Hidden issues when installing heat pumps into buildings with existing heating systems

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Abstract

Fluctuations in energy prices and new technology, raises new issues of how to renew heating systems in old buildings or how to build new ones. If electricity is the source of heat, novel heat pumps are easily motivated in most climates, as it is easy to convince consumers that total use of electricity for heating may be cut by 50%. This has initiated market forces and heat pumps are today manufactured, sold and installed more than ever under lacking supervision. This in turn actualizes, once more, the question what is likely to happen when installing ad hoc heating or cooling (air conditioning) parallel to existing heating and ventilation systems? Are we as consumers actually without our knowledge, in a desperate need of more in detail knowledge/legislation to rule out unsuccessful installations? Can unsuccessful usage or installation cause new problems or even threat to our health! This is the issue that will be penetrated further in our article where surprising problems of an ad hoc heat pump installation (air conditioning unit) is exposed and exemplified. The example shows that even small heat pumps may have a surprising effect on local changes of temperature and relative humidity. The effect of the heat pump installation, which has been used for both heating as cooling, is illustrated by color pictures showing findings of mildew stains, see figure 1. The article includes calculations on how to avoid mould or mildew stains, and factors that enforce conditions for local mould, mildew or fungi growth.

Keywords: electric heating, hygroscopic, moist air ventilation, mildew growth, cooling

Introduction

Heating of buildings is big business and a vast field of individual solutions. Winter moisture condensation is probably the most common moisture-related problem that affects houses. In its mildest form, it appears only as harmless surface condensation on windows. In severe cases it causes decay that might affect the structure itself. In between these extremes, it can manifest itself as mildew growth on the interior finish, or as ceiling stains, ceiling leaks or paint peeling. Moisture is added to room air in a variety of ways. It is also removed in a variety of ways. The balance created between the rate of moisture generation and the rate of moisture removal establishes the equilibrium humidity level (or relative humidity) in a house, and consequently the potential for future problems [8]. Building walls, roofs and ceilings are constantly exposed to changes in indoor and outdoor climate. The variations in temperature, moisture and air pressure have a major impact on the physical state and performance of the building components. They represent factors that determine the overall durability and sustainability of the building envelope.

In order to make a good design, all methods for the prediction of the hygro-thermal behaviour of the building components are issues of great interest in building engineering. The final result should be an envelope that sustains all internal and external environmental impact, and allows a good comfort for the inhabitants.

The results of poor design are well known [3]. Some related to moisture are:

- toxic emissions resulting in unhealthy indoor air quality (Sick Building Syndrome)
- growth of rot, mould and mildew
- increased heat loss at higher moisture contents
- cracking and other damage due to moisture movements (damages occur due to moisture state and moisture gradients in the building components)
- onset of corrosion
- degrading strength, stiffness and creep properties of structures

It becomes more and more important to predict, already at the design stage, thermal comfort, energy losses, risk for moisture problems etc. Often small mistakes in the design phase have great influence on running costs and risk for failures. Moisture aspects are involved, directly or indirectly, in many decisions during the building process. It is therefore important to have good, reliable prediction tools.

At present, the standardised Glaser method [6] for calculation, prediction and evaluation of moisture performance is considered as rarely applicable. This simple, one-dimensional, steady-state calculation model has been implemented in standards and codes of practice of many countries. It is frequently used to assess the moisture safety of structures. As it is well known, the method has a lot of limitations. It cannot handle heat and moisture capacity; neither can it handle air transfer through structures and capillary liquid flow. As a result, constructions that are qualified as good moisture design, may in reality, due to built-in moisture, precipitation, wind-driven rain, vapour exchange and air exfiltration face the problems mentioned [4].

For example may simple electric resistance heat be supplied by centralized forced-air furnaces or by heaters that are specific for each room. Room heaters can consist of baseboard, wall, space and radiant heaters. It is also possible to use thermal storage systems to avoid heating during times of peak power demand but ventilation is needed all around the clock to have fresh air. Ventilation increases the complexity of the issue, whilst ventilation affects the heat balance as well as partial mass balances of for example oxygen, carbon dioxide or partial pressure of water vapor and even dust particles. Traditional board heaters are usually installed underneath windows. There, the heater's rising warm air counteracts with cool air falling from the cold window glass. Baseboard heaters are seldom located on interior walls because standard heating practice is to supply heat at the home's perimeter, where the greatest heat loss occurs. Board heaters should sit at least three-quarters of an inch (1.9 centimeters) above the floor or carpet. This is to allow the cooler air on the floor to flow under and through the radiator fins so that it can be heated. The heater should also fit tightly to the wall to prevent the warm air from convecting behind it and streaking the wall with dust particles (creating grey strikes). These detailed rules are the outcome of many decades of practical experience from heating of buildings. The issue that we will now penetrate further is the question of which rules that could be important when installing heating or cooling (air conditioning) parallel to existing heating and ventilation systems?

Theoretical background

The rate of moisture production and the rate of its removal establishes the resulting levels of humidity in a house. Living activities, humidification, ground moisture and the house itself, all contribute to the moisture load. Most of this is removed by exchanging inside air with outside air, and only a small portion is removed by vapor diffusion through the enclosing envelope. The effect of the heat and cooling unit is illustrated by color pictures showing findings of mildew stains, see fig's 1 and 2.

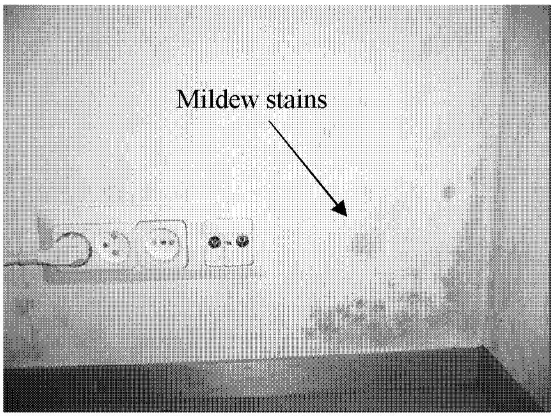

Figure 1. Photo of the corner having mildew stains.

