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„Humid Air" and cooled walls

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The humidity of room air is a necessary influence of design under the aspects of thermal behavior, technology and conservation.

The moisture absorption in the walls through sorptive materials or dehumidification on the cold window surface by dew point condensation is low because of the new thermal characteristics of these components.

The moisture load of a room briefly or also continuously, caused by technological processes or the users can't be compensated.

Today, the walls are used like a floor heating system. New developments refer to the fact that in the near future the wall is using like a chilled ceiling system.

The authors would like to show the danger of fall air streams and the condensation of water caused by chilled walls.

The distribution of temperature, velocity and humidity of room air, calculated with a three-dimensional mathematical program, is shown. It becomes more clearly, that it's necessary to realize an integral process of design by co-working of architects, users and engineers to avoid problems of humidity and to give the guaranty of thermal comfort.

Introduction

When evaluating the thermal comfort factor for persons in a room it is assumed that "at a normal temperature of 20 ..22 °C the relative humidity is to be kept within the limits of φ = 35 ... 65 %, whereas at higher room temperatures up to 26 °C the humidity should be reduced to 55 %, corresponding to a moisture content (absolute humidity x) of 11.5 g/kg dry air" [1]. In view of this wide permissible range, little attention is generally paid to the relative humidity when considering personal comfort.

There is significant influence, however, in respect of the moisture absorption and release of the material (see also sorption isotherm) of the surfaces enclosing the room, of interior furniture [2] and for example also from clothing [3], especially under unsteady flow conditions. This has been augmented recently by problems with odours, which are especially relevant in the case of high air humidities.

In the past, the materials of the surfaces enclosing the room were often designed such that the layer at the surface was able to compensate both sudden and longer-term fluctuations in the relative humidity by way of absorption or desorption [4]. At the same time, the leaks at the seals of the room openings were so great that average room air humidities over time were overall significantly lower. The window has always been a good indicator in cases where the air humidity is too high [5]. The glass is not able to absorb moisture, and the lower surface temperatures, compared to the temperatures of the remaining structure of the room, caused the moisture to condense on the window glass.

Through measures to reduce heating power requirements, the elimination of "draughty" windows" has reduced the "airing factor" (outside air flow) to such an extent that the increases in the air humidity arising from moisture sources within the room [6] can no longer be compensated and dissipated. The result is generally cooling below the dew point and the subsequent formation of mould and mildew [7].

Humidity response in modern buildings

The possibilities for installations of surface heating and cooling systems [8] are becoming ever broader. Whereas, just a few decades ago, it was in most cases only the floor or, in certain circumstances, the ceiling which was used for heating purposes, the greater interior heat loads are now promoting solutions with cooled room surfaces. The surface temperatures of these cooled surfaces are generally determined by comfort criteria and by the relevant dew points.

New developments are also beginning to make use of wall constructions for heating [9]. A use of these constructions for cooling, however, will have one unavoidable effect. At these cooled vertical surfaces, which are currently incorporated into the plastering, it is possible for conditions to arise which would lead both to structural damage and to uncontrolled down-draughts and personal discomfort. It appears important to note that the use of cooled surfaces should always be considered from the viewpoint of the interactions between cooling, ventilation, building design and the "moist air".

It is known that a laminar downward flow is formed relatively quickly at cool vertical surfaces (e.g. windows). As orientation for this air flow, a limit temperature difference of $\vartheta_R - \vartheta_{O,i} \leq$ 4... 5 K is generally considered uncomfortable in normal rooms. It is for this reason that radiators are generally installed below such cool surfaces.

Horizontal surface cooling systems are frequently combined with source ventilation systems. The ventilation system is usually intended to maintain the air quality in the room. The volume of the air flow, however, is also decisive for the humidity of the room air.

Figure 1 illustrates the differing changes of state for conventional ventilation systems and for source ventilation in combination with a cooling ceiling.
It generally applies that:

$$\frac{\Delta h}{\Delta x} = \frac{\dot{Q}}{\dot{m}_W} = \frac{\dot{m}_A (h_{Room} - h_{Supply})}{\dot{m}_A (x_{Room} - x_{Supply})} \qquad \text{whereby} \quad \dot{Q} = \dot{Q}_{Latent} + \dot{Q}_{Sensibel}$$

For the cooling ceiling, however,

$$\dot{Q}_{change} = \dot{Q} - \dot{Q}_{ceiling}$$

The following example demonstrates the difference clearly.

