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Energy Demand for the Conditioning of the Supply Air in Ventilation

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1. Main tasks of Air Conditioning

The main tasks on A/C-plants are:

1. The transport of air in order to be able to decrease the air contamination in the rooms.
2. The transport of water in order to control the humidity-level of the air in the rooms.
3. The transport of thermal energy in order to control the temperature-level of the air in the rooms.

The transport mechanism of No. 1 and No. 2 is only possible by moving air to the rooms and back. But No. 3 can be achieved also by circulation of heat carriers in liquid stage.

To compare the enthalpy-transport by air volume with the enthalpy-transport by water circulation it is necessary to calculate not only the transportation energy but also the carried heat:

Transportation Energy: $P = \frac{\dot{V} \cdot \Delta p}{\eta}$

Carried Heat: $\dot{Q} = \dot{V} \cdot \rho \cdot c_p \cdot \Delta t$

The ratio of $\dot{Q}$ and P gives an idea of the carried heat by one unit of transportation energy.

Typical values for air and water cooling are given in table 1.

As we can see it is possible to transport nearly 450 times as much heat by water than by air with the same energy supply to pump or fan, respectively.

The air systems themselves also have great differences in this value because of the high range of pressure drop.

Therefore a lot of systems are bivalent, using air and water. The ammount of air is calculated for the air renewal to reach the desired indoor air quality. The heat transport which can not be done by this air volume is done by a water system in induction units or free convective cooling using heat exchangers at the walls or cooled ceilings.

There are large differences in the demand between comfort A/C and industrial application. Industrial applications ask mostly for special conditions either in temperature or in humidity and mostly for air renewal. Therefore it is fairly difficult to give a general overview. But in the comfort A/C-area some trends can be shown clearly.

	Unit	Air	Water
Density ρ	kg/m³	1,2	1000
specific heat capacity c_p	J/kg K	1000	4200
temperature difference Δt	*K*	8	10
Power efficiency η of fan/pump	-	0,8	0,8
pressure drop	*Pa*	1000	10000
$\dot{Q}/P$	-	7,6	3360

Table 1: Typical values for air and water cooling.

2. Heat load from human bodies

The different heat transmission mechanisms take over different parts of the total heat load. The ratio is depending on various parameters. With rising air-temperature the convection is decreasing meanwhile the latent heat by evaporation is increasing. In fig. 1 the influence of

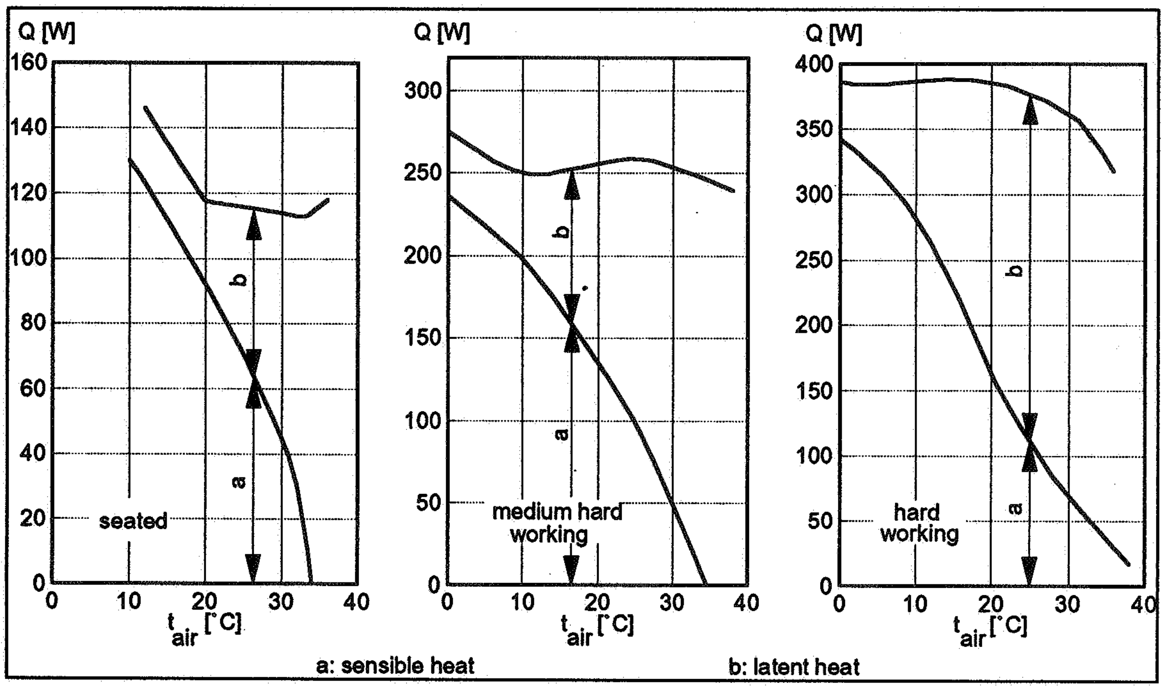


Figure 1: Heat-transmission of persons in normal clothing /1/

the activity level on the different ratios is shown. The total heat losses with an activity level related to 120 W (left part of Fig. 1) is fairly constant over a wide range of temperature. But the ratio between the latent heat and the sensible heat is very different at various air temperatures.