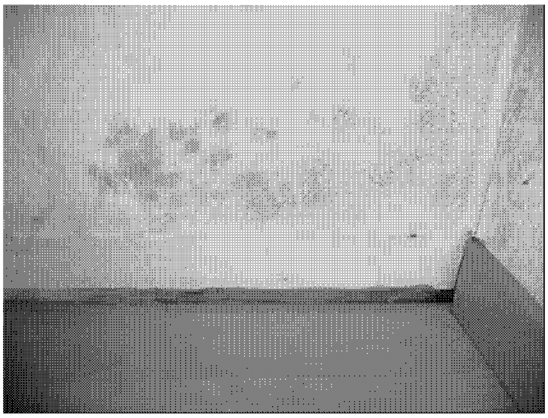

Figure 2. Same corner, no mildew under the baseboard!

We declare the following heat and mass balance for the mildew stain, in fig 1 (see also fig 4):

$$\underbrace{\alpha(t_a - t_{wall})dA}_{\text{heat by convection}} + \underbrace{\alpha_R(T_a^4 - T_{wall}^4)dA}_{\text{heat by radiation}} + \underbrace{\alpha_C(t_{outside} - t_{wall})dA}_{\text{heat by conduction}} = (h_{w0} + c_v t_a - c_w t_{wall})d\dot{m}_v \qquad (1)$$

Equation (1) is describing that we have heat transferred both by radiation as well as conduction to the surface of the mold stain. Equation (1) needs an expression for the mass transfer that couples the heat and mass transfer. In this work mass transfer is described with the Lewis equation referring to Berg et al [1],

$$\frac{d\dot{m}_v}{dA} = \frac{\alpha'(x_{wall} - x)}{c_a + x_{wall} c_v} \quad (2)$$

where α' is the apparent mass transfer coefficient. The used analogy holds for both laminar as well as turbulent flow and we can now start to look at some basic definitions as well as limiting cases, such as dew point temperature.

Moist air calculations – used state chart

As the reader might have recognised different drying handbooks have different air state charts as Bowen, Mollier and Grosvenor charts. The here shown perspectively transformed Salin-Soininen chart is added to give the reader a possibility to familiarise himself with the use of state changes illustrated in a Salin-Soininen chart and the coverage of this chart compared to Bowen and Grosvenor charts, see figure 3 from Berg [5].

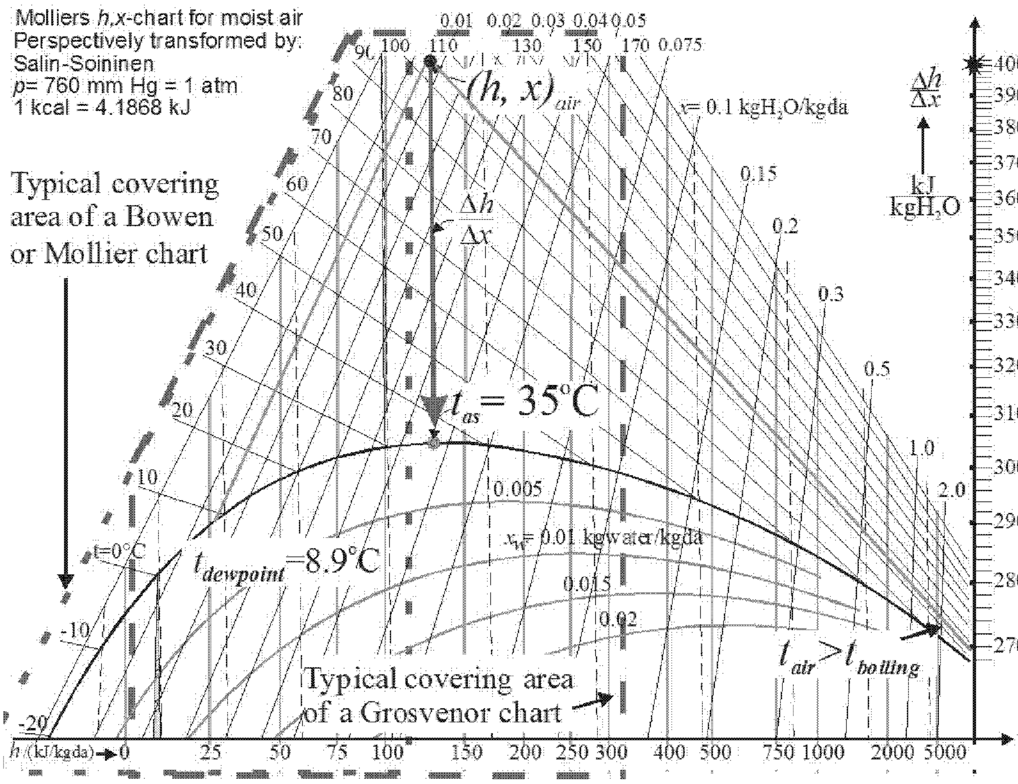

Figure 3. The perspectively transformed Mollier chart, known as Salin-Soininen chart.

