VENTILATION SYSTEM PERFORMANCE

11th AIVC Conference, Belgirate, Italy
18-21 September, 1990

Paper 20

BUILDING PERFORMANCE AND VENTILATION SYSTEM

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Summary

With a dynamical model, the thermal behavior of a single office room is simulated. The model includes among other things the behavior of occupants, the heat production of machines and lights, the heat flux into masses, real weather data (hourly observations) and different HVAC and control systems. The computer program calculates monthly and yearly energy consumption and a statistical distribution of the room air temperature. It can also be used to investigate the time evolution of physical processes for short periods.

A parametric study shows how the U-value of the facade and the building performance influence the energy consumption. Climatic conditions and types of HVAC-systems are also varied.

For office buildings with an envelope of a good quality, the total energy consumption is predominantly determined by the electrical supply power of the machines (computers, copying machines, etc). Other factors may be important, as for example the type and the control strategy of the HVAC-system. The building performance and the ventilation system are strongly related to the comfort of the occupants.

1. Introduction

The performance of a building is governed by the user behavior and by the features of the building. *Comfort and energy consumption* are important characteristics of the building performance. Their interdependence may be investigated by parametric simulation studies.

In this paper results are presented which apply to modern office buildings.

2. A Dynamical Model for Room Simulations

The dynamical model used in this study is named HIT-KOMFORT [1]. HIT is the acronym of High Insulation Technology, which means a building concept [2] based on low-U-value windows and a comfort ventilation system [3]. The model has been developped on behalf of the experience, that the *performance* of such a building is *totally different* compared to a conventional type.

HIT-KOMFORT is a model for the dynamical simulation of the thermal and energetical performance of a single office room. The behavior of the occupants, all the relevant heat sources and sinks and the thermal masses are included. Different HVAC-systems can be used.

The computer program produces three types of results:

- **energy consumption**
  Included are among other things the energy consumption for lights, machines, ventilators, etc. Heat recuperation is also simulated.
  The energy consumption is directly related to the operation costs and to questions about environmental protection.
- **energy balance**
  Energy balance of the room, e.g.: transmission losses, losses due to crack flow, sun gain, heat gain of lights and machines and the effects of the HVAC-system.
  These are the primary parameters in the course of the computations. They can also be a help to understand the physical and technical processes.
- **temperatures**
  Temperature statistics (period: one year) and evolution in time (some days).

The physical processes (visual and infrared radiation, convection at the surfaces, heat conduction into the thermal masses, heat sources and sinks) were transformed into an electrical network with 18 resistances and 14 capacities. A time step of 6 Minutes is used in order to simulate also the thermal discharge of the room air.

Different sets of hourly weather data, each for the period of one year, can be used. The program needs the outdoor temperature and the solar radiation. The outdoor temperature influences the transmission through the fassade und the energy amount for the pre-conditioning of the supply air. The transmitted solar radiation effects as heat load and controls the operation of the sun protection and the lights.

In the context of modern HVAC-systems, the terms "cooling" and "heating" must carefully be defined: it has to be distinguished between the pre-conditioning of the air (affects the energy consumption) and the energy input/output of the air to/from the room (energy balance). E.g.: In many office rooms excess heat is produced even in winter. The room may then be cooled (passiv cooling) by the ventilation system although the outdoor air has to be heated up.

The standard version of the computer program offers five different types of HVAC-systems, each of them with a realistically modelled control concept:

1. Natural ventilation
    - window opening at office time
    - radiator heating

2. Mechanical ventilation
    - all-air system
    - cold outdoor air is heated up to the prescribed supply air temperature
    - supply air can additionally be heated, if needed (controled by room air temperature)
    - two different air change rates controlled by the room air temperature
    - free cooling at night
    - system off, if $t_a > 22^\circ C$

3. Air condition
    as "mechanical ventilation", except:
    - outdoor air can be cooled to have the prescribed supply air temperature

4. Combined air-water-system
    - air system for room air quality, similar to "air condition", except: fixed air change rate
    - water system for energy transport, mainly cooling by ceiling-mounted radiators

5. Traditional HVAC-system
    as "air condition", but:
    - supply of heat energy by wall-mounted radiators

The model has been *validated* with measurements of real buildings. It is a tool for parametric studies (research and consulting) and for the interpretation of observations (research).