Higher activity level related to 250 W (middle part of Fig. 1) or to 350 W (right part of Fig. 1) shows the same tendency. The sensible heat is always the sum of convection and radiation.

At higher temperatures the evaporation must take over sometimes incomming radiation. In cars e.g. the incoming solar radiation must be considered already at lower room-temperatures. This solar radiation meets the human body and transports heat to the body which must be bilanced by additional evaporation. That is the reason why a large amount of water vapour ist transported to the air.

Main standards and regulations are done for offices with fairly the same activity level for all persons in the room. But also in these rooms a different heat transmission to the room can be seen in comparing the different individuals. /2/

Because the parameters of the heat convection are fairly stable, and because of the constant body temperature and a fixed clothing the control mechanism of the body temperature by changing the heat losses can only be done in the latent heat range. The rise of the temperature of the body surface can only be shifted in very small limits and the room air temperature and the air-velocity can not be ajusted individually. A change in the radiation is also not possible at a fixed wall temperature and given room configuration.

Fairly often different activity levels can be found in the same room. Some examples are shown with the following values (Tab. 2).

activity	range of heat transmission	mean value
1. seated	90 W - 150 W	120 W
2. typewriting	120 W - 170 W	150 W
3. speaker	160 W - 250 W	200 W
4. waiter	200 W - 300 W	250 W
5. dancing	200 W - 400 W	300 W

Table 2: Activity levels.

These activity levels are very different but we can find them in the same room at the same time and with the same clothing. As it was shown in fig. 1 the total metabolic rate is nearly independent of the temperature. However, the distribution of the heat transmission to radiation, convection and evaporation therefore depends also on the room temperature. Calculated values on the bases on some measurements are shown in the next table (Tab. 3).

3. Humidity and comfort

If we regarde a ball-room we will have seated persons, speaker, waiter and dancing groups which have only a small difference in radiation and convection. To be able to meet the heat balance the human body sends water to the surface to reach evaporation cooling. The related amount of water will be at 20°C between 45 g/h and 220 g/h. The relative values at 26°C are 90 g/h and 300 g/h.

This amount of water must be transfered to the air. This can be reached by a high mass transfer coefficient or by a big difference between the absolut humidity at skin level and in the room air. An increase of the mass transfer coefficient will also give an increase of the heat transfer coefficient. This correlation is given in the Lewis law.

When we use the same values of the absolut humidity as in normal office buildings we will get no common comfort in rooms with very different activity levels.

	20°C					26°C			
	Heat	Radiation	Convection	Evaporation	Water	Radiation	Convection	Evaporation	Water
Seated	120 W	45 W	45 W	30 W	45 g/h	30 W	30 W	60 W	90 g/h
Typewriting	150 W	50 W	50 W	50 W	72 g/h	33 W	33 W	85 W	125 g/h
Speaker	200 W	60 W	55 W	85 W	125 g/h	40 W	37 W	123 W	180 g/h
Waiter	250 W	65 W	70 W	115 W	170 g/h	43 W	45 W	162 W	230 g/h
Dancing	300 W	65 W	80 W	155 W	220 g/h	43 W	50 W	207 W	300 g/h

Table 3: Heat distribution with the same clothing and different activity levels.

In table 3 we see that at 20°C a seated person will have a convective heat transfer of about 30 W and an evaporation heat of about 60 W. A dancing person, however, will have about 50 W of convective heat and more than 200 W by evaporation. If this will be done by a higher mass transfer coefficient the convective heat losses of a sitting person will increase too and will cause the feeling of draft.

To be able to avoid this the high water mass transfer must be reached with a big difference of absolut humidity instead of an increased transfer coefficient. This means a temperature of 20°C and a low absolut humidity in the air with the standard air velocity will meet the comfort conditions for both groups of the population in the same room. The small temperature difference and a normal heat transfer coefficient will not give any draft for sitting persons and also give enough evaporation potential for people with higher activity level like speakers, waiters and dancers.

The relative humidity in the rooms should not be lower than 30 %. Below this level the nose and the throat can dry out and this must be avoided. In a lot of different materials which are used in buildings a low humidity can also give a high electrostatic load which also cause discomfort /3/.

