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VENTILATION REQUIREMENTS FOR MOISTURE CONTROL IN DIFFERENT CLIMATES.

Johnny Kronvall

Dep. of Building Science
Lund University

P.O.Box 118
S-221 00 LUND
Sweden

1 VENTILATION AS A MEASURE FOR MOISTURE CONTROL IN DWELLINGS

One of the most important reasons for ventilation of dwellings is moisture control.

The ventilation need is mainly based on comfort and durability aspects. The ventilation behaviour of the inhabitants depends on both air temperatures, inside and outside, and indoor moisture (and odour) conditions.

As outdoor conditions are very different in various climatic zones, the ventilation strategies differ between different countries during different parts of the year.

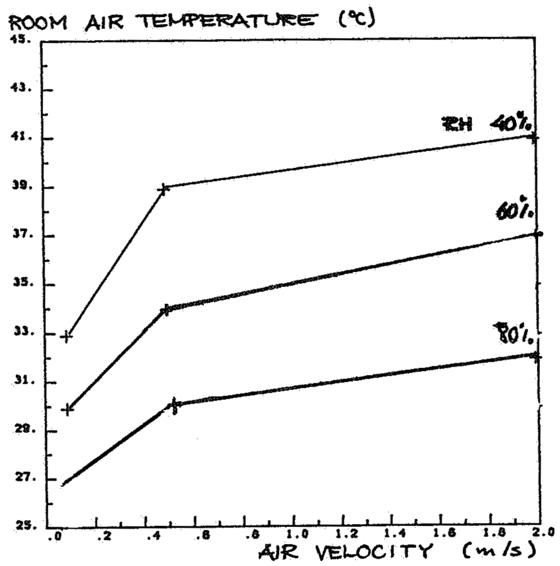
Many of the design data are fairly well known while others, for example criteria for mould growth, are not. A parameter which differs a lot between various countries and cultures is the amount of moisture generation in the house, due to cooking, cleaning etc.

1.1 Comfort aspects

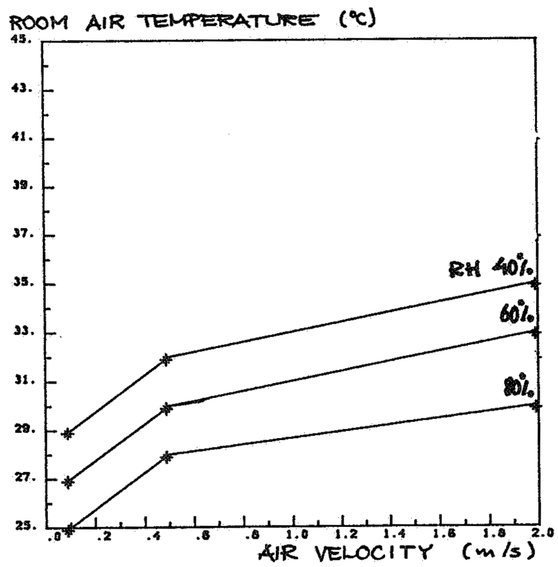
Indoor air temperature, air velocity and relative humidity, as well as radiative indoor temperatures, are important parameters for people's feeling of comfort in buildings.

In the high temperature range Markus and Morris (1980), for example, give comprehensive comfort charts for these parameters as well as the activity level and clothing of people.

Adamson (1986) gives a condensed table based on the work mentioned above. Figure 1.1a and 1.1 b are produced from this table.



a



b

Figure 1.1 Maximum room air temperature, at which 70% (a) or 80% (b) are satisfied, for sitting people (1.0 met) with light clothing (0.6 clo) as a function of air velocity for different relative humidities.

From the results it can be seen that high indoor temperatures are more endurable if the relative humidity is low and/or the air is in motion. This is of course due to the metabolic heat balance of the human body. Lower relative humidities increase the rate of evaporative heat loss from the surface of the body in the same way as high convective flows.

In the low temperature range the risk of feeling cold is of course the most important overall design criterion. Figure 1.1c is based on Fanger (1973) but plotted in a somewhat different way to be comparable to the figures 1.1a and b.

