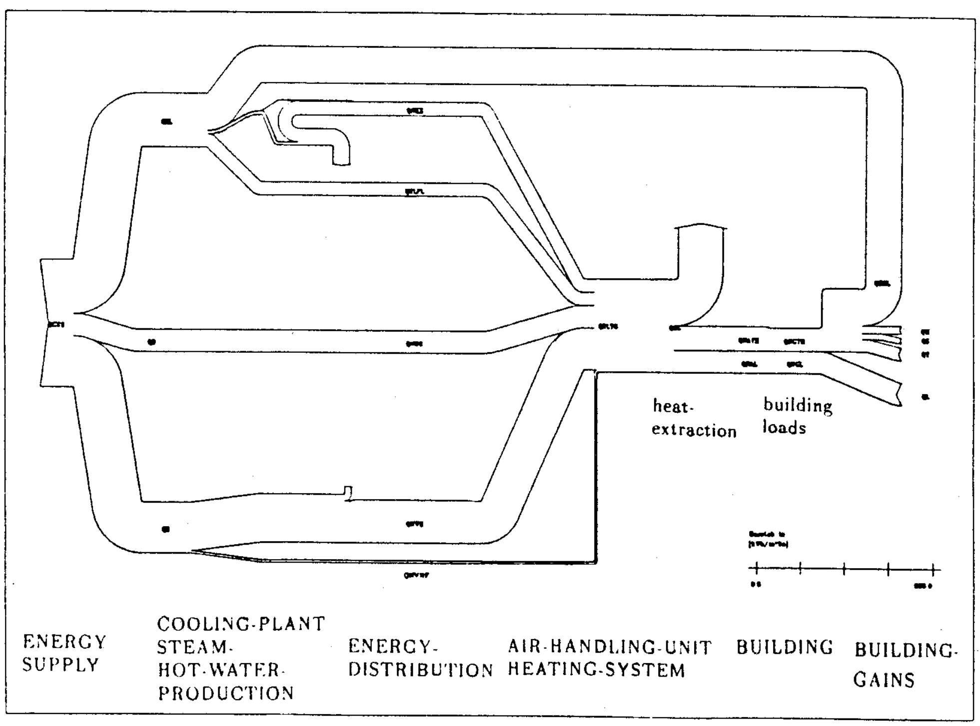


Figure 2: Energy flow diagram for an office building with single duct constant volume air conditioning system with perimeter radiator heating, yearly results