		Conventional system	Cooling ceiling with source ventilation
$\dot{Q}$	kW	5	5
$\dot{Q}_{ceiling}$	kW		2
$\dot{Q}_{change}$	kW		3
$\dot{m}_A$	kg/h	2.0	2.0
$\Delta h / \Delta x$	kJ/kg	9000	5400

The use of cooling ceiling or cooling surfaces thus produces a generally flatter curve for the change of state than with "air-only" systems. The specific nature of the source ventilation means that the temperature of the inward air flow should lie only 2 to 3 K [10] below the room air temperature, which makes a significantly broader dehumidification necessary for the combination of cooling ceiling and source ventilation.

It is difficult to achieve this intake air point with classic refrigeration processes, as the surface temperature of the surface cooler would have to lie at least 4 K below the classic 6/12 °C chilled water system. This would bring a permanent danger of freezing and the consequence of the refrigeration unit being switched off.

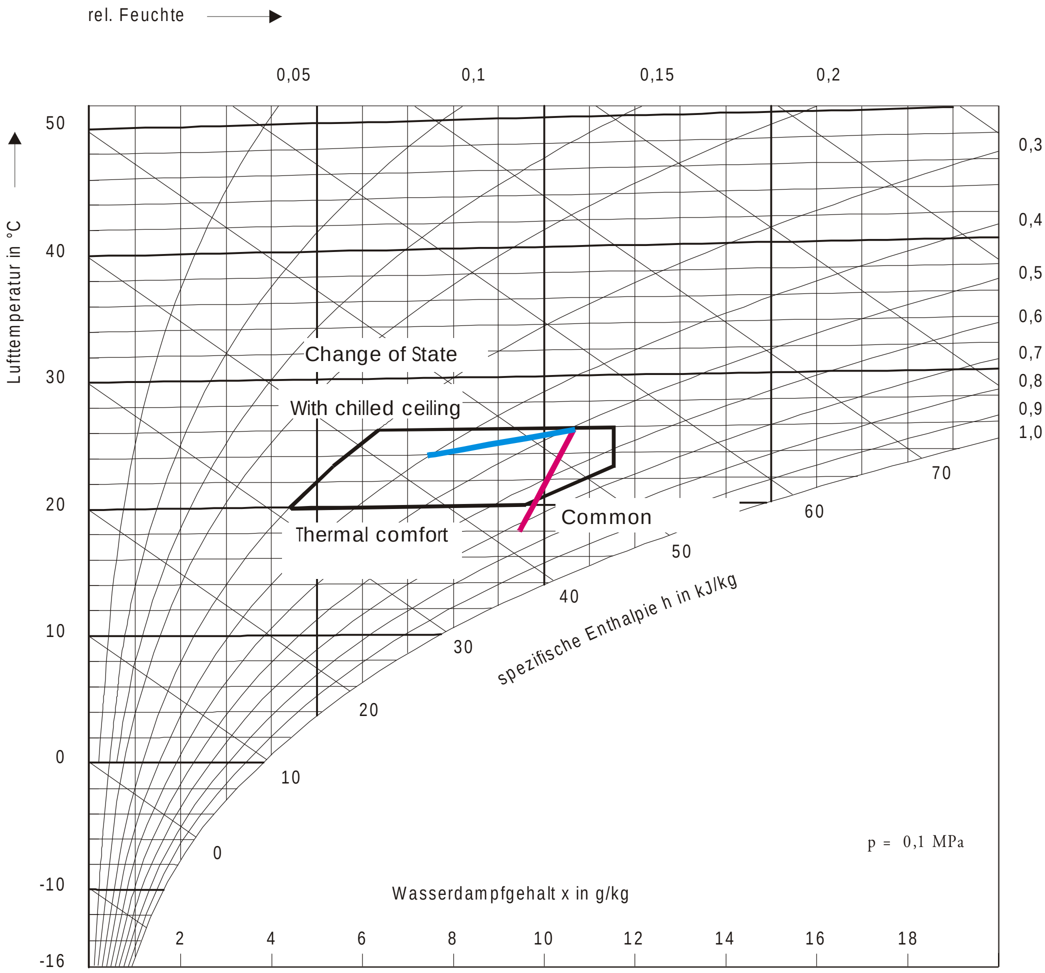

Fig. 1: Differences in the change of state

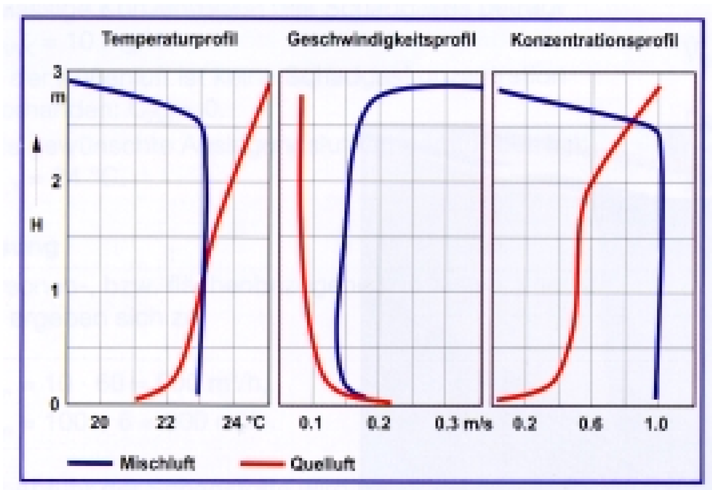

Fig. 2: Temperature and concentration distribution according to [10]

Alongside this effect at the conditioning of the air, it is equally difficult to implement the system in the room to be cooled. It is well known that the source ventilation leads to stratification in respect of both temperature and concentration [10] (Figure 2).

The temperature distribution can be considered positive from the point of view of comfortable room air temperatures in the zone most frequented by the persons in the room. The concentration distribution, i.e. the moisture content of the air, on the other hand, is somewhat less favourable. This appears especially critical in the case of:

- sudden changes in the moisture load
- constantly high moisture loads and insufficient ventilation
- an insufficient sorption capacity of the surface materials of the cooling surface