The results, which are presented in this paper, apply to an office room with the following features:

- floor surface: 23.2 m^2
- air volume: 64.9 m^3
- panel height: 0.9 m
- area of glazing: 4.4 m^2
- U-value panel: 0.3 W/m^2K
- U-value frame: 1.3 W/m^2K for HIT-windows
  2.0 W/m^2K for other types
- glazing: varied
- crack flow: varied
- no heat transfer to other rooms
- lights: 15 W/m^2 (below 500 lux)
- sun protection: exterior (above 10000 lux)
- occupants: 2, 70% of office time
- machines: varied, up to 50 W/m^2

- maximum heat load: 15 W/m^2 lights or sun
  5 W/m^2 occupants
  x W/m^2 machines
  total: up to 70 W/m^2
- HVAC-system: types 2 or 4
- efficiency of heat recovery: 0.6

3. Range of Energy Consumption

The energy consumption of buildings varies over a very large range. This is even true, if one concentrates on one specific type. In figure 1, the yearly total energy consumption for four different cases are given, demonstrating this fact. It leads to the urgent question about the reasons of the extreme variability and the possibilities to avoid excessive energy consumption. Therefore, the *relevance* of the different parameters and their *interdependence* has to be investigated.

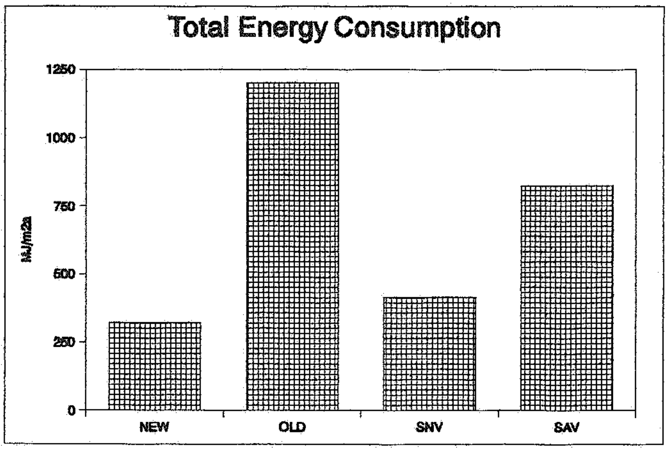


Figure 1. Yearly total energy consumption
NEW = HIT-part of an old office building in Winterthur, Switzerland, which was extended in 1988. (Conditions for the extension were not optimum.)
OLD = conventional part of this building. (Leaking window frames)
SNV = swiss nominal value, recommended by the Swiss Society of Engineers and Architects (SIA)
SAV = swiss average in 1988 (buildings with heavy deficiencies have been excluded)

A strongly dominating factor, which can not be influenced by the building designer, is the **energy consumption for machines**. If one assumes the electrical supply power of the computers, copying machines, etc, to be 50 W/m^2, they would already consume around 500 MJ/m^2a ! In figure 2 the total yearly energy consumption for four different situations is given as a function of the supply power. They arise from the variation of two further parameters:

1. climate/weather data
    - Kloten 1983
      swiss midlands climate
      av. temp. = 9.4°C
      solar radiation = 4066 MJ/m^2a
    - Samedan 1985
      alpine climate
      av. temp. = 0.8°C
      solar radiation = 5245 MJ/m^2a
2. type of glazing
    - IV3 (tripple insulated glazing)
      U-value = 2.1 W/m^2K
      visual transmission rate = 74%
      crack flow = 0.37 ac/h
    - HIT window with film type 88
      U-value = 0.76 W/m^2K
      visual transmission rate = 65%
      crack flow: none

In all cases, the same HVAC-system and control strategy is adapted: it is the combined water-air-system (type 4) with a water temperature (ceiling radiators) of 19°C beeing active for room air temperatures above 23°C. The ventilation operates during office times at 1.5 air changes per hour.