It is to be remembered when doing studies of moist air that a drawn state-diagram is valid only at a certain total pressure, *p*. Normally, depending on the weather conditions the total pressure, at se level, vary from 90 kPa to 105 kPa. And in cases above sea level we must remember to include the altitude to have accurate

calculations. Therefore, absolute pressure p, should be kept as a variable while it might otherwise cause ill-conditioned energy balance calculations.
We see that the influence of the total pressure can be illuminated with an example, shown in fig 3, where we like to measure the air humidity x, with a psychrometer, in a heated air stream where total air pressure is 98 kPa (see dashed arrow fig 3, air state changes "towards" the wet bulb temperature, t_{as}). We start by measuring the dry bulb temperature t=105°C and the wet bulb temperature $t_{wb}=t_{as}$=35°C. The measured temperatures are then used to find a correlating x-value, $x=(M_v/M_g)(p_v/(p-p_v))$.
For normal air pressure 101.3 kPa, we obtain from fig 3, $x \approx 0.007$ kgH$_2$O/kgda and t_{DP}=8.9°C. Then when making the moist air state equations, dependent on the total pressure, we obtain $x \approx 0.0082$ kgH$_2$O/kgda, i.e. 17% higher (t_{DP}=11.2°C)! The formula for humid air enthalpy on a dry air basis is.

$$h_a = tc_a + (h_{w0} + tc_v)x \tag{3}$$

as we se from eq (3) is the x-value multiplied in energy balances with the latent heat of water vapour. Faults in "x-values" influences therefore energy calculations more at higher humidity, and the error is in worse case proportional to the error in moisture content. Further equations for moist air properties can be found in references [1,3 and 5].

Example – The studied house

Fig 4 is a photo of the ad hoc installed air conditioning unit at the outside ceiling of a house built in 1987.

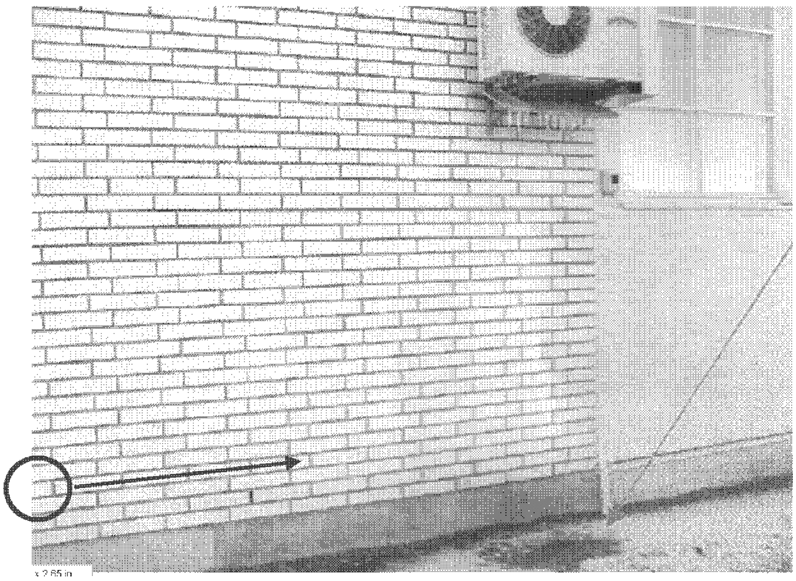

Figure 4. Photo of the ad hoc installed air conditioning. Mildew stains in fig's 1 and 2 where found only at the inside ceiling in the left corner along the arrow of this photo.

Evidence of ice and droplet marks where found during winter time. However, drilling holes from outside and measuring "zero moisture" in the wall isolation proved that the moisture could not come from the outside.

The inhabitant claimed that both his wall as well the outside water drainage system had to be renewed (leaking moisture retarder or broken piping) and that the moisture problem had to be taken care of collectively by the house consortium which consisted of 11 more similar houses (without similar problems!). The stated problem had therefore to be analytically solved to convince both the inhabitant as well as third party experts about the work order, i.e. renewal of the inner wall paper and teaching the inhabitant to use his heat ventilation and air conditioning (HVAC) system correctly. Fig 5 is a copy of the drawing of the house wall. The arrows in the drawing are showing possible paths for moisture transfer.

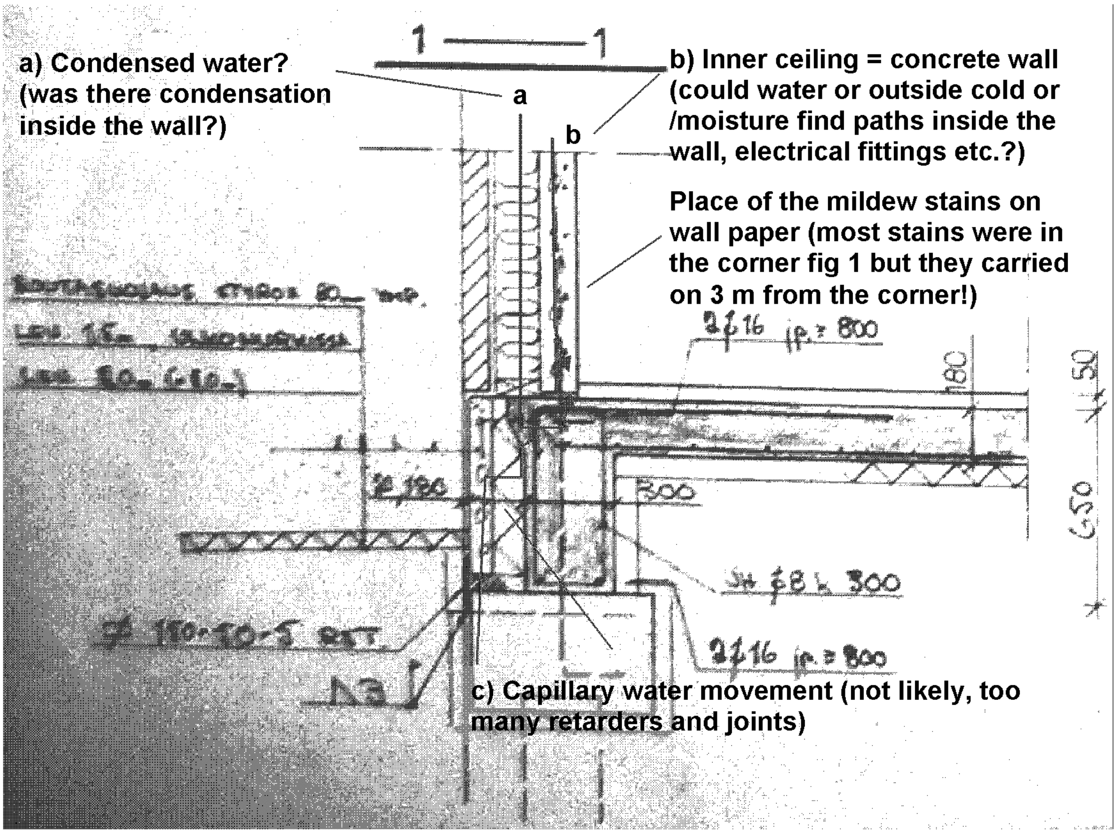

Figure 5. Copy of the drawing of the house wall.