The following example (which could be described as the "wash-house effect" or the "condensation trap") could serve as illustration [11].

> Until the mid-1950s laundry was commonly washed in special laundry rooms (wash-houses), which were generally cellar rooms with a small window in the air shaft. This window was single-glazed and measured approx. H x W = 0.20 * 0.35. The walls were plastered with lime plastering.
>
> The high moisture loads arising from the washing process (water vapour from boiling, evaporation at open water surfaces and the wet, warm or cold laundry) inevitably produced relative humidities of the order of 60...80 %, in some cases even up to full saturation and mist.
>
> To prevent an extremely high rate of sorption of the water vapour through the plastering, and thus to avoid moisture damage, the window served as a condensation trap, i.e. the humidity condensed on the single-glazed window with its relatively low surface temperatures and was then removed from the cellar via a condensation drain channel (Figure 3).

These effects can also be demonstrated in room air-flow simulations [12]. The temperature and velocity distributions and the moisture concentration were calculated for a room with a high moisture load. The results are to be seen in Figures 4 to 6. Figure 4, first of all, shows the response in a room with source ventilation only. The moisture released in the room is concentrated in the area of the ceiling. In Figure 5 there is now a cooled vertical surface. All other conditions remaining equal, the moisture from the ceiling zone is drawn into the area of the cold surface. It is clearly visible that the moisture accumulates in the vicinity of the cooled surfaces and that there is thus a partial danger of cooling to below dew point.

When using cooled surfaces, therefore, consideration must be given not only to the heat loads and temperatures, but also to the moisture loads and their both steady and unsteady flows.

