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Energy Consumption and Comfort of Modern Air-Conditioning Systems for Office Buildings.

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Abstract

Selection of an air-conditioning system is generally determined by the sensible heat load of the building, as the total of external and internal loads. 3 systems with a mean specific sensible heat load of 60 W/m^2 floor area are compared.

System 1: VAV-system, representing a turbulent mixed flow ventilation.

System 2: Air-water induction system with ceiling induction units, representing a combined turbulent mixed flow - displacement flow ventilation.

System 3: Chilled ceiling system combined with displacement ventilation.

Comparing these 3 systems there is little difference in energy consumption, if they are well designed and correctly operated and the room air temperature is allowed to float freely within a zero energy band. The difference between fixed and floating room air temperature is higher (10 %).

Futhermore the important influence on comfort and energy consumption of typical user faults, of wrongly designed or poorly adjusted VAV-systems and of poor maintenance is shown.

1. Conditions for selection and comparison

Selection of most suitable air-conditioning system is generally determined by the maximum total cooling load of the building.

Further criteria are design, orientation and use of the office building. Generally the optimum HVAC-system varies from building to building.

Fig. 1 shows design areas for air-water and air-only-HVAC-systems dependent upon the specific cooling load and the specific ventilation rate. The limits are due to discomfort, poor air quality an inefficiency.

At a moderate specific cooling load of max. 60 W/m^2, representing standard office rooms with a medium thermal load produced by office equipment of 10 W/m^2 and with a good shade level, these HVAC-Systems are compared with regard to comfort, energy consumption and investment cost.

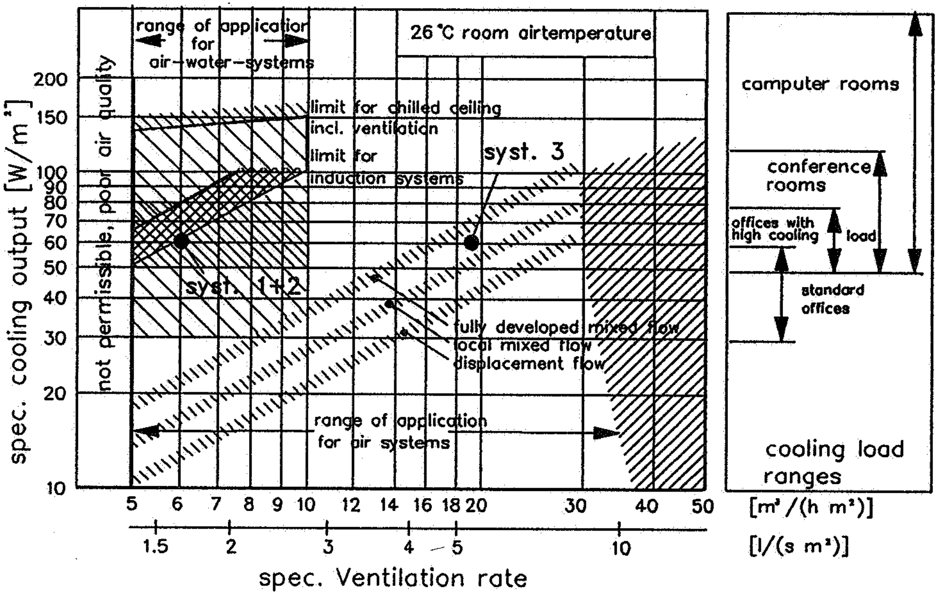


Fig. 1: Range of applications for HVAC-Systems

2. Description of building and HVAC-systems

The office building has 4 floors and a total area of 5.000 m^2. The mean axis is east-west orientated, so that the peaks of cooling load appear simultaneously (diversity factor 0.95). The ratio of window surface area to outside wall area is 0.5.

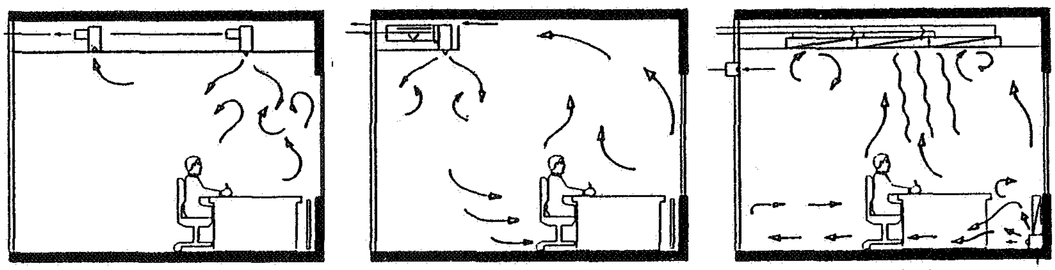
HVAC-System no. 1 is a VAV installation with 2 roof top air-handling-units and a total maximum air flow rate of 95.000 m^3/h (outdoor air). The rooms are cooled by primary air, emitted by highly inductive slot diffusors in the false ceiling of the rooms (radiators below the windows).

