HEALTHY BUILDINGS BUT LESS ENERGY CONSUMPTION
How can Air Conditioning Technology help?

Ben Bronsema, Consulting Engineer ONRI
Ketel Consulting Engineers Ltd, DELFT

From the 1970s onwards thermal insulation of buildings has improved and air infiltration reduced. On the other hand, the internal thermal load has increased so much since the 1980s due to personal computers and peripheral equipment that cooling is nearly always required during working hours. In order to economise on the energy needed for cooling, it has become common practice to allow the inside temperature to rise as much as possible in accordance with the Fanger thermo-physiological model. Practical research has shown that office workers cannot appreciate the temperatures of 25°C and higher that occur in the application of that model. At higher air temperatures the emission of VOC's from inside also increases and the human sense of smell becomes keener; the result is more SBS complaints. For the sake of thermal comfort and a good perceived air quality; the temperature in offices should he limited to 23°C à 24°C while the ventilation supply must often be increased to 75 - 100 m3/hour/person, roughly double the usual volume. Both these measures augment the energy consumption and that is, of course, highly undesirable. However, air-conditioning technology can eliminate this unfavourable consequence by means of innovative techniques, and it appears that a better inside climate can be achieved at less energy consumption.

The Indoor Climate in Summer: Conflict between Theory and Practice?

Optimum thermal comfort is one of the most important conditions for achieving a hea1thy indoor climate. Many complaints disappear if the room temperature is well adjusted to the human activity. Too high a room temperature in particular can cause problems, but what is too high?

HVAC engineers apply various norms and standards in answering that question. Mostly such norms are based on the thermo-physiological model developed by Fanger. At a clothing coefficient of 0.5 - 0.7., considered to he typical for office workers and an activity level of 1.2 met, the maximum allowable room temperature – Ti_{max} - is in the summer usually set at 25°C - 26°C. See Table 1.

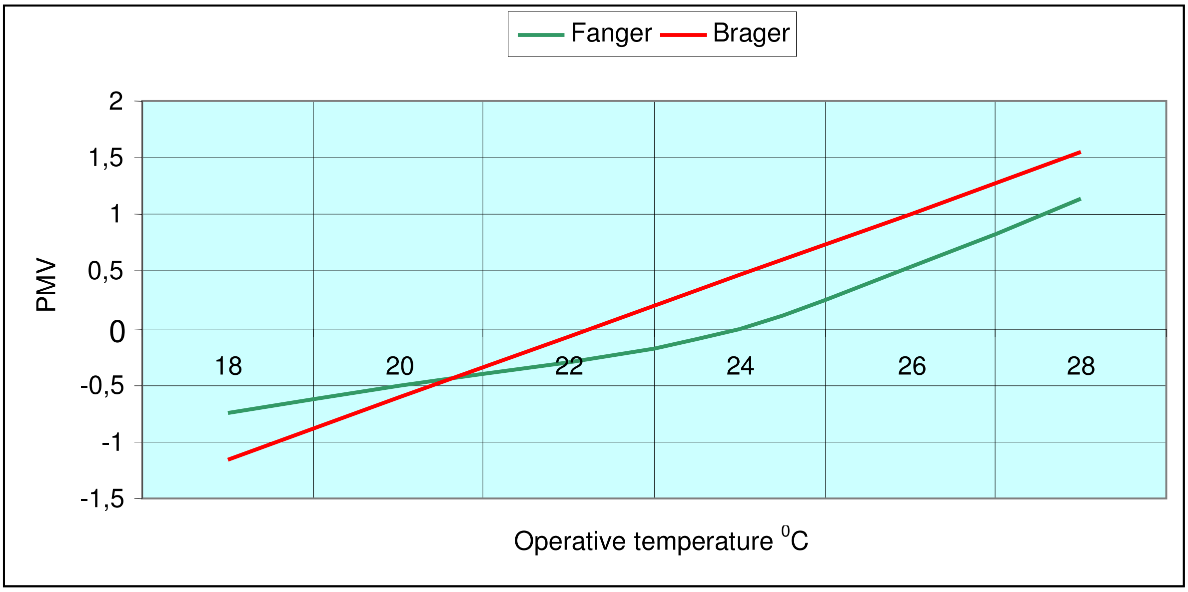
Table 1. Maximum room temperature in the Summer

Source	Activity level	Clothing	Ti_{max}
ANSI/ASHRAE 55-199	1,2 met	0,5 clo	26^0 C
DIN 1946	1,0…1,5 met	0,5…1,0 clo	25^0 C*
ISSO 19 (NL)	1,2 met	0,7 clo	$25{,}5^0$ C*
ISO 7730	1,2 met	0,5 clo	26^0 C

* excess allowed for 10% of the working hours

In the 1980's various researchers undertook empirical investigation of the thermal climate in existing office buildings. The findings revea1ed considerable differences between the real appreciation of the interior climate and what it should have been according to the Fanger model. This is illustrated by Figure 1, taken from Brager's research [1].