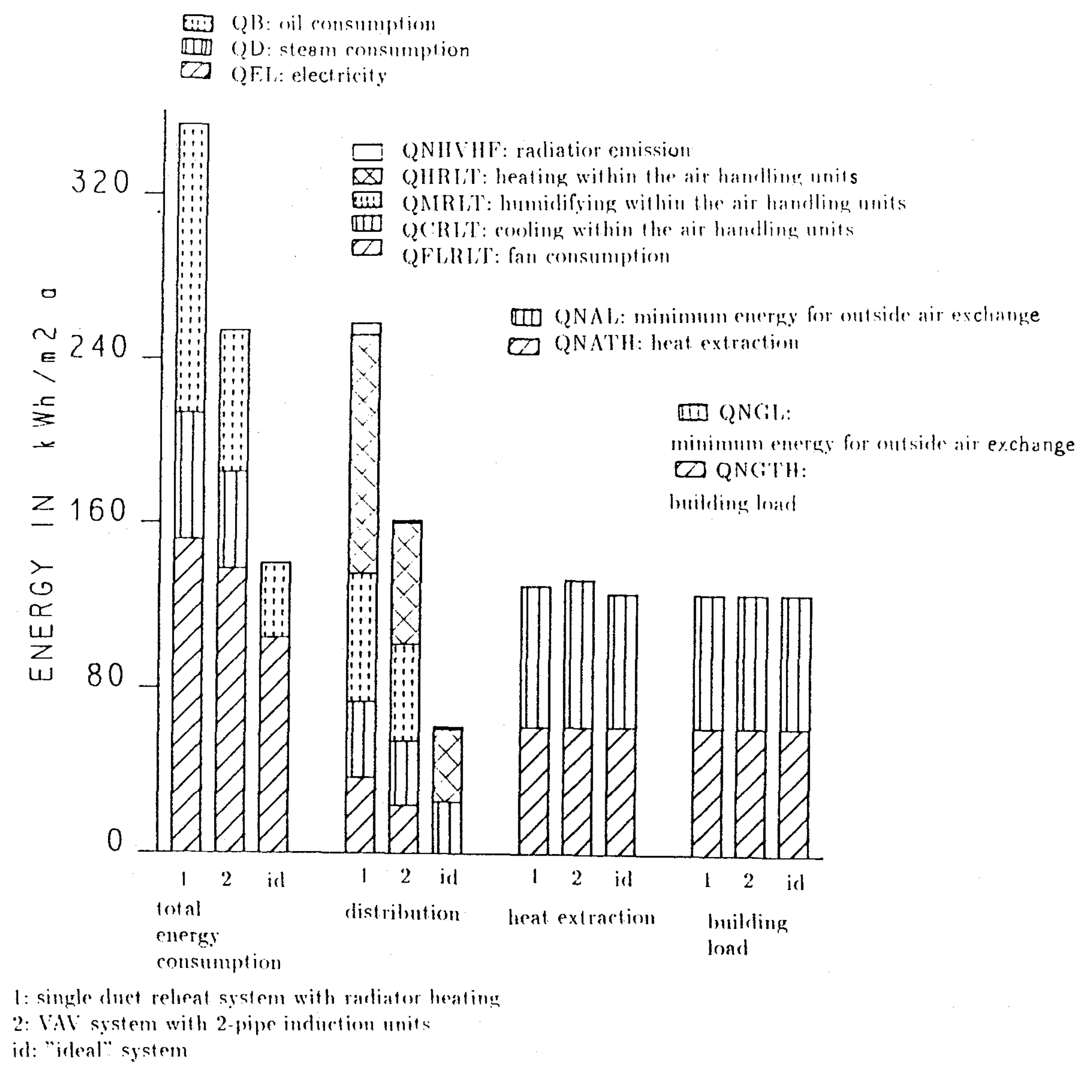
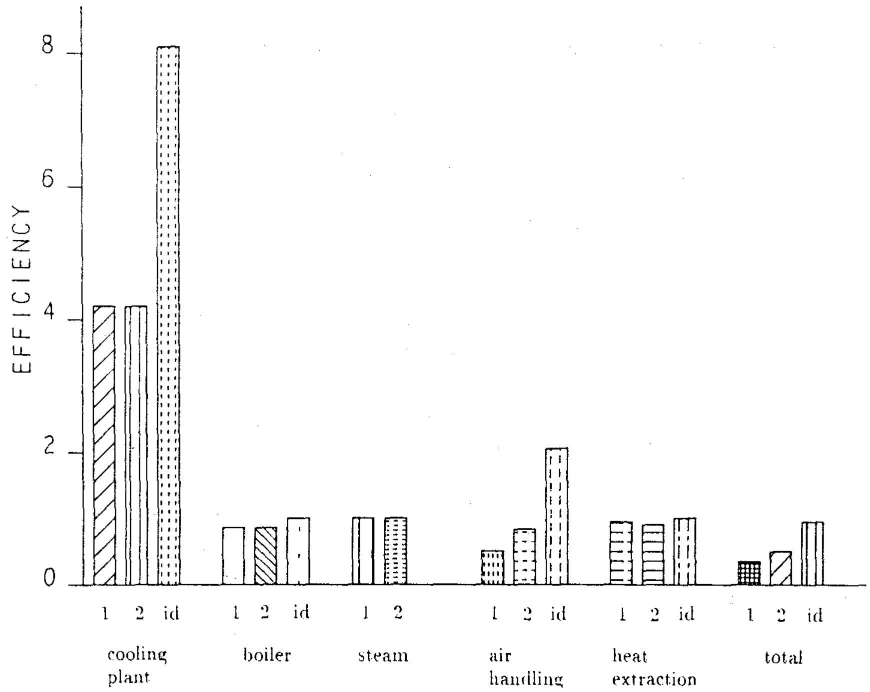
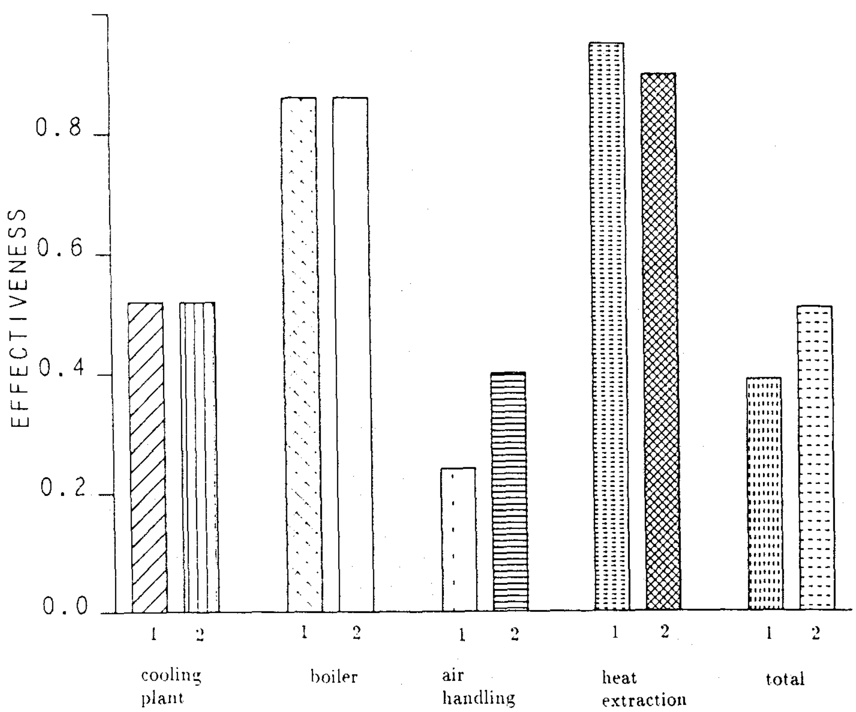


Figure 3: Comparison of the energy consumption of two air conditioning systems and an ideal system, yearly results



1: single duct reheat system with radiator heating
2: VAV system with 2-pipe induction units
id: "ideal" system

Figure 4: Comparison of the yearly efficiencies of two air conditioning systems and an ideal system



1: single duct reheat system with radiator heating
2: VAV system with 2-pipe induction units

Figure 5: Comparison of the yearly effectiveness of two air conditioning systems