Hygroscopicity

In the case of hygroscopic matter the water content normally has to go over 12-15 % moisture before being biologically active [2]. If the wall paper reaches a critical water content of 12% already at equilibrium moisture content of RH=80 %, then this is established at 22°C with a dew point of 18.4°C, giving a temperature/dew point difference of 3.6°C (see e.g. the Mollier h/x diagram, fig. 3). Sorption isotherms can be found in ref [2]. From the above it is clear that the wall paper could be exposed to the risk of mildew growth when the equilibrium moisture content reaches RH=80 %.

The studied process – Sources of moisture

Moisture can be added intentionally to room air through the use of humidifiers, or unintentionally through normal living activities. It is also added as ground moisture that migrates through the foundation walls and basement or crawl space floors from the surrounding soil. It is estimated that an average family of 4 generates 7 to 12 litres of water on an average day and increase to over 23 litres on wash days. Table 1 shows typical amounts of moisture generated by normal living activities.

Table 1. Moisture Generation in houses [8].

Sources of Moisture	Quantity, L
Floor mopping 7.4 m²	1.09
Clothes drying* (unvented)	11.97
Clothes washing* (unvented)	1.96
Cooking (unvented)* (If gas, add 1.24L)	0.92
Bathing-	
Shower	0.23
Tub	0.05
Dishwashing*	0.45
Human Contribution (per H)(average)	0.18
House Plants (per H)	0.02

*Based on a family of 4

Surface Condensation

The user of heat pumps, have to be aware, that if moisture is generated faster than it can be removed, the relative humidity will rise until condensation occurs. Condensation will occur on a surface when its temperature falls below the saturation temperature (or dew point) of the air adjacent to it.

The moisture equilibrium, which may also be stated as the temperature/dew point difference, is a significant definition to describe formation of condensation. If the equilibrium moisture content of air is low, for example at 60% relative humidity, then the temperature/dew point difference is approx. 8°C. At higher equilibrium moisture content, for example of 75%, a drop in temperature of 5°C is sufficient to trigger condensation [2], which in turn initiates the use of following equations, where the saturation pressure is defined by the eqation known as Antoines equation,

$$p_v^{'} = 10^{5.127 - \frac{1690}{230 + t/^{\circ}\mathrm{C}}} \cdot \mathrm{bar} \tag{4}$$

And by assuming continuum without mass transfer we simplify eq. (1) into the following form,

$$(t_a - t_{wall})\alpha_a = (t_{wall} - t_{outside})\alpha_C \quad \text{which gives} \Rightarrow t_{wall} = \frac{t_a\alpha_a + t_{outside}\alpha_{wall}}{\alpha_a + \alpha_{wall}} \tag{5}$$

And when the relative humidity is defined by,

$$RH = \frac{p_v}{p_v^{'}} \tag{6}$$

we obtain,

$$RH = \frac{10^{\,5.127 - \frac{1690}{230 + \frac{t_a\alpha_a + t_{outside}\alpha_{wall}}{(\alpha_a + \alpha_{wall})} \cdot {}^{o}\mathrm{C}}} \cdot \mathrm{bar}}{p_v^{'}} \tag{7}$$

The equilibrium humidity level that is eventually reached will depend not only on the rate of moisture generation, but on its rate of removal as well for this we obtain the following equation,

$$RH_{inside} = \frac{RH_{outside}\,p_v^{'} + \Delta p_{inside}}{p_v^{'}} \tag{8}$$

Where Δp_{inside} is a function of the evaporated water in the household i.e.,

$$\Delta x = \frac{V_w \rho_w}{V_a \rho_a /(1 + x)} \tag{9}$$

We can see from eq. 5 that the inside surface temperature of an exterior wall, for example, will depend on the indoor and outdoor air temperatures and on the amount of thermal resistance between the surface and the exterior, see fig 6 and 7 using as indoor temperature, $t_a = 22^o\mathrm{C}$. The air's ability to hold moisture decreases as its temperature is lowered. Air adjacent to a colder surface loses its capacity to store moisture as it cools, and eventually condensation occurs. Lower humidity levels are usually required in colder weather to reduce this risk. Because of their lower surface temperatures (especially single or double glazed windows) are usually the first surfaces on which condensation is noticed, see fig 6. For that reason they are often used as an indicator of excessive humidity. Minor condensation can occur without excessive humidities however and can be ignored if it is not causing problems. Excessive humidity also causes condensation within closets and kitchen cabinets, because these surfaces are shielded from the heated room air and are cooler than unshielded surfaces. The corners at the junction of walls and ceiling are also prime locations for condensation problems, see fig 5 to 7, case 1 and 2. The presence of framing and the influx of cold air around the perimeter of the ceiling from the roof vents can lead to lower surface temperatures at these locations. Improperly applied insulation can also be a factor. Care must be taken to ensure uniform and effective coverage of the entire insulated area. The calculated humidity levels at which condensation will occur on window surfaces, as well as wall surfaces are shown in fig 6. These are only approximations since a number of factors can affect window or wall surface temperatures. For example, the perimeter is colder than the centre of the glass and will therefore show condensation earlier.