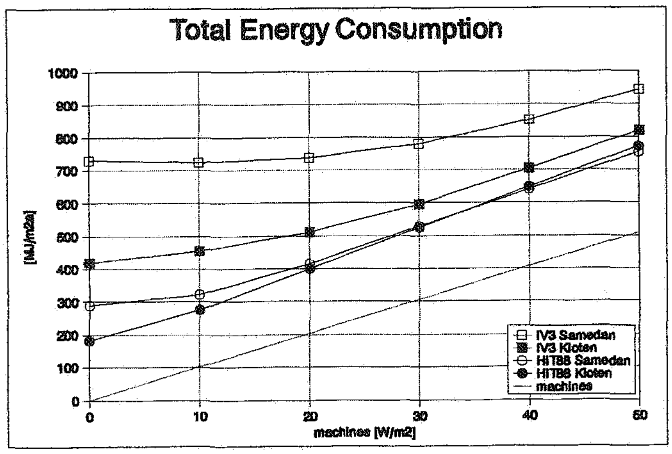


Figure 2.
Yearly total energy consumption as a function of the electrical supply power of machines.

The results show the clear *predominance of the supply power* as a parameter in most of the cases. For well insulated fassades in a moderate climate, the functional relation is linear, whereas in the alpine climate some additional heat energy is needed, if the internal heat loads are low. But nevertheless, the climatic influence is nearly negligible. In the case of a conventional fassade, the internal heat loads loose of their dominance, but other factors become more relevant: these are the climate, but equally important the U-value of the fassade.

The air change rate of the mechanical ventilation is an other relevant factor. Assumed are an overall U-value of 0.6 W/m^2K, absence of crack flow, electrical machine power of 10 W/m^2 and a mechanical ventilation system (type 2). The air change rates are kept constant within one case, but varied as a parameter in the range of 0.5 up to 6.5 ac/h. The energy consumption for the ventilation system is presented in figure 3, again for the climates of Samedan and Kloten. It is obvious that, depending on the maximum air change rate and climate, this *can be the dominating part* of the total energy consumption. With the above mentioned assumptions, the climate gains its importance by the temperature of the outdoor air, which has to be brought up to the supply air temperature. But if one considers a conventional fassade, the transmission losses would also have to be covered by the mechanical ventilation.

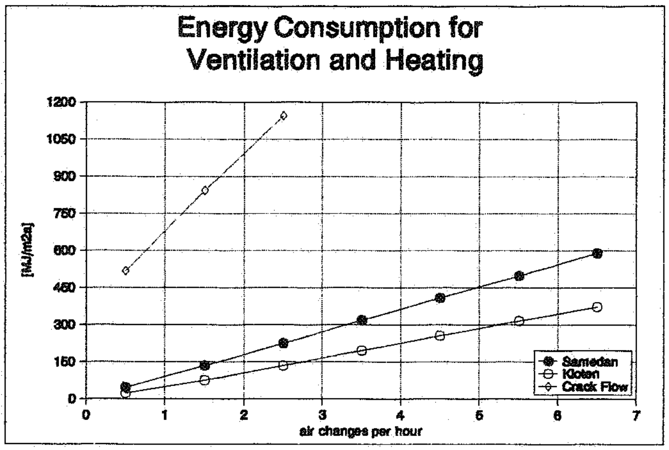


Figure 3.
Yearly energy consumption for ventilation and heating.

In buildings of poor quality, losses due to **crack flow** can accumulate to a considerable amount. As an example, a naturally ventilated room with double insulated glazing and leaking window frames is considered. The intensity of crack flow, measured in air changes of room volume per hour, is taken as parameter. In figure 3 (upper left part), one can see the energy consumption of the radiator heater for the swiss midland climate. Obviously, excessive heat amounts can be lost, if the fassade is not tight enough.