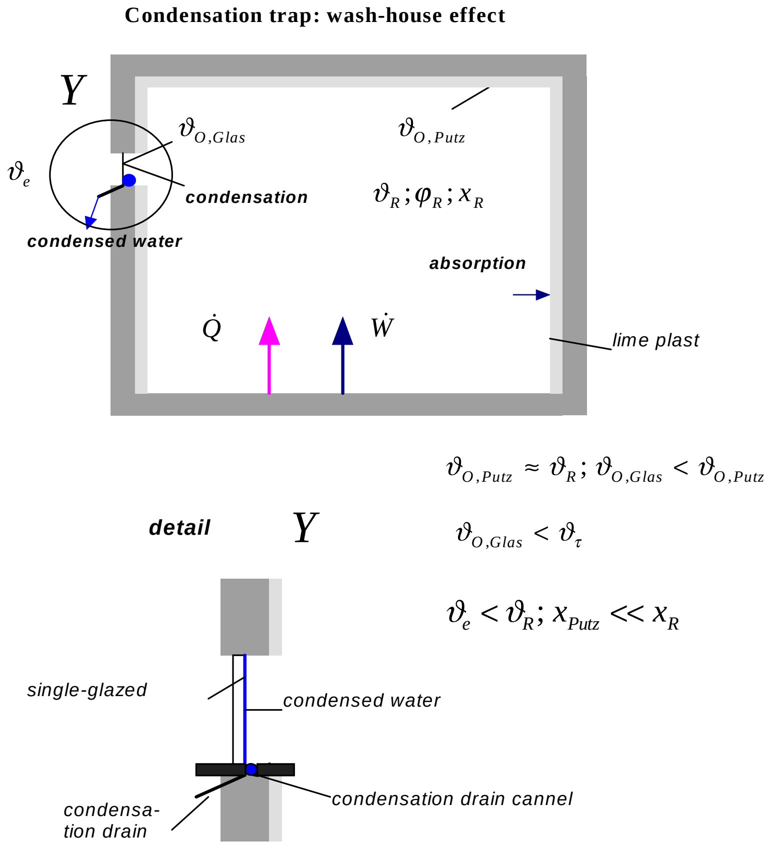

Fig. 3: Schematic representation of a condensation trap in a "wash-house"