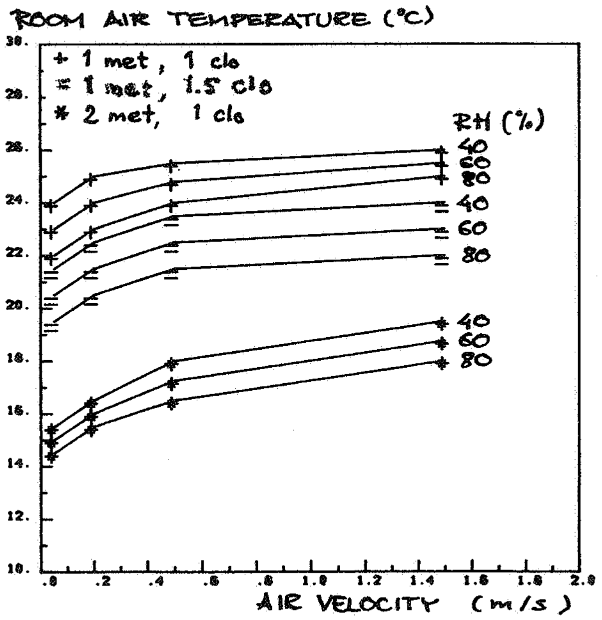


Figure 1.1c Optimum air temperature as a function of air velocity for different relative humidities.

It can easily be seen from the figures that both the metabolic rate (1 met = sitting people, 2 met = medium activity, for example domestic work) and clothing (1 clo = medium clothing, 1.5 clo = warm clothing) influences the comfort for different air temperatures, air velocities and relative humidities.

At low activity levels draught from windows etc must be compensated by higher indoor air temperature. Low indoor air temperatures are more endurable if the relative humidity is high.

For sitting people with medium clothing in a calm room, an indoor temperature of around 22-23°C seems to be optimum, while for domestic work with medium clothing the optimum temperature seems to be quite low, around 15°C. Warm clothing, sweater etc, can create acceptable comfort for sitting people at around 20°C provided that no draught occurs.

Keeping all other parameters than relative humidity constant, it can be seen that comfort is not very much influenced by the relative humidity level. The comfort "gap" corresponds in most cases to approximately 2°C, meaning that the same comfort can be created at a lower temperature with high relative humidity or at a higher temperature with low relative humidity.

1.2 Durability aspects

Two main durability aspects of indoor moisture conditions will be pointed out here and analysed further on in the paper- risks for condensation of moist air and mould growth.

Condensation is the phenomenon created when water in vapour phase is transferred into liquid phase. Generally, this occurs on a cold surface with a surface temperature lower than or equal to the dew point temperature (corresponding to RH=100%).

Mould growth on a surface is possible if there exists:

- an organic material to grow on (substratum)
- a suitable temperature (generally greater than appr. +5°C)
- a suitable humidity level (most often quoted to be RH=70% or more).

The mould growth is generally of low intensity at lower temperatures but the activity is strongly stimulated by increasing temperature. Sometimes it is also claimed that mould growth is possible only if the surrounding air is calm. This, however, does not seem to have been proved.

Analyses of risks for surface condensation or mould growth on the inner part of a building's envelope thus involves estimations of local surface temperatures and the moisture condition of indoor air.

In the same manner as mould can grow and condensation can occur on inner surfaces of a building, these phenomena may take place within a building component or an adjacent space, for example an attic.

The risk criteria are the same, i.e. moisture conditions above a relative humidity of appr. 70%, at certain temperatures and under longer periods may be harmful to organic material.

Of the two transfer mechanisms, moisture diffusion and moisture convection, the latter one is without doubt the more harmful. Except in very special cases, such as freezing-houses, etc., moisture diffusion can be neglected in the design procedure. This is due to the fact that diffusion is a very slow process and possible condensation amounts are small.

However, conditions with higher air pressure inside a building than outside, may create very unfavourable moisture convection problems. The moist air is transferred out from the building through cracks etc and creates high relative humidities or condensation when the heated and moist air (in cold climates) meets parts in the construction which have lower temperatures.

Examples of severe moisture damage caused by moisture convection are moisture accumulation, mould and rot in roof constructions and attics.

1.3 Air humidity and ventilation

The relationship between outdoor and indoor moisture conditions is:

$$v_i = v_o + \frac{G}{nV}(1-e^{-nt}) \qquad (1.3a)$$

where

v_i = vapour concentration in indoor air g/m^3

v_o = vapour concentration in outdoor air g/m^3

G = moisture supply, kg/h

n = ventilation intensity, h^{-1}

V = room (house) volume, m^3

t = time, h

The expression G/(nV) corresponds to the so called moisture addition, (g/m^3).

The factor $(1-e^{-nt})$, which stands for the non-steady state case, must be taken into account sometimes, for example if a considerable moisture supply is started in a small poorly ventilated space, while in many other time averaged cases the factor can be neglected. By writing eq. 1.3a in a somewhat different way:

$$v_i = \frac{G}{V}\,\frac{1-e^{-nt}}{n} + v_o \qquad (1.3b)$$

the total influence of time and ventilation intensity can be studied by plotting time vs. $(1-e^{-nt})/n$ for different n-values, figure 1.3.