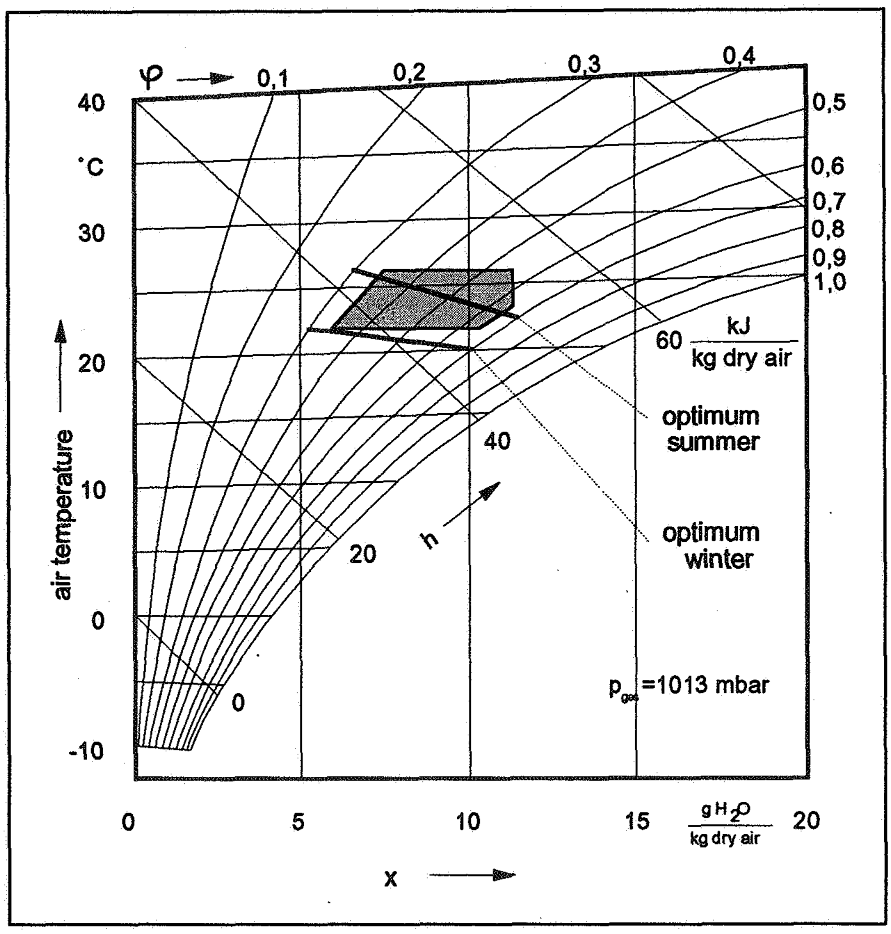
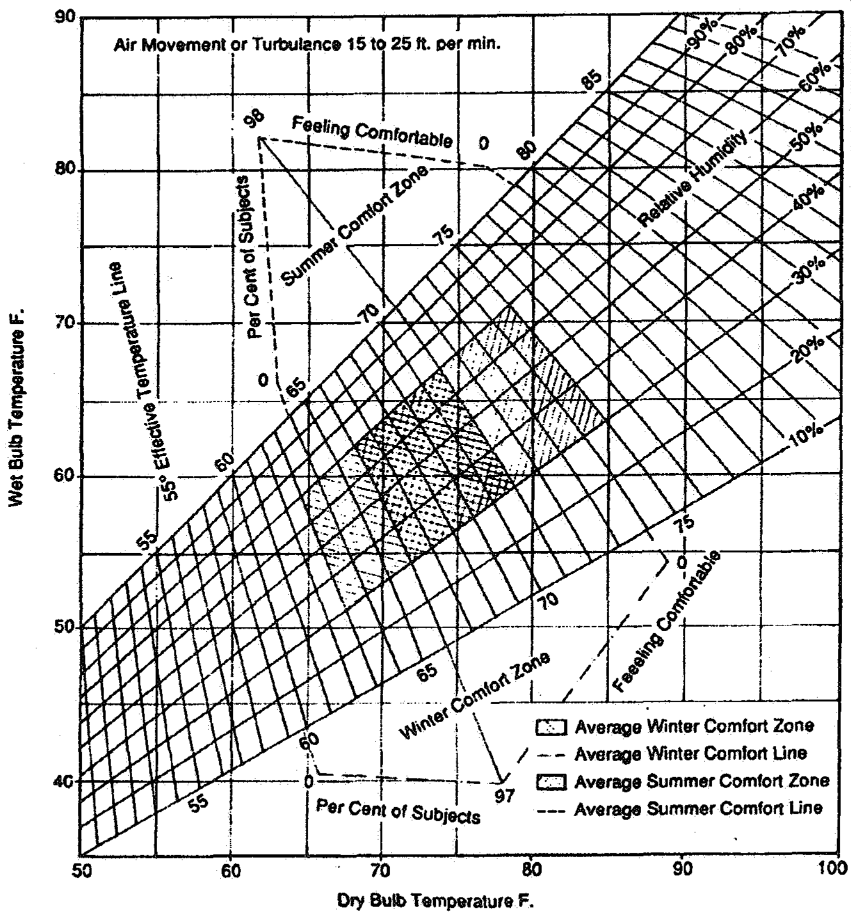


Figure 2: Comfort zone DIN 1946 pt 2.