The gain of natural **light** depends on the area of the glazing and the visual transmission rate. For an office room without windows (interior space), the consumption of electricity for the lights amounts approximately 150 MJ/m^2a, whereas with normal double glazing (size as defined above), this is around 30 MJ/m^2a. Consequently, for low-energy office buildings, the lighting (natural and artificial) has also to be optimized with respect to the total energy consumption.

4. Fields of Operation of a Mechanical Ventilation System

With displacement ventilation a high comfort (good air quality, no draft) can be achieved. Nevertheless, there are operational limitations [5]: the supply air temperature must be some where between 18 and 20°C, the vertical temperature difference in the zone of occupancy should not exeed 3 K and the velocities should be kept as low as possible. Consequently, the energy transport capacity of this type of ventilation is limited. The field of operation of **all-air ventilation systems with displacement flow** in office rooms is therefore restricted to offices with moderate internal heat loads.

Here, a case is presented with HIT-windows and a mechanical ventilation (type 2) operating at 1.0 and 5.0 ac/h, respectively, controled by the room air temperature. Again, the electrical supply power of the machines is the independent parameter. The results are the annual mean room air temperature (figure 4, left scale) and the number of hours with $t_i > 27.5^\circ C$ (figure 5, right scale). All the statistical numbers were sampled at office times only. The figure indicates, that the number of hours with "high temperatures" should be used as a criterion to limit the field of operation for the all-air mechanical ventilation. From this, an upper limit for the maximum heat load seems to be some where around 40 W/m^2, which, in this case, corresponds to an electrical supply power of the machines of 20 W/m^2.

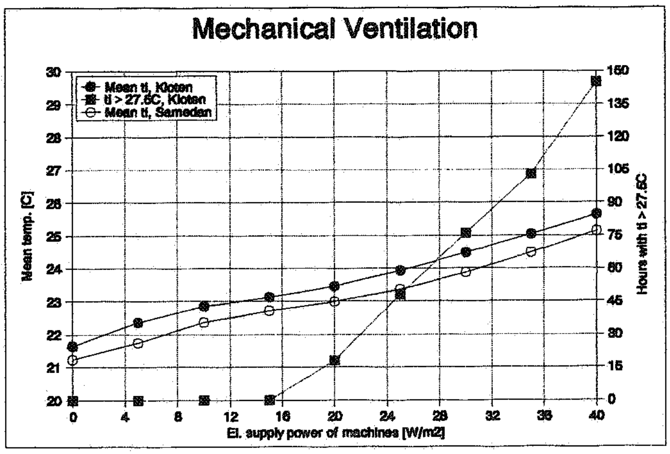


Figure 4. Annual mean room air temperature (left scale) and number of hours with "high" room air temperatures (right scale) as a function of the supply power of the machines.

5. Thermal Comfort and Energy Consumption

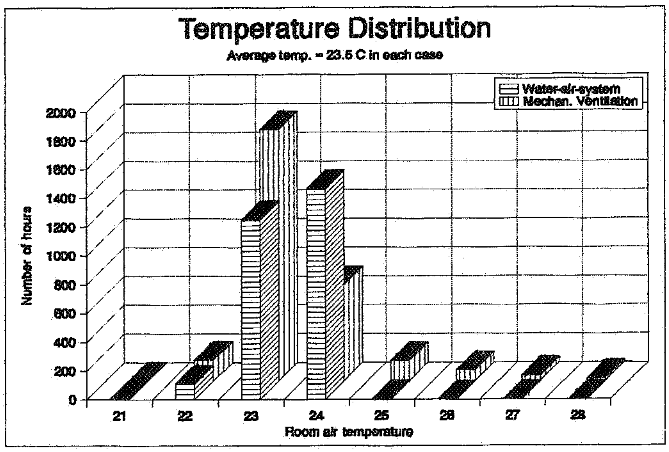
Many laboratory tests, field studies and numerical calculations (flow models) have already been carried out to investigate the comfort conditions of different ventilation systems, and further research will have to be done in future. The total of these investigations is rather comprehensive with respect to the observed parameters, but restricted to a very limited number of climatic conditions (winter case, summer case). Quite often, it is only possible to look at stationary situations.