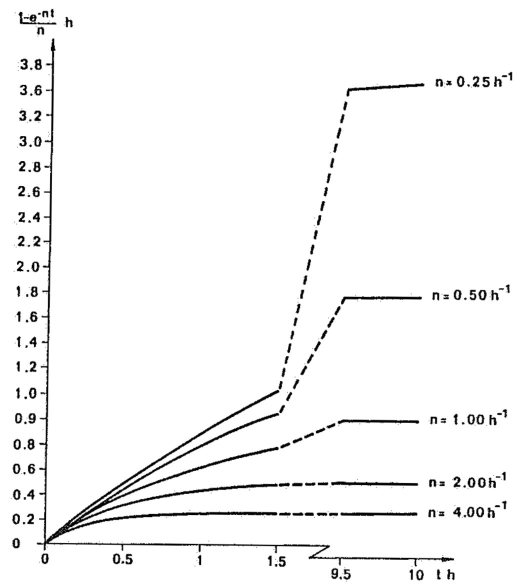


FIGURE 1.3

The indoor relative humidity RH_i, is:

$$RH_i = \frac{v_i}{v_s(\vartheta_i)}$$

where $v_s(\vartheta_i)$ is the vapour concentration at saturation point at the indoor temperature ϑ_i.

In order to make proper estimations of indoor moisture conditions two main questions must be answered:

- What magnitude of moisture supply

and

- what ventilation intensity

could be expected in practice?

The magnitude of the moisture supply in dwellings is far from well-known and, in many cases, this is also true of ventilation intensity.

It is also important to take into account where the moisture is supplied and if there are any ventilation devices there, taking care of the moist air. In many countries flats are normally equipped with exhaust ventilation devices in kitchens and in bathrooms, i.e. rooms where moisture supply is high and frequent.

Sandberg (1973) states that if air is extracted from a room where moisture is supplied, the water vapour concentration in other rooms around will not noticeably rise. Hence, it is possible to study the moisture behaviour of each room separately.

If ventilation devices for extracting air from rooms with high moisture supply do not exist or are not used, the moisture situation in the dwelling as a whole will be much more critical. The anticipation of no (or very little) influence on the moisture condition in adjacent rooms does not hold any longer.

A correct estimation for a non-intentionally ventilated flat (only "natural ventilation" due to leaky walls, windows etc.) is that all the rooms in the flat will get about the same ventilation intensity. This could vary due to wind, air temperatures etc.

Table 1.3a gives approximate values for possible moisture supplies to a flat.

Supply source	Moisture supply kg/h
People, low activity	0.03 - 0.06
medium work	0.12 - 0.30
heavy work	0.20 - 0.30
Bath room, tub bath	0.7
shower	2.6
Kitchen, cooking etc	
electrical stove	0.6 - 1.5
gas fired stove	2.0 - 3.0
daily mean, electrical	0.1
gas	0.2
Wash-drying	0.05 - 0.5
Plants, small (per plant)	0.005 - 0.01
medium	0.007 - 0.015
large	0.01 - 0.02
Aquarium	0.01

Table 1.3a Possible moisture supplies in a dwelling. Mainly from Erhorn & Gertis (1986).

An accumulative and approximate calculation of the moisture supply to a dwelling can now be made.

	Supply kg/h	Accumulated min	Accumulated max
Plants, 20 small	0.1 - 0.2	0.1	0.2
10 medium	0.07 - 0.15	0.17	0.35
5 large	0.05 - 0.1	0.22	0.45

Aquarium	0 - 0.01	0.22	0.46
2 persons low to medium work	0.06 - 0.60	0.28	1.06
Kitchen, electrical stove (E)	0.1	0.38	1.06
gas stove	0.2	0.38	1.26
Bath room, rough estimate	0.1	0.48	1.36
Washing, drying clothes etc	0 - 0.25	0.48	1.61

Thus the total moisture supply to a dwelling could be estimated to 0.4 - 1.6 kg/h or 10 - 40 kg/24 h. This moisture supply interval could be compared to values claimed by other authors, Table 1.3b.

Loudon (1971)	Bonafont (1969)	Croiset (1968)
15.4 kg/24 h (washing day) 7.2 kg/24 h (average day)	8.5 kg/24 h	10 kg/24 h

Table 1.3b Daily moisture supply to dwellings.