Figure 1 - Thermal comfort and operative temperature according to Brager



The neutral conditions (PMV = 0) occurred at 22°C, while the model predicts 24.5°C. Assuming that the tbermo-physiologica1 model is correct, the conclusion must be that the subjective parameters clothing and activity levels of Table 1 are too low. For clothing the coefficient of 0.5 is on the low side for Europe. Furthermore, normal office chairs insulate about 15% - 20% of the body surface. This can be compensated by increasing the clo value by 0.1 to 0.2; to, say, 0.75 [2]. For office activity a level of 1.2 met (= 70W/m2) is usually assumed. In practice, however, the activity/metabolic rate level may well he higher than defined above for the following reasons [2]:

* Office staff usually spends some of the time walking to and fro and the effect of the corresponding activity level of 1.7 met does not cease abruptly when they sit down again.
* Prevailing stress causes the metabolic rate to increase.
* Coffee consumption also increases the metabolic rate. Five cups per day equals l0 W/m2 = 0.12 met
* Many people are in a poor physica1 condition, contrary to those taking part in the model research.

For all these reasons it seems reasonable not to set the activity/metabolic rate level below 1.4 for every day office conditions.

The recommended room temperature (Ti_{max}) within the parameters suggested above (0,75 clo/1,4 met) are shown in Table 2.

Table 2 Recommended Room Temperature

Parameter	PMV>>	-0,5	0	+0,5
0,5 clo / 1,2 met	Ti ^{0} C	23^0 C	24,5^0 C	26^0 C
0,75 clo / 1,4 met	Ti ^{0} C	20^0 C	22^0 C	24^0 C

THE WARMER THE SMELLIER: SO KEEP IT COOL

Office air is often not fresh. Many people are sensitive to that and stale air is therefore considered to be one of the causes of the Sick Building Syndrome [3). If the room temperature is higher than needed, the atmosphere is, or is perceived to be, stuffy.

There are two causes for this phenomenon. First, the emission of Volatile Organic Compounds (VOC's) from finishing and furnishing materials usually becomes stronger as the temperature increases. Moreover, at higher temperatures the moisture of the skin is greater and so is the emission of body odour. Second, human perception of air, quality also depends on the room temperature and on the relative humidity. The air is perceived as being fresher and less stale at a lower temperature and humidity. Various scientists have investigated this phenomenon [4). The concussions all point in the same direction.

Most noteworthy are Wyon's [5) findings.

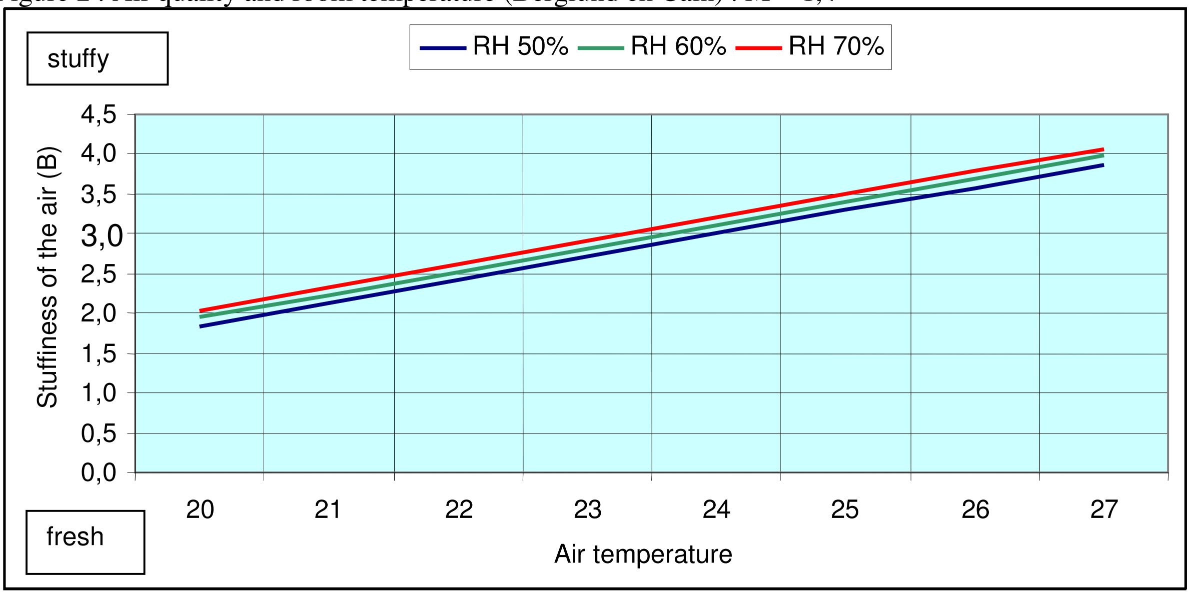
He found that above 20°C - 21°C almost all SBS symptoms increase sharply as the temperature rises. At 20° - 21° only 10% of the persons interviewed comp1ained of headache and tiredness. At 24.5°C the proportion of complainants had risen to 60%.