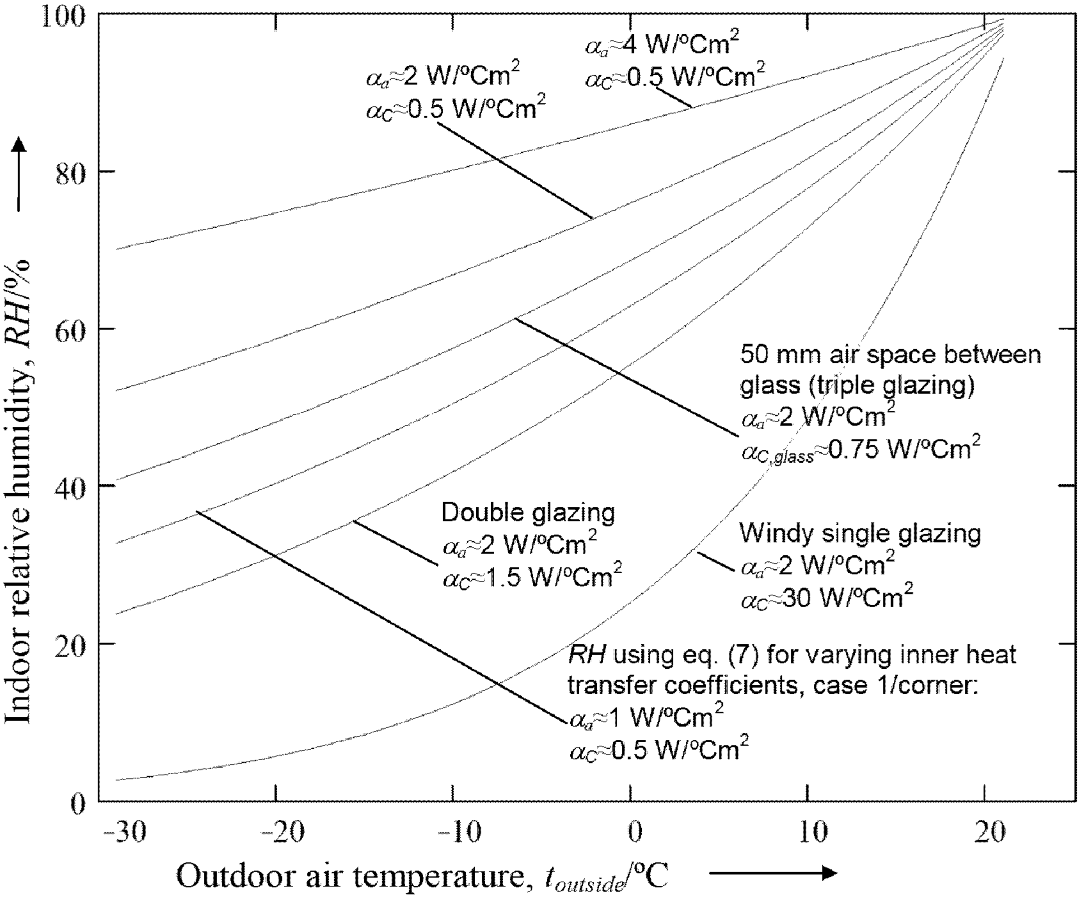

Figure 6. Relative humidities at which surface condensation occurs

The effect of air change rates and moisture generation on the possibility of condensation may be know assessed by superimposing equation 8 on fig 6 giving fig 7.

Fig. 7 shows the humidity levels that would be reached in the house under consideration, i.e. a ground floor area of 108 m^2, for different rates of moisture generation and air change using both eq. (7) and eq. (8). Lowest curve 1 shows the effect of heating outdoor air at 60 % RH to indoor temperature without adding moisture. Curves 2 to 4 illustrate the equilibrium relative humidities for two rates of moisture generation (7 litres per day to represent average days, 12 litres per day to represent wash days) and two rates of air change (0.5 and 0.25 air changes per hour to represent relatively tight houses with and without flues), again assuming 60 % outdoor RH. Doubling the rate of moisture generation has the same effect on the relative humidity as halving the air change rate. Really problematic moisture level, area marked with nr 10, is reached for curve 5 (eq. 8) showing the effect of heating outdoor air at 70 % RH to indoor temperature at an air exchange rate of 0.25 volume changes/h and 12 litres evaporated water per day. In this case we see that the indoor moisture is both higher than RH=80 % and the relative humidity has excesses the dew point temperature and initiates condensation. Since actual moisture generation and air change rates vary, these curves are provided only to illustrate the relationship between air change, moisture generation and outdoor temperature. A study of indoor humidities at similar conditions as the Nordic countries is found in reference [12].