The investigations of O. Fanger /4/ about the thermal comfort shows a much smaller influence of the humidity, but these values are only valuable for office buildings. The reason of these results is the very small change of activity level, a very simular clothing and a fairly stable air temperature. As shown the activity level is of great influence. It is not possible, therefore, to use the values for office buildings in a much broader scale. In figure 2 the optimal conditions are shown compared with the comfort zone of DIN 1946 part 2. These results can also be shown by experiments. /5/.

In air conditioned testrooms a group of about 30 people had to find out which rooms seems to be colder compared with the other one.



PSYCHROMETRIC CHART WITH EFFECTIVE TEMPERATURE LINES FOR STILL AIR
Shaded area indicates the comfort zone. (Reprinted by permission from the American Society of Heating and Ventilation Engineers' Guide 1932)

Figure 3: Psychrometric chart by Samuel Lewis 1932 /6/.

Unanimously they stated that a room with 26°C and 30% humidity is definetly cooler than a room with 24°C and 60 % humidity. These tests give the line of optimum conditions for summer (see figure 2). A very similar result can be derived from psychometric chart by Samuel Lewis from 1932 (see figure 3) Additionally Lewis also gives an optimum line for winter which is also shown in figure 2.

4. Influence of the humidity on the refrigeration capacity

The cooling load is not enough to discribe the refrigeration capacity because it is also necessary to consider the air changes. The air change rate cause especially in summertime a different dehumidification load which effects the refrigeration capacity. The minimum air changes are influenced strongly by the material which is used in the interial design. This can be shown in table 4 /7/. This example shows how great the influence of the material can be to the total energy consumption offer building. This influence is somewhat higher than the influence of the insulation.

	ventilation [m^3/m^2 h]	air changes [ach]	energy demat for heating [W/m^2]
marble floor	0,1	0,04	1
carpet floor	2 up to 8	0,8 up to 3,2	25 up to 100

Table 4: Ventilation rates.

In summer everybody is speaking about cooling in air conditioning plants when he is going to decrease the air temperature. For the dehumidification we have to calculate in central Europe a difference between the highest outdoor enthalpy and the enthalpy at the dew point of the supply air of about 25 kJ/kg dry air. It is very important to know that the highest enthalpy is not in the area of the highest temperature.

5. Refrigeration systems for A/C

Mainly refrigeration systems for air conditioning are running with a temperature range of 6°C up to 12°C. Nearly all water chillers are designed for this temperature. The 6°C as supply temperature is necessary to reach the dehumidification of the outdoor air used for air renewal.

Normally the same system temperature is used to transport heat from inner heat gains to the central system. In chilled ceiling systems the temperature a the surface must be about 20°C in summertime to avoid condensing water at the surface.

chilled water temperatures supply/ return	cooling capacity	electrical power input	C.O.P	relative C.O.P
5°C / 10°C	198 kW	42,5	4,6	1
6°C / 12°C	208 kW	43,1	4,82	1,048
10°C / 15°C	250 kW	45	5,55	1,21
15°C / 20°C	298 kW	47	6,34	1,38

Table 5: C.O.P.´s for different chiller temperatures.

If there is used the same water chiller either for the dehumiditation and for the cooled ceilings the 5°C or 6°C chiller water will be mixed with return water to reach the higher supply temperature of about 15°C. If the water chiller will be devided in two parts working on a different temperature level a lot of energy can be saved. In table 5 the C.O.P. for different chiller temperatures are shown. They are measured in a water cooled condenser with 30°C/35°C. Compared with the supply temperature of 5°C the chiller has 38 % increase in C.O.P. at 15°C water supply temperature. If the COP of a chiller is increasing, the energy used by the cooling tower is lower at the same cooling capacity. This is a very high energy saving which must be considered in new system design.

These figures show a big influence of the temperature. Therefore the refrigeration systems for the A/C -plants will be devided in future. One part takes the dehumidification loads from the handling of the outdoor air with a supply water temperature of 5°C or 6°C and the other part is taking the inner load at temperatures between 15°C and 20°C. This needs quite a different design but saves a substantial part of the power input.

6. Conclusion

A/C -technology is changing especially in the comfort part by considering the influence of the humidity. A main development in energy savings is the seperation of dehumidification and transport of sensible heat gains.

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