System 2 represents an induction-system with a total primary air rate of 30.000 m^3/h (outdoor air rate per person 60 m^3/h). The induction units are installed in the space above the false ceiling. Roughly 2/3 of the load is compensated by chilled circulated room air.

System 3 consists of a cooling panel system in the ceiling and an air conditioning device with a constant air rate (30.000 m^3/h). Air terminal devices for displacement flow are arranged along the centre line of the outside wall. The exhaust air has a constant temperature of 21 °C.

The typical flow patterns of all 3 systems are illustrated in fig. 2.

System 2 is a combination of complete mixed flow below the slot-diffusor and displacement flow in the residence area but in contrast to pure displacement flow with a very low rise in temperature between occupant's foot and head area.



System 1: VAV
turbulent mixed flow

System 2: Induction
combination 1 + 2

System 3: Chilled ceiling
+ displacement flow

Fig. 2: Typical air flow pattern of 3 modern HVAC-Systems

3. Comparision of thermal comfort and air quality

Normally occupants do not complain when thermal loads are maximal and room air temperature is still acceptable (28 °C). In this case room air flow is comfortable. The VAV-system with turbulent mixed flow may be at its comfort limit, when the control system requires a full air volume rate at a low room air temperature (22 °C). Displacement flow causes draughts, when the temperature rise is higher than 2 K and the air temperature at low levels (0,1 m) falls below 21 - 22 °C.

ture is allowed to rise by 3 - 4 degrees above the preset temperature value (as allowed by German Standards), savings in energy and capital cost up to 10 % are possible, as shown in Fig. 3 and 4.

This example shows that the difference in energy saving between the 3 HVAC-Systems is less than the effect of control strategy, which allows a zero energy band between heating and cooling operation. This design criterium is especially important for VAV-Systems, as cooling capacity is dependent upon ventilation. The maximum air flow rate can be reduced to 75 000 m³/h.

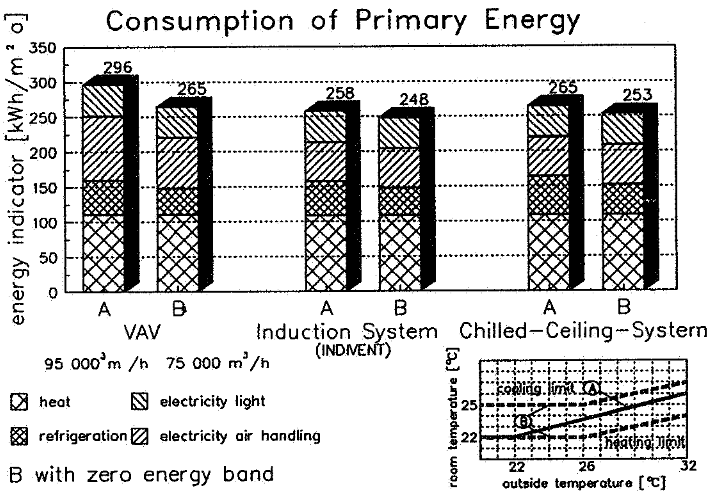


Fig. 3: Comparison of energy comsumption

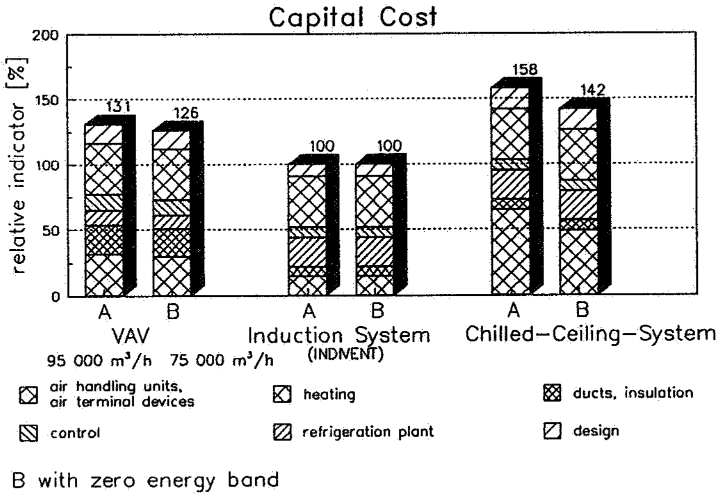


Fig. 4: Comparision of capital cost

Thermal comfort of systems 2 and 3 is relatively high, the comfort of system 3 is reasonable and air quality is acceptable due to higher air volume rate.