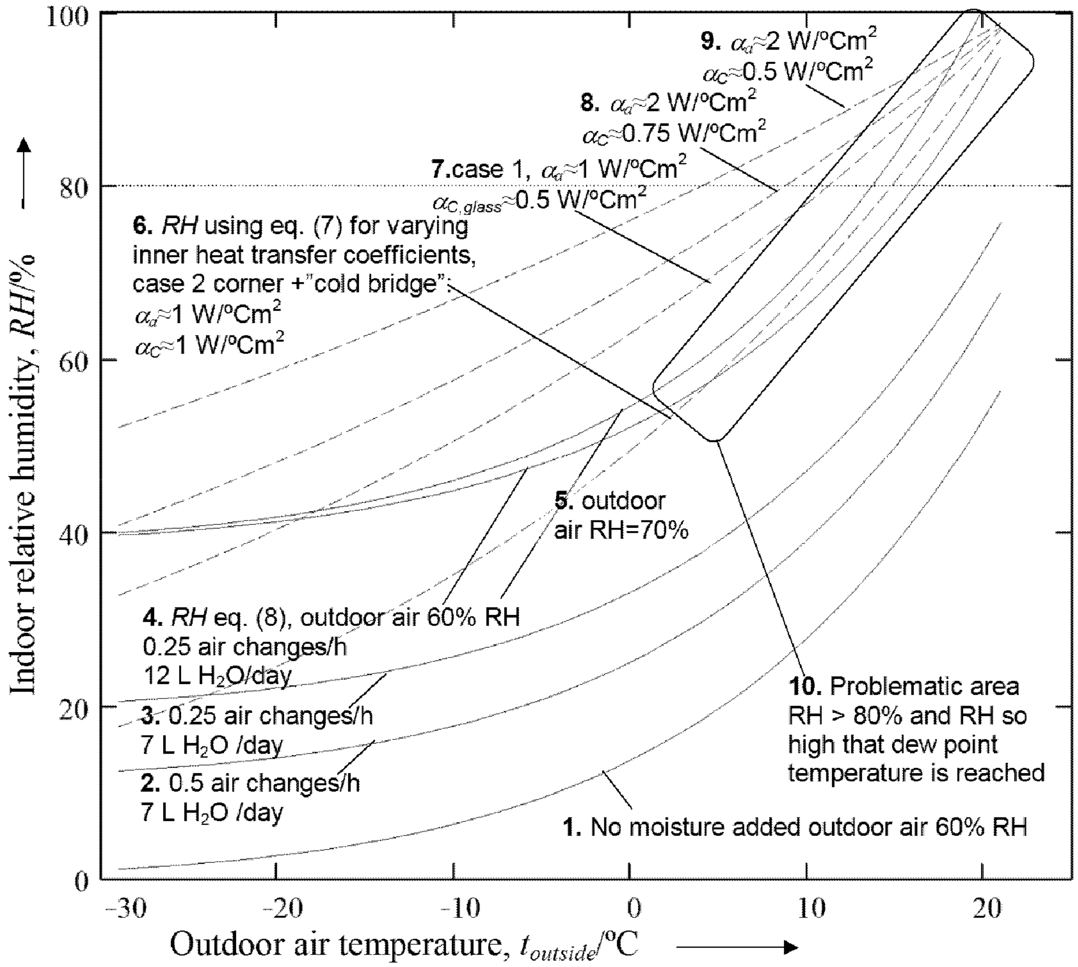

Figure 7. Equilibrium humidities for constant rates of moisture generation and ventilation (calculated for outdoor air at 60 % RH)

Condensation control through ventilation becomes more difficult, as outdoor air at an elevated humidity level, approaches the temperature of indoor air. As the outdoor temperature increases, the inside wall surface temperature increases. Thus higher humidity levels can be maintained without causing condensation. As the outdoor temperature increases, however, outside air at a constant relative humidity is able to absorb less and less moisture when it is heated to room temperature. At some point, this diminishing capacity to absorb additional moisture becomes the overriding factor. When the temperature rises above this point, the ventilating air is able to absorb less and less moisture before window condensation occurs. This effect is shown in fig 8.

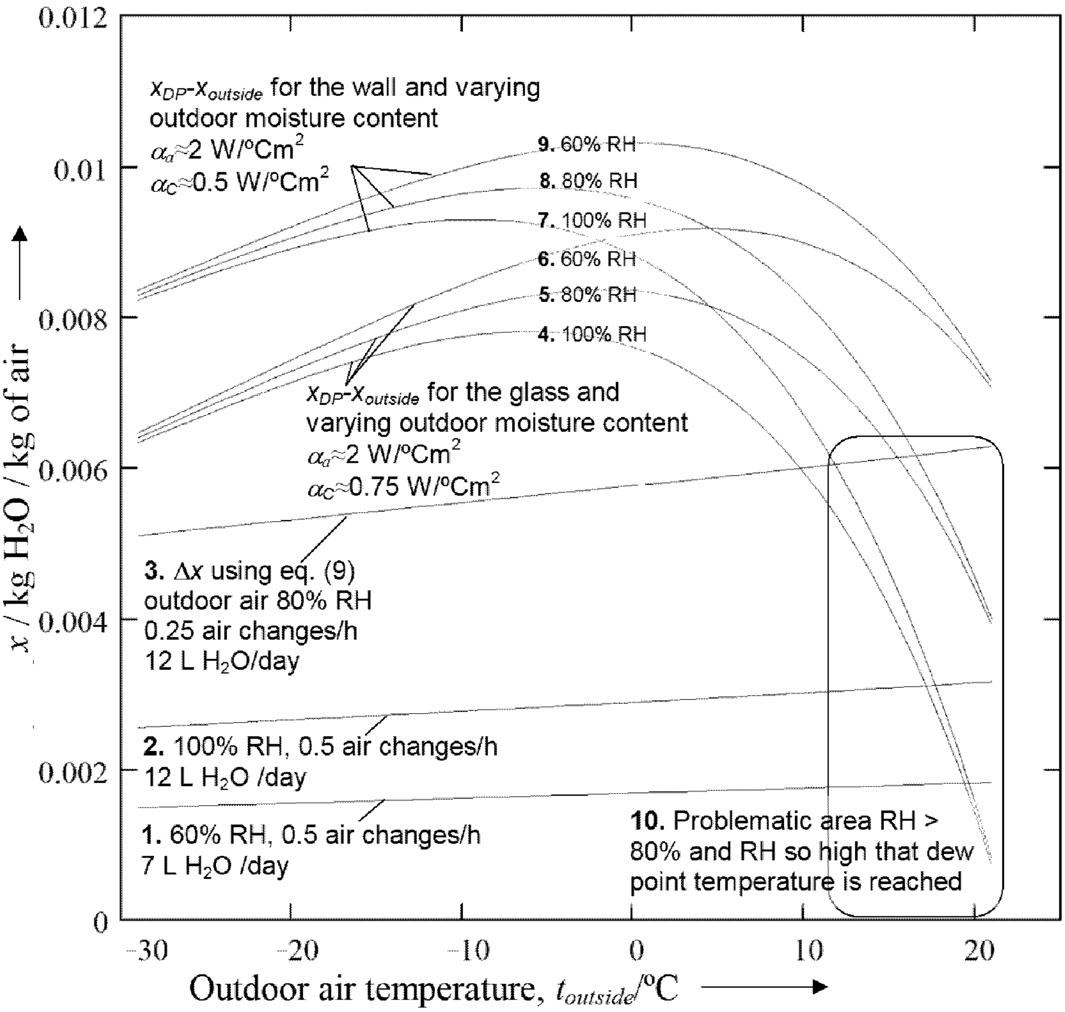

Figure 8. Maximum amount of water that can be added to air before condensation occurs on glass or wall.