For a flat with a volume of 250 m^3, this corresponds to moisture additions (G/(nV) of the following magnitude, Table 1.3c.

n (n^{-1})	G/(nV) (g/m^3) G = 0.4 kg/h	 G = 1.6 kg/h
0.5	3.2	12.8
1	1.6	6.4
2	0.8	3.2
5	0.32	1.3
10	0.16	0.6

Table 1.3c Moisture additions (g/m^3) for different moisture supplies and ventilation intensities.

The other main question concerns which ventilation intensity could be expected in practice in different situations.

Estimations of the resulting ventilation intensity, due to different ventilation measures performed by the occupants, have been reported by Gertis (1983), based on results from several authors, Table 1.3d.

Ventilation measure	Ventilation intensity (h^{-1})
Windows and doors closed	0 - 0.5
Windows ajar and Venetian blind closed	0.3 - 1.5
Windows slightly open, no Venetian blind	0.8 - 4.0
Windows half open	5.0 - 10.0
Windows completely open	9.0 - 15.0
Windows and window-door completely open	40

Table 1.3d Estimated ventilation intensities due to different ventilation measures. After Gertis (1983).

The relatively large intervals for the ventilation intensity in the table is of course due to different wind - and stack-effect actions that can be expected on a building.

2 PRINCIPLES FOR RISK ANALYSES

In this chapter we will deal with combined effects of moist air, cold surfaces on the inner side of the dwelling envelope and risks for condensation, mould growth etc.

2.1 Surface phenomena

The surface temperatures of different parts of the inner side of the building envelope (walls, roofs, windows etc) are of essential interest in order to analyse the humidity conditions for a building.

The thermal analysis could be simplified by using a local formulation of the heat transmission coefficient of a building component, U_{loc} (W/(m^{2}K)). This formulation implies that there is only one-dimensional heat flow in the vicinity of the local "spot". (No cross-conduction). The indoor surface temperature, ϑ_{si} of a building component etc. could be written:

$$\vartheta_{si} = \vartheta_{ai} - \frac{U_{loc}}{\alpha_i}(\vartheta_{ai} - \vartheta_{ao}) \qquad (2.1a)$$

where

ϑ_{ai} and ϑ_{ao} = air temperature indoors and outdoors respectively, ^{o}C

α_i = indoor surface heat transfer coefficient, W/(m^{2}K)

In a given climate situation

$$\vartheta_{si} = \vartheta_{si}(U_{loc}, \alpha_i) \qquad (2.1b)$$

The local U-values for some building components are given in table 2.1a.

Building component	U_{loc} (W/m^{2}K))
0.25 m masonry (brick)	1.7
0.15 m concrete	3.0
0.15 m wood	0.7
0.15 m steel	4.0
Window, single-glazed	5.0
double-glazed	3.0
triple-glazed	2.0

Table 2.1a Local U-values for some building components.

The indoor surface heat transfer coefficient, α_i, is by definition:

$$\alpha_i = \frac{q}{\vartheta_{ai} - \vartheta_{si}} \qquad (2.1c)$$

where

q = heat flow density, W/m^2

The magnitude of the indoor surface heat transfer coefficient in different situations has been studied by several authors.

Gertis (1983) gives the following approximate values suitable to practical design:

Situation	α_i (W/(m^{2}K))
Undisturbed, free vertical surface	8
Corner, no furniture	6
Corner, behind furniture	4

Table 2.1b Practical design values of indoor surface heat transmission coefficient. Gertis (1983).

For windows it is worth-while carrying out a special discussion on local phenomena of heat transmission.

Windows with air cavities, such as double- or triple-glazed ones, have no constant U-value along the height of the glass. Due to natural convection within the cavities there is a local maximum of the U-value in the bottom part of the window of the magnitude 1.5 U_{mean}.

Partly as a result of this, also the inner surface heat transmission coefficient varies from top to bottom of the glazed part of a window.

From a practical point of view it is desirable to describe these variations in an acceptable way by varying only one of the parameters, keeping the other at an averaged value. In Jonsson (1985) such a formulation is worked out.

In brief, from Jonsson's results, a versatile design approach for estimating minimum inside surface temperatures for double and triple-glazed windows in a cold climate could be:

- Let the mean U-value, U_{mean} of the window represent the overall heat transmission of the window.

- Let the minimum temperature be calculated as a function of U_{mean} and α_{min}.

α_{min} appears normally in the bottom of the window glass, and for most cases a value of

$$\alpha_{min} = 5 \ W/(m^2K)$$

is applicable.