HVAC-Systems	$\vartheta_{max.}$ ($\vartheta_{o,max.}$)	$C_{max.}$ [cm/s] 1,1 m .... 0,1 m	T_u 3)	$\Delta\vartheta$ [K]	μ 4)	air quality (cooling operation)			
						η_a	e_a	$1/\tau n$	AQI 5)
1 VAV	26 °C (26 °C)	18 1) (15) 2)	40-60 %	± 0,2	1	0,4 ... 0,5	0,8 ... 0,9	3,4	1,1 ... 1,5
		18 (15)							
2 Induct.	26 °C (26 °C)	12	~ 40%	< 1	0,8	0,5 ... 0,6	1,0 ... 1,2	2	1,0 ... 1,4
		22	8-20 %						
3 Chill.C.	27 °C (26 °C)	10	~ 50%	2	0,85	0,6 ... 0,7	1,1 ... 1,3	2	1,3 ... 1,8
		22	8-20 %						

1) max. air volume rate 95.000 m³/h

2) max. air volume rate 75.000 m³/h

3) $Tu = Sv/c \cdot 100$

4) $$\mu = \frac{\vartheta(1,8) - \vartheta_{sup}}{\vartheta_{ex} - \vartheta_{sup}}$$

5) $AQI = \eta_a \cdot e_a \cdot 1/\tau_n$

$\vartheta_{max.}$: max. room air temperature

$\vartheta_{o,max.}$: max. operative temperature

$c_{max.}$: max. air velocity at two heights above floor

c: mean velocity

T_u: turbulence factor of velocity

s_v: standard deviation

μ : temperature charge factor

η_a : air exchange efficiency

e_a : local air exchange indicator

$1/\tau_n$: nominal air exchange rate (1/h), annual mean

AQI: air quality index

$\Delta\vartheta$: temperature rise between 0,1 and 1,1 m

Table 1: Comparison of Thermal Comfort and Air Quality

4. Comparision of energy consumption and capital cost

Maximum cooling capacity and consequently energy consumption and capital cost depend on how the system is controlled. When the desired preset value of the room air temperature is a strict function of the outdoor air temperature, highest cooling capacity is achieved on cooler days with high sun radiation. If the room air tempera-

5. Impact due to user faults, poor installation and maintenance on comfort and energy consumption

In practice faults due to user manipulations, incorrect installation, incorrect control and poor maintenance may have a greater influence on comfort and energy consumption than the system differences between the HVAC-systems.

The following example shows what happens, when 50 % of the occupants in a general office aera do not close the sun blinds. Fig. 5 shows a temperature plot above daytime for perfect and partial shading. The temperature rise of more than 7 K makes a central sun blind control necessary. The blinds should be closed early in the morning and opened late in the evening. In the meantime occupants should be able to adjust their blinds individually.

A typical fault in VAV-system installation is wrongly designed, missing or faulty pressure control in air handling units or ducts. These faults result in an increase in electric power of 10 - 15 % p. a.

Another example of energy waste in air-water-systems is simultaneous heating and cooling operations. Possible reasons are:

- no death band in heating-cooling-sequence
- proportional band of thermostat valve too large (too large dispersions)
- wrong thermostat setting by occupant

When, for example, 20 % of the radiator thermostat valves in our building have a wrong setpoint of 24 °C, 4 % extra primary energy is necessary.

Poor maintenance results not only in hygienic problems, but if heat exchangers, filters and heat recovery system are fauled, electric power required for ventilation is 10 - 15 % higher than normal (system 1).

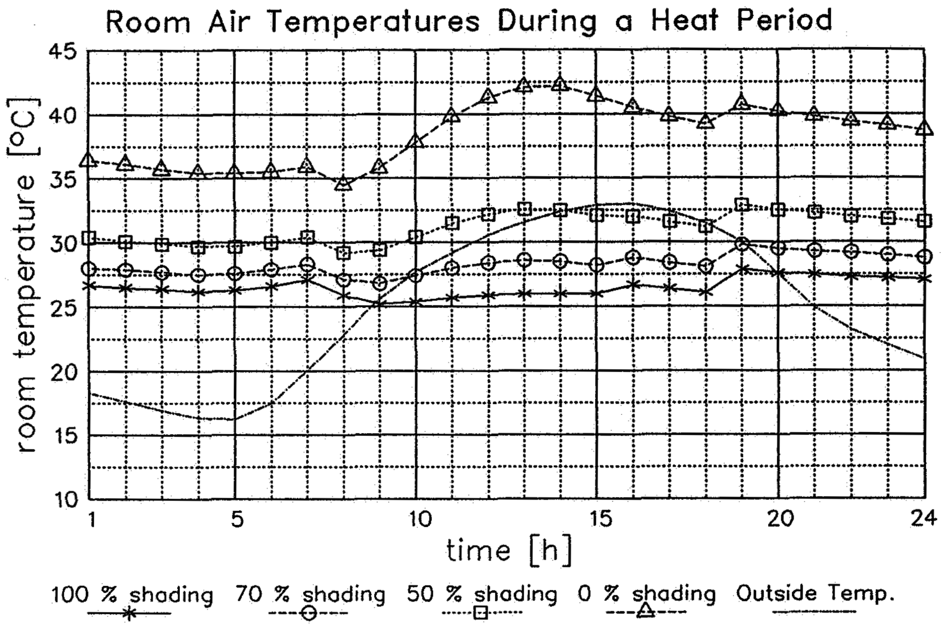


Fig. 5: Impact of shading on comfort and energy consumption