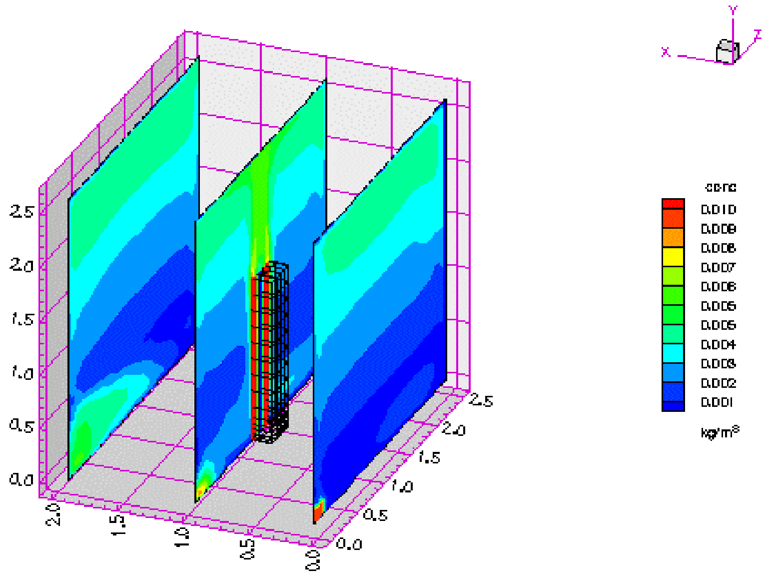

Fig. 4: Distribution of air humidity without cooling surfaces

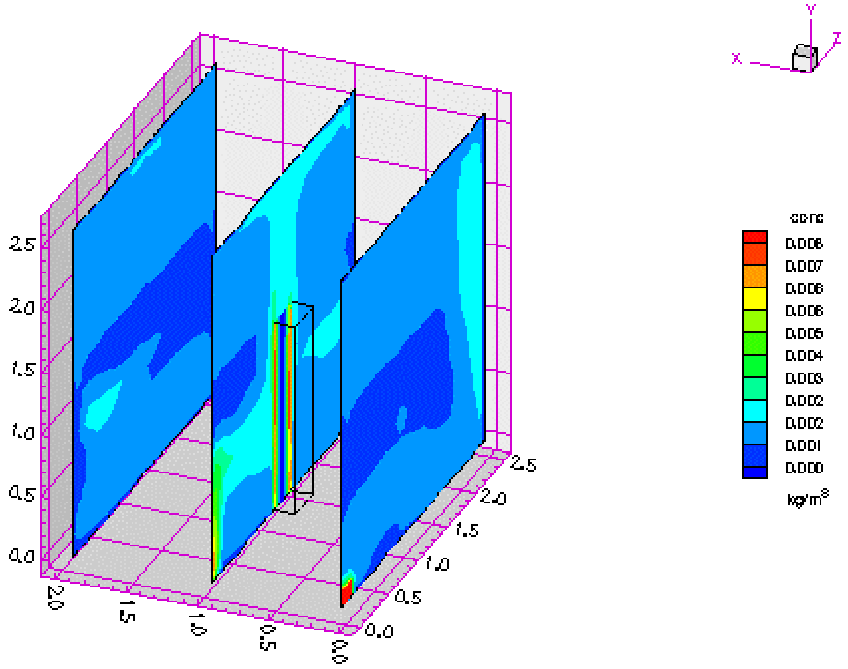

Fig. 5: Influence of vertical cooled surfaces on the humidity distribution

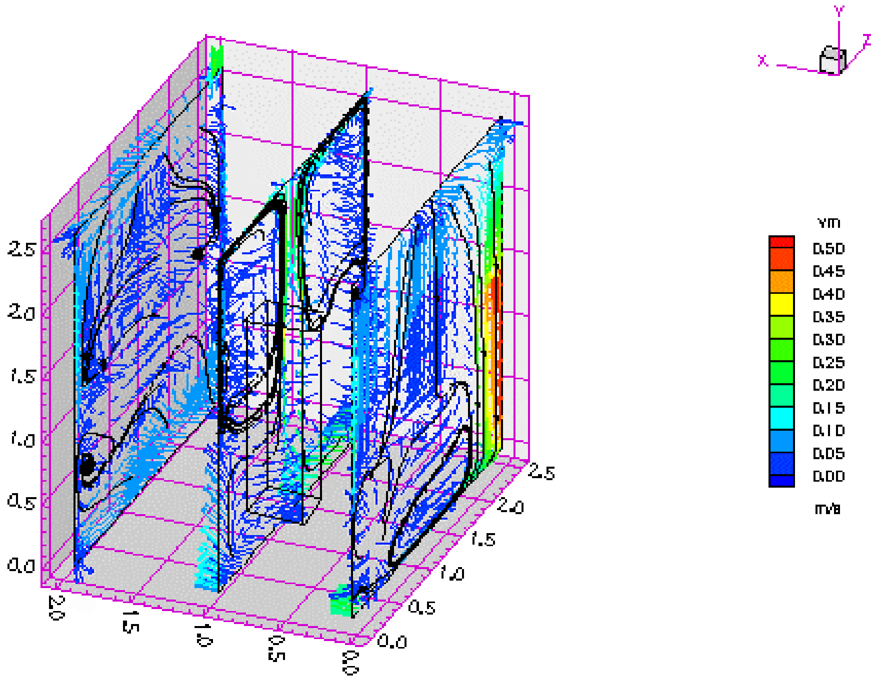

Fig. 6: Room air flow with cooled vertical wall surfaces

Conclusions

The planning of room air-conditioning systems in combination with cooled surfaces demands a completely new approach on the part of the engineer when designing the components. Whereas air humidity was in the past considered at most with regard to personal comfort, the use of cooling ceilings and cooling walls will make it necessary to take moisture transport processes into account also from the point of view of building physics. The use of vertical heating surfaces for cooling is to be viewed especially critically, since this produces not only downward draughts but also changes to the humidity profile. At the same time it must also be noted that the consideration of the altered changes in state in the room gives rise to new problems, above all with regard to the conditioning of the air and the refrigeration system.

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