Outdoor air at a relative humidity of 100%, for example, will be least likely to cause condensation on triple glazing when the outdoor temperature is about -6°C and corresponding value for the wall is -9°C. Above (or below) this optimum value the condensation risk is increased. Above this value, the outside air will quickly lose its ability to absorb additional moisture, making condensation control through ventilation very difficult. This explains why most condensation or moisture problems are reported in the fall, at the beginning of the heating season. Also the hygroscopic materials in the house usually dry out at this time, adding to the problem. During these periods, dehumidifiers may be more effective in controlling indoor condensation than ventilation.

Hidden Condensation

All houses undoubtedly experience some condensation within wall and roof spaces during cold weather. Condensation does not generally cause problems, since wood constructions should be built so that moisture is usually dissipated before decay can start. The optimum conditions for decay occur when the moisture content of the wood is at or above its fibre saturation point (around 30%) and the temperature is from 18° to 35° C. At temperatures above 38°C decay organisms are destroyed. Below 18°C their growth is slowed, and around 0°C, it practically ceases. Wood can therefore be wet for prolonged periods without decay, provided that the temperature is near 0°C or over 38°C. If the moisture content is maintained below 20% decay will not occur, regardless of the temperature. As windows and doors are made more air tight and flues are blocked off or eliminated, a higher percentage of the total moisture will be expelled by air leakage through the exterior wall and ceiling spaces.

Contrary to what one may expect, condensation does not occur initially within the insulation, even though the temperature may be below the dew point of the air. It collects on the first solid surface that is below dew point temperature, usually the wall or roof sheathing. If the condensing surface's temperature is below freezing, the condensation will be in the form of frost or ice. When condensation progresses to the stage, that the insulation becomes wet, its thermal resistance decreases, promoting surface condensation on the room side as well.

Holes cut for electrical boxes in exterior walls and ceilings create obvious opportunities for air leakage into concealed spaces when there is a positive internal air pressure. There are many other less obvious entry points as well. Holes drilled for electrical wiring are usually oversized to facilitate wire installation. They not only connect adjacent stud and joist spaces, but when drilled through top and bottom wall plates, they connect the basement and the attic with the walls adjacent to them. This creates a path for moist room air. Plumbing installations have the same effect. Less obvious still are the leakage paths created where floors or partitions intersect exterior walls, where partitions intersect ceilings, or where bathtubs are adjacent to exterior walls [8].

How to identify the cause of mold and mildew problem

Mold and mildew are generic terms for various types of fungi. Fungi produce enormous quantities of microscopic spores. These spores are always present in the environment and are spread by air currents. When these spores find a hospitable environment they will germinate. If small patches of germinating spores are ignored you will get a mold bloom or outbreak. A mold bloom is basically zillions of fungi producing enormous quantities of spores. EPA [7] gives some general rules. Mold and mildew are commonly found on the exterior wall surfaces of corner rooms in heating climate locations. An exposed corner room is likely to be significantly colder than adjoining rooms, so that it has a higher relative humidity (RH) than other rooms at the same water vapor pressure [7].

If mold and mildew growth are found in a corner room, then relative humidities next to the room surfaces are above 70%. However, is the RH above 70% at the surfaces because the room is too cold or because there is too much moisture present (high

water vapor pressure)? The amount of moisture in the room can be estimated by measuring both temperature and RH at the same location and at the same time.
Suppose there are two cases. In the first case, assume that the RH is 30% and the temperature is 21ºC in the middle of the room. The low RH at that temperature indicates that the water vapor pressure (or absolute humidity) is low. The high surface RH is probably due to room surfaces that are "too cold." Temperature is the dominating factor, and control strategies should involve increasing the temperature at cold room surfaces.
In the second case, assume that the RH is 50% and the temperature is 21ºC in the middle of the room. The higher RH at that temperature indicates that the water vapor pressure is high and there is a relatively large amount of moisture in the air. The high surface RH is probably due to air that is "too moist." Humidity is the dominating factor, and control strategies should involve decreasing the moisture content of the indoor air.
In cases with wall paper we refer to Nyberg [10] that says that relative humidities above 70% can easily lead to mold growth; for safety, it is generally recommended that libraries keep their relative humidity below 65%. Relative humidity below 40%, however, can cause books and paper to become fragile from dryness. Hence the acceptable range is 45% to 65%. It is possible, however, that some molds can begin growing at 70% relative humidity or higher and then continue growing at relative humidities of less than 70%. Because of this, new installations should be checked for mold and treated, if necessary.

Concluding remarks

Figures 1 and 2 make us wonder, if we as consumers just should continue to buy heat conditioning units, or are we in a need of more knowledge of the possible impact of ad hoc air conditioning and heating!
Assuring correct air distribution is just as important, if not more important, than pumping high volumes of ventilation air into a space. Florida extension service [11] mentioned that one building was designed to deliver ventilation air at more than 15 CFM/per person (cubic feet per minute), in accordance with ASHRAE Standard 62-89, and they ended up with an unacceptable CO2 level of over 3,000 parts per million (ppm). Although not dangerous, levels of CO2 over 1000 ppm indicate relatively stagnant air. The obvious problem was poor air distribution and improper HVAC balancing (heat ventilation and air conditioning). Investigations also have found that the air conditioning balance of a home is frequently changed by the occupant's lifestyle habits, such as closing bedroom doors and changing ventilation during night time. This action may cut off a return air grill, increasing air pressure in the bedroom and air loss as well.
According to [11] is the ideal relative humidity range in between 37 and 55 percent (the relative humidity in many Florida buildings often reaches levels of 60 to 80 percent). Opportunistic mildew spores may therefore be the cause of many indoor IAQ problems. Mildew, or mold, is an important indicator of excessive moisture problems and can contribute to allergies.