An analysis of surface related moisture problems in general is however rather complex. A number of parameters must be set and/or calculated:

- volume of room or dwelling

- ventilation intensity
- moisture supply
- outdoor and indoor temperature and relative humidity
- risk criterion on inner surface (set critical value of RH)
- indoor surface heat transfer coefficient
- local heat transmission coefficient

Possibilities to study the sensitivity, in different aspects, due to changes in level of one or more parameters, could be done in a rather simple way by means of a multi-diagram (figure 2.1a).

The use of the multi diagram is shown in the following example.

Example

Investigate the ventilation need for a dwelling (volume 250 m^3) under winter condition, in order to avoid moisture conditions for mould growth on the wallpaper behind a sofa for two different levels of moisture supply; 0.4 and 1.0 kg/h.

Wall: 0.25 m brick masonry.
Outdoor conditions:
  air temperature + 1^oC
  relative humidity 90%

Indoor air temperature = 20^oC and 15^oC

Solution:
Study figure 2.1b.

Result:
Minimum ventilation intensity (h^{-1}):

Indoor air temp	Moisture supply	
^oC	0.4 kg/h	1.0 kg/h
20	0.4	1.0
15	0.8	1.9

Figure 2.1 a

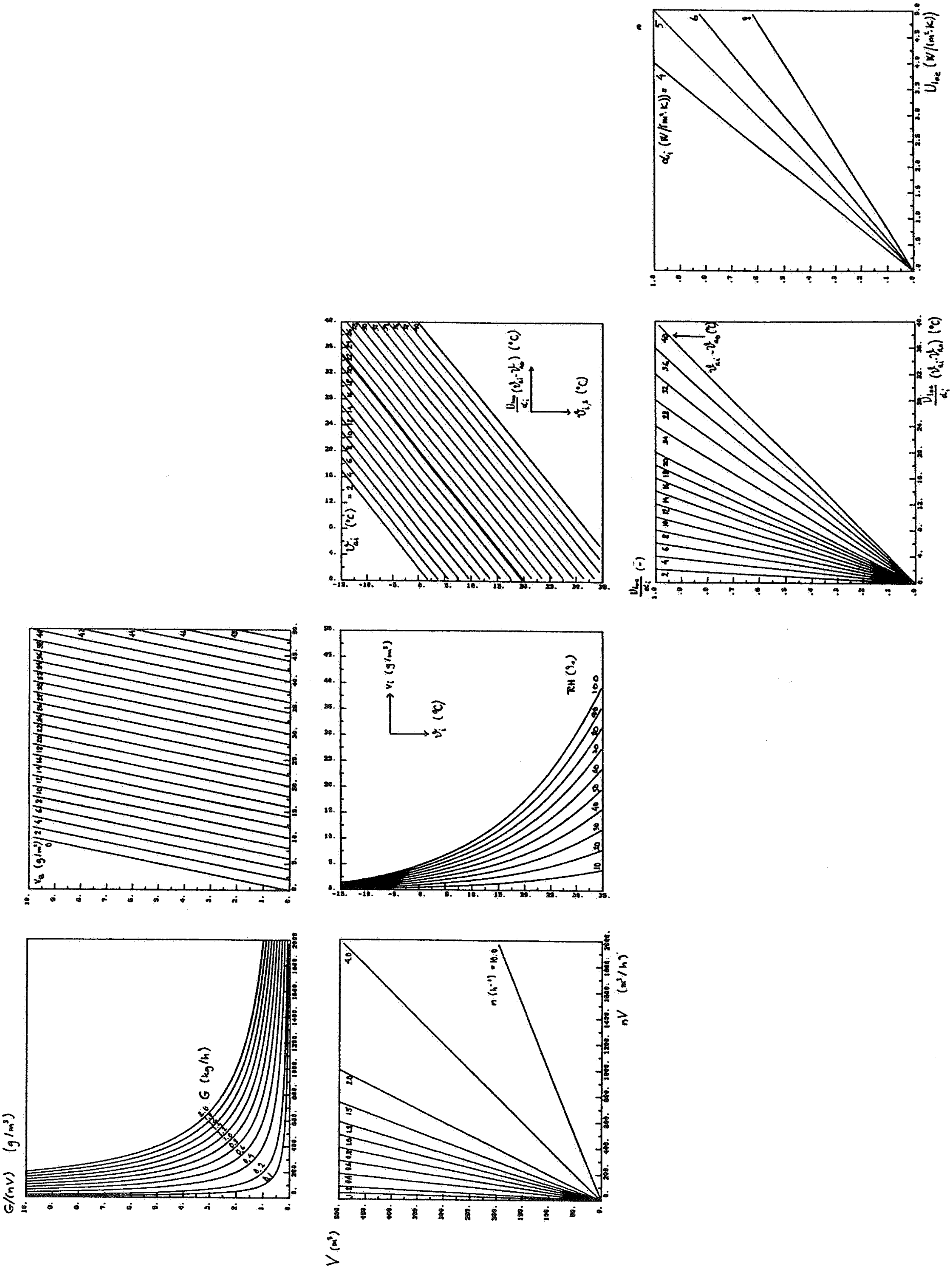
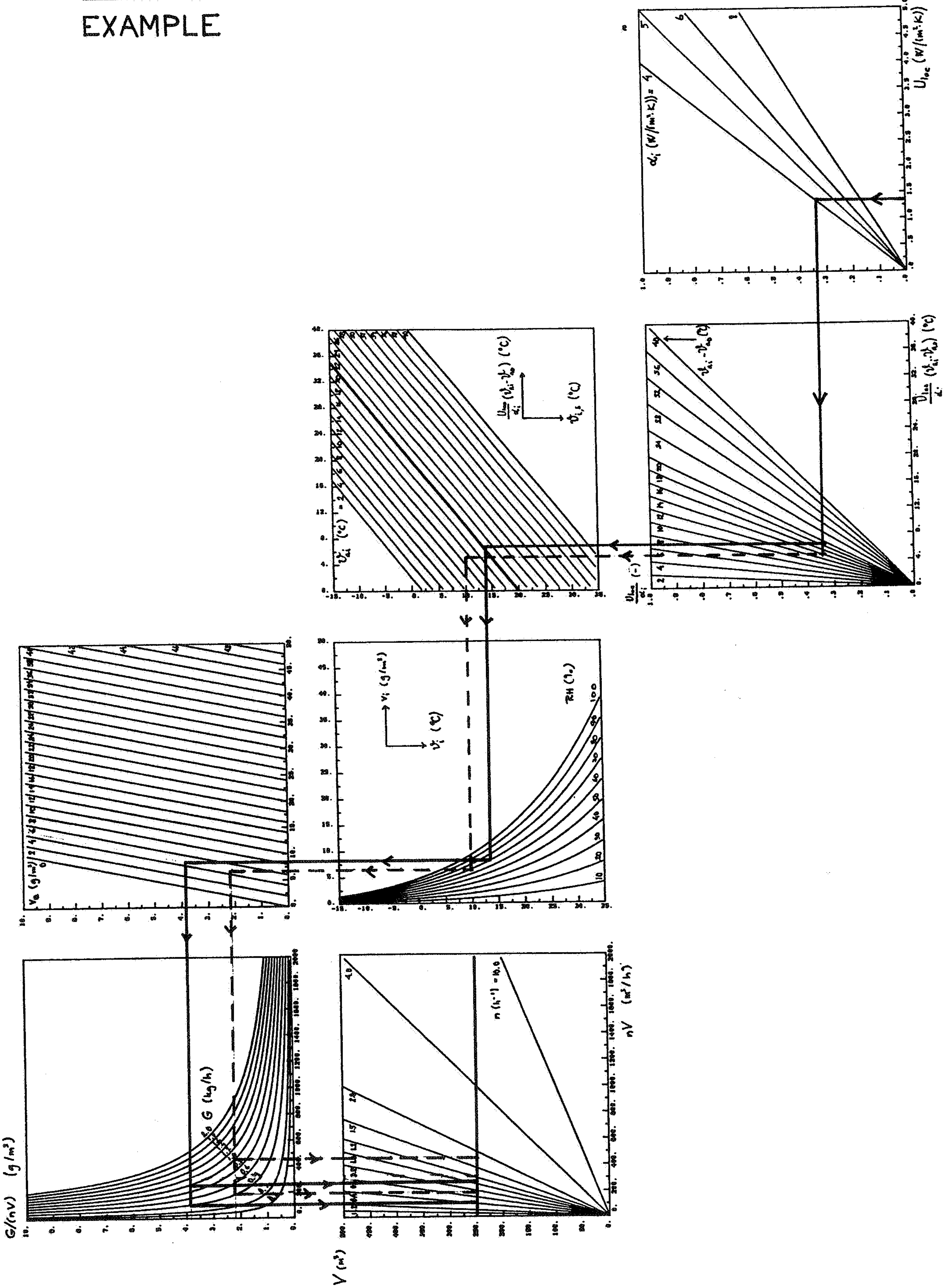


Figure 2.1b

EXAMPLE



2.2 Moisture conditions within building components

As outlined above (part 1.2), the durability or function of a building component may be diminished under influence of moist indoor or/and outdoor conditions.

If no measures, such as use of vapour barriers etc, are undertaken to protect the inner/of a building component, condensation or very moist conditions are likely to occur in some cases. The vapour transfer may be convective or diffusive.