Wyon's dictum:

* temperature down to the lower limit of the comfort range;
* maximum humidity of 30 % R.H.

Berglund and Cain [6) have investigated the relationship between room temperature and perceived air quality in laboratory conditions. They have set up a remarkable equation for the interdependence of air quality, air temperature, dew point temperature and metabolic rate. The author of the present article has converted the equation from °F to °C. Figure 2 reflects the results.

Figure 2 . Air quality and room temperature (Berglund en Cain) . M = 1,4



Equation: $\boxed{B = 0{,}254T_a + 0{,}038T_{dp} + 0{,}2095M - 3{,}88}$

Where:
B = Stuffiness
T_a = Air temperature
T_{dp} = Dewpoint temperature
M = Metabolic rate

Both field and laboratory research agree that there appears to be an interaction between the temperature and the perceived air quality, which deteriorates as the former rises. The effect is less at low humidity.

As for the perceived air quality it is wise to keep the temperature at the lower limit of the comfort range. A glance at table 2 and Figure 2 shows that in summer conditions a design temperature of 22°-24°C (23°C ± 1K) is a sound point of departure.

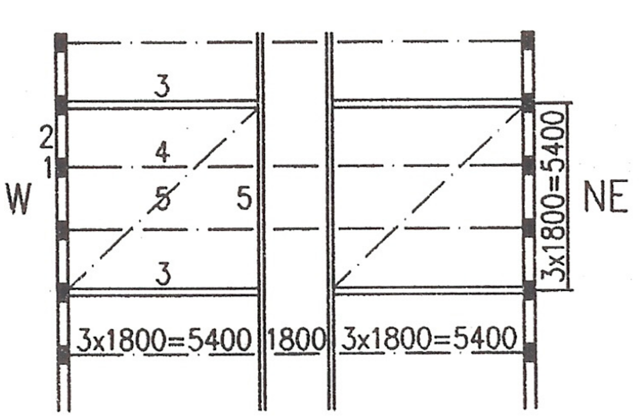
INDOOR CLIMATE, AIR-CONDITIONING AND ENERGY CONSUMPTION

Air-conditioning is intended to ensure a healthy and comfortable inside climate, and provided the system is well designed, well run and well kept, it can prevent about 80% of the SBS problems. But, air-conditioning uses up energy and causes pollution through the emission of CO_2, NO_x, SO_2, etc., which is bad for the environment. Energy saving is important in modem society; it should not, however, be done to the detriment of the indoor climate. Office workers are required to give optimum performance and are entitled to a good inside climate. It is incumbent upon the conscientious HVAC engineer to reconcile the opposing interests of the exterior and interior climates as much as possible. This task is not made any easier by the above arguments for lower temperatures in summer and, hence, more cooling. Moreover, better understanding of VOC emission and air quality leads to increased ventilation of 75 - 100 m3/h/person, or roughly double !he volume considered sufficient until recently. Both requirements increase energy consumption. That is not wanted!

Several air-conditioning systems will be compared below as regards the quality of !he indoor climate in summer and the energy required.

The basis for the comparison are the two office spaces as in Fig. 3, which are assumed to be part of a building where the ratio of useful surface to gross floor area is 0.7. The inside thermal load is assumed to be 40W/m^2 (people 8 - lighting 12 - P.C.'s etc. 20W/m^2).

Figure 3 - Partial floor plan



1 = Stony façade

2 = Windows double glazing 40% of inner facade - outside screens

3 = Light partition walls

4 = Concrete floor with screed and carpet

5 = Acoustic false ceiling

The following HV AC systems have been considered:

A - V A V system with terminal reheat,
B - 4-Pipe induction system,
C - 4-Pipe Fan-coil system,
D - 4-Pipe Ceiling heating/cooling.