HVAC systems have a significant effect on the health, comfort, and productivity of occupants. Issues like user discomfort, improper ventilation, and poor indoor air quality are linked to HVAC system design and operation.
In existing buildings, envelope upgrades are often necessary to maximize comfort and energy efficiency, such as reducing envelope leakage. In fact, over 80% of air quality problems (IAQ problems) can be identified by a "yes" answer to one or more of the following four questions [11]:

1. Is there a vapor retarder installed on the interior side of exterior walls?
2. Is the air conditioning unit(s) improperly sized to address the actual sensible and latent loads?
3. Do the floor coverings have a rough finish or is carpeting a thin pile mildew resistant carpet?
4. Were fiberglass ductboards used in the duct system?

Removal of moisture

Moisture can be removed according to [8] in three basic ways: by diffusion through the building envelope, by mechanical dehumidification and by the replacement of interior air with exterior air. Moisture removal by diffusion occurs as the moisture migrates through the enclosing materials in the direction of lower water vapour pressure towards the exterior. This accounts for a relatively small proportion of the total moisture. For instance, in a house with a polyethylene vapour barrier, diffusion accounts for less than 5 percent of the total moisture removal. Mechanical dehumidifiers remove moisture from room air by blowing it through a series of cooling coils. Water is condensed on the coils where it is collected and removed. Dehumidifiers are normally designed for optimum efficiency at 27°C air temperature and 60% relative humidity (RH). At normal room temperatures and humidity levels below 50%, their efficiency drops markedly. Since relative humidities in excess of 40% or so can cause serious condensation during cold weather, dehumidifiers are not very practical in winter. They are more effective when used in the summer to reduce basement humidity levels, which can be considerably higher than 50% RH. Exposed earth floors in crawl spaces or basements can produce as much as 45 litres of water a day if the ground is wet. Even exposed rock can release substantial quantities of moisture. Earth floors should therefore always have a ground cover (usually 0.10 or 0.15 mm polyethylene) to reduce the amount of moisture entering the house. Hygroscopic materials, such as wood, will also contribute moisture. Wood absorbs increasing amounts of moisture from the air as the relative humidity increases. In regions with elevated summer and fall humidities, it could absorb an additional 4 to 5 percent of its weight in moisture. This moisture will be released during the heating season, when indoor humidities are lower. Assuming an average moisture increase of 4%, the floor assembly and partition framing of a 108 m^2 house, will contribute approximately 100 additional litres of water during the heating season. This is only a portion of the total water contributed by all materials, however, as they adjust to the drier indoor humidities. Moisture added during construction by concrete, plaster, and unseasoned wood will also be released during the initial heating season. Therefore, moisture problems tend to be most severe the first year after construction. The greatest proportion of moisture is removed from houses by the replacement of inside air with outside air. When cold outside air is introduced into a house and heated, its relative humidity is reduced, and it can absorb additional moisture. Outside air at -30°C and 100% RH when heated to 20°C, for example, will have an RH of less than 2%. The constant replacement of inside air with outside air carries away moisture; the higher the air replacement rate, the lower the humidity level. The air exchange routes may be as direct and obvious as ducts, flues, or open doors and windows. They may also be indirect, through the fabric of the building: at the junction between foundation and sill plate, or through the numerous cracks and openings that exist in seemingly solid walls and ceilings that enclose the heated space. Moist air that escapes directly, without passing through stud spaces or roof spaces, does not normally create problems. When the exfiltration route does pass through these spaces, however, condensation can occur within them giving rise to a variety of potential problems.

Summary

The rate of moisture production and the rate of its removal are controlling the level of humidity in a house. Living activities, humidification, ground moisture and the house itself, all contribute to the moisture load. Most of the moisture load is removed by exchanging inside air with outside air, and only a small portion is removed by vapor diffusion through the enclosing envelope. Most houses experience some degree of condensation, but only a relatively small percentage will develop serious problems because of it. Attention to detail is required during construction to ensure that there will be as few leaks as possible that will permit room air to enter concealed spaces. The provision of additional ventilation can also be used to control mildew growth or condensation.
HVAC systems have a significant effect on the health, comfort, and productivity of occupants. Issues like user discomfort, improper ventilation, and poor indoor air quality are linked to HVAC system design and operation. Evaluating your HVAC needs or opportunities will be greatly aided if you are familiar with integrated building design concepts. We believe that the results of this work will increase knowledge of how heat pumps have to be used or installed in old or new buildings. Increased knowledge and constructive criticism is needed to reduce the number of unsuccessful installations. Gained trust from successful installations, is in turn clearly needed, to ensure that this mature and environmentally friendly technology, after decades of development, finds consumers full approval!

Notation

A	m^2	area
α	W/m^2K	heat transfer coefficient
c	kJ/kgK	specific heat
h	kJ/kg	enthalpy
$m, \dot{m}$	kg, kg/s	mass, flow of mass
M	kg/mole	molar weight
n	mole	moles
p	kPa	pressure

$q, \dot{q}$	kJ, kJ/s	heat, flow of heat
R	kJ/mol K	ideal gas law constant
RH		Relative humidity
ρ	kg/m3	density of matter or fluid
τ	s	time
T, t	K, °C	temperature
x	kgH2O/kgda	air humidity
X	kgH2O/kgbd	moisture content dry basis
Y	kgbd/kgtot	dryness
$y, \Delta y$	m	length normal to wall

Subscripts, superscripts

‘		state of saturation, dew point, vicinity of a surface
a,as		air, adiabatic saturation temperature
bl		boundary layer
C		conduction
da, bd		dry air, bone dry
DP		dew point
m	max	mean value, maximum value
p		paper
outside		outside air
R		radiation
v,w		vapor, water
wb		wet bulb temperature of a psychrometer

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