The modell, which is presented in this paper, offers the opportunity to overcome these deficiencies, though at the expense of the variety of the parameters. In the following, the room air temperature is used as a simple indicator of the thermal comfort.

The **thermal performance** of a room lies some where between the two extremes:

- The temperature must remain constant during operation time. This means, that all heat gains or losses (due to internal heat loads, transmission, etc) must immediately be balanced out by the HVAC-system. The implication on the size and power of the system are well known!
- The temperature may vary over a wide range during a day or over the seasons. Disregarding the air quality, a simple heater may be sufficent.

Whereas in production processes, the first strategy might have to be applied, the temperature in an office roome normaly may vary to a certain degree. (Quite often, the customer defines to what extent variations will be accepted.)



In figure 5, the temperature distributions of two cases can be compared for the above defined office room and a supply power of 20 W/m^2 (40 W/m^2 max. heat load). The HVAC-types 2 and 4, respectively, were given. The target values were chosen in such a way, that the average room air temperature over the year (office times only) were 23.5°C in each case. The figure shows, that the temperature distribution for the all-air system extends over a wider range than for the combined water-air-system. This can also be expressed with the number of hours, when the temperature exceeds 24.5°C:

Type	Hours	Energy
2	274	426
4	4	405

The table reveals, that in the less comfortable case, more energy is consumed (total energy consumption in [MJ/m^{2}a]). This is due to the fact, that with heat loads as assumed here, the mechanical ventilation operates at its maximum air change rate nearly all the time. This causes comparatively high energy consumptions for ventilators and pre-conditioning of the outdoor air.

Finally, it is looked at a control parameter of the combined water-air-system (same room as above). The target cooling temperatue, at which the water system comes into operation, is varied from 22°C up to 26°C. (The model incorporates a linear valve-function with a spreading of 2 K).

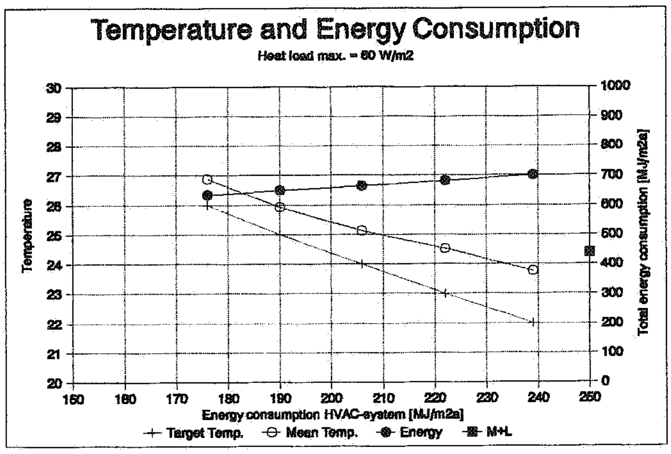


Figure 6.
Mean room air temperature and energy consumption as a function of the target cooling temperature.

The results are presented in figure 6, where four parameters are related to each other:

1. Target cooling temperature (left axis)
2. Energy consumption for HVAC-system (horizontal axis)
3. Mean room air temperature (left axis)
4. Total energy consumption (right axis)

With a target cooling temperature of 22°C, the HVAC-system consumes approximately 240 MJ/m^{2}a, the mean temperature is 23.8°C and the total energy consumption is 700 MJ/m^2a. In all cases, the lights and machines consumed 440 MJ/m^2a. The essential insight is, that raising the target cooling temperature up to 26°C, the total energy amount is reduced by about 10%, though at the expence of an acceptable thermal comfort.

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