Energy Consumption

The annual energy consumption of the building, expressed in terms of Primary energy (kWh/m^2 gfa) has been calculated for indoor temperatures of 22° - 24°C (23°C ± 1 K) in summer and 20° - 22°C (21°C ± 1 K) in winter, corresponding to the optimum values mentioned earlier. See Table 3.

Table 3.: Annual Energy Consumption of Four HVAC Systems - kWh/m^2 primary energy

System	A	B	C	D	D*
Heating	134	104	83	89	51
Cooling	71	50	41	33	-
Pumps / Fans	48	36	32	32	37
Total HVAC - kWh/m^2	253	190	156	154	88
Ditto %	100%	75%	62%	61%	35%
Lighting - kWh/m^2	34	34	34	34	34
PC's etc.	66	66	66	66	66
Total building - kWh/m^2	353	290	256	254	188
Ditto %	100%	82%	73%	72%	53%

System D requires less energy than the others, closely followed by C, which provides far less comfort. See Table 4, below.

A further significant advantage of the ceiling system is the possibility of energy efficient heat and cold generation. Since the ceiling temperature is fairly high in Summer, cold can be abstracted from the soil, e.g. by means of a closed soil absorber, which can serve as a heat source for a heat pump in winter. The effects of the latter combination are shown under D*.

To arrive at an overall view for the building, the power consumption for lighting and office equipment (P.C. 's, etc) bas been also calculated on the basis of a yield of 0.33 for converting primary energy into electrical energy.

Quality Comparison

Besides the energy aspects, there are also quality differences between the systems with regard to providing a healthy indoor climate. See Table 4.

Table 4. Quality Comparison of four HV AC Systerns

System → Quality element ↓	A	B	C	D
1- Air quality	0	+	+	++
2- System pollution	+	0	0	++
3- Maintenance	+	+	0	++
4- Noise nuisance	+	+	+	++
5- Thermal comfort	+	+	+	++
6- Flexibility	0	+	++	+

++ = good
\+ = fair
0 = passable

Explanations

1- Air Quality

With system A, the air is usually recirculated in order to economise on energy. Thus, VOC's, ETS and fine dust particles that are not trapped in the normal filters remain in circulation and reduce the air quality. Systems B and C draw in 100% of the air supply from outside, but recirculate it in the rooms. With System D there is no recirculation al all.

2 - System Pollution .

Systems B and C internally recirculate the room air and are the most sensitive to pollution. System D causes the least air movement and is the cleanest.

3 - Maintenance

System C requires the most attention with the separate circulation fan and the filters. Cooled ceilings (D) need no maintenance.

4 - Noise Nuisance

The circulation fan in system C is a source of noise, especially at full power. Cooling from the ceiling is silent since a large part of the thermal load is absorbed by radiation (Silent Cooling).

5 - Thermal Comfort

System D causes the least air movement so the risk of draught is slight. Moreover, due to radiation, effective room temperatures are 1°- 1.5°C lower than the air temperature. That enhances comfort.

6- Flexibility

System A cannot cope with thermal loads exceeding what it has been designed for. In system C the fan RPM can be easily increased, but that is to the detriment of both noise and thermal comfort. The flexibility in system D consists of replacing passive surfaces with active surfaces and/or adding cooling convectors to the existing system.

CONCLUSION

With regard to efficient use of energy and a healthy indoor climate, cooled ceilings are the best choice among the current HVAC systems. It should be preferred especially in. the case of high thermal loads.

REFERENCES

1. Gail S Brager (1992). "Using laboratory based models to predict comfort in office buildings". *ASHRAE Journal, April 1992.*

2. B. Bronsema (1993). "Het binnenklimaat in de zomer in de zomer: Conflict tussen theorie en "praktijk? *Klimaatbeheersing 22 (1993) nr. 9 (in Dutch).*

3. P.O. Fanger (1987). "A solution to the Sick Building Mysterie". *Proceedings Indoor Air '87 - Volume 4*

4. B. Bronsema (1994). "Waar het warm is stinkt het: dus hou het koel". *Klimaatbeheersing 23 (1994) nr. 4 and 5 (in Dutch)*

5. David P. Wyon (1993). "Current indoor climate problems and their possible solution" . *Invited paper to the international Scientific Conference "Indoor IJr Quality Problems - fiom Science to Practice" Warschau, 24-26 november 1993.*

6. I.G. Berglund, W.S. Cain (1989). "Perceived air quality and the thermal environment". *Proceedings of the ASHRAE/SOEH Conference I.A.Q. '89 The Human Equation: Health and Comfort.*