Some apparent risk cases are:

- Outer parts of building components under relatively constant low outer temperature (cold climates)

- Inner parts of building components in artificially cooled buildings in hot climates

- Cold parts in building components, due to non-steady state conditions in all climates under certain conditions, (for example night-radiation out from roof constructions).

The risk of critical moisture conditions within building components is, of course,connected to the ventilation of a building. However, this is more a question of making a proper design and construction of the building component. Hence it will not be discussed in detail in this paper.

3 VENTILATION REQUIREMENTS IN DIFFERENT CLIMATES

3.1 Climatic data for different climatic zones

A climate of a place on Earth can be described by many parameters. Two main parameters for this study are temperature and humidity.

For the analyses carried out in this paper, the four possible combinations of hot and cold temperature and dry and humid moisture conditions were investigated. As a comparison, a moderate climate was investigated too, Table 3.1 .

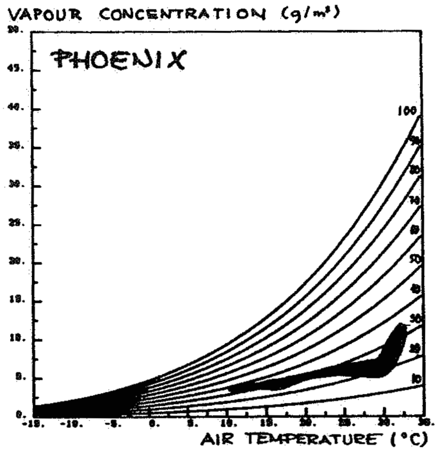
Place	Latitude	Longitude	Elevation (m)	Climate
Phoenix, Ariz.,USA	33°26'N	112°01'W	340	hot,dry
Singapore	01°21'N	103°54'E	8	hot, humid
Saskatoon, Sask., Canada	52°08'N	106°38'W	157	cold,dry
Lerwick, Shetland Islands,UK	60°08'N	01°10'W	83	cold, humid
Lund, Sweden	55°43'N	13°12'E	73	moderate

Table 3.1

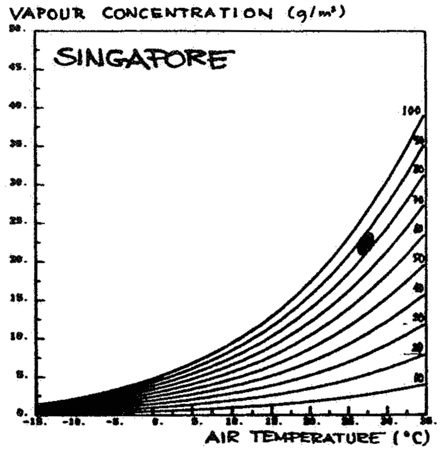
Climatic data concerning temperature and humidity of the five places are presented in Appendix 1. Main source: Landsberg (1985).

The data are presented in an illustrative way in Figures 3.1a-3.1e.

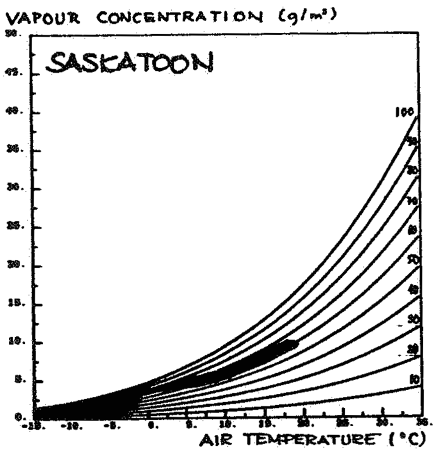
(a)



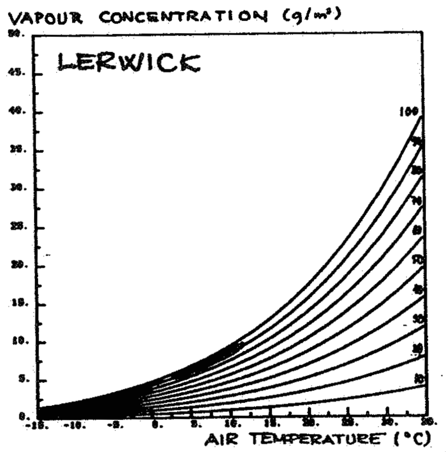
(b)



(c)



(d)



(e)

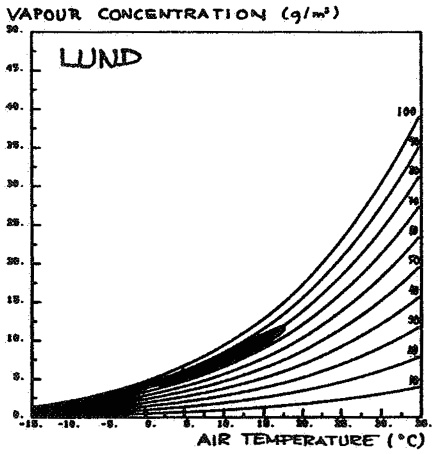


Figure 3.1 Outdoor temperature and moisture conditions of the selected places

3.2 Principles for moisture - ventilation analysis

An analysis, in order to determine ventilation requirements for moisture control, can follow different lines. As outlined earlier in the paper the following aspects may be of interest.

What minimum ventilation intensity is required for different levels of moisture supply, in order to

- minimize human discomfort in the dwelling?
- avoid critical moisture conditions for the building material?

If really reliable results of such an analysis are desired, the heat balance of the building under non-steady conditions must also be calculated. This is important especially in hot climates, where the influence of thermal inertia is large.

For these cases, analyses carried out by Adamson (1986), fully taking into account the thermal behaviour of the building, can offer considerable help.

At least the winter case, and also to a certain degree the spring and autumn cases, can be analysed in a more simple way. The main steps in such a simplified analysis are as follows:

1. Determine outdoor temperature and moisture conditions
2. Investigate the ventilation need for different moisture supplies, (kg/h), see part 1.3
3. Set damage criteria such as condensation risk etc.
4. Perform the analysis according to point 2 for different (design) indoor temperatures

In relation to what is practically obtainable as far as moisture conditions are concerned, different targets are likely to be used in different climates.

3.3 Analyses

3.3.1 Hot and dry climate

Reference place: Phoenix, Arizona, USA

Climatic conditions: Cf. Figure 3.1a. The daily mean temperature varies between around 10 ^{o}C in January and 33 ^{o}C in July. The diurnal variations are normally large. The daily mean relative humidity never exceeds 40%. Sunshine and high night-radiation are very frequent due to clear sky.

Building design: Typical building-design strategies for passive-design (no mechanical ventilation or cooling equipment) in hot and dry climates are:

- Dense built up areas, narrow streets, courtyards, white painted walls and roofs, small windows, etc. to prevent too high solar gain on the outside of the building

- High external and internal thermal capacity in order to level out the temperature fluctuations in the building

- Thermal insulation in walls and roofs (newer buildings)

Passive-design ventilation strategies: In order to produce acceptable indoor thermal comfort, ventilation in the day time is kept at a low level (hygienic ventilation) while at night the ventilation is forced (10-40 h^{-1}, depending on season).

Analysis

Two questions are interesting to investigate

- What minimum ventilation intensity is required in the day time? (A).
- How can the high ventilation intensity at night be arranged and what hygienic phenomena can be expected? (B).

A complete thermal analysis of the thermal behaviour of a building in the Sahara has been carried out by Adamson (1986). In figure 3.3.1a the indoor and outdoor air temperatures of a building on a hot day in July are shown.

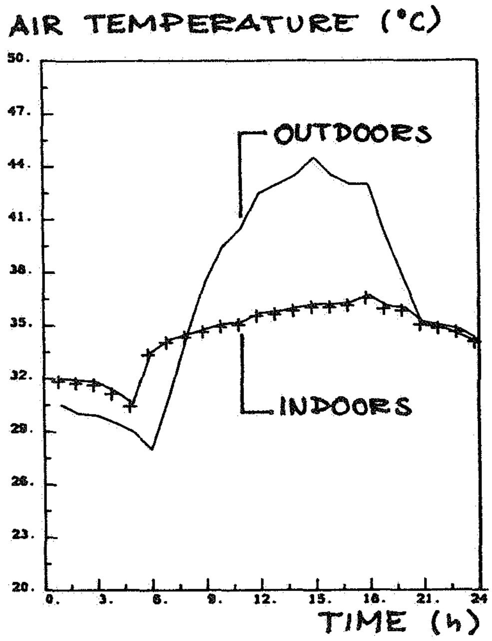


Figure 3.3.1a Computed indoor and outdoor air temperatures for a building in the Sahara on a hot July day. Day ventilation 1.1 h^{-1}, night ventilation 20 h^{-1}.

A

Since outdoor humidity is very low, it is easily shown that the indoor relative humidity never can reach high critical levels even with very high levels of moisture supply. Hence, the minimum ventilation intensity is settled by other factors than indoor humidity such as odour control.

B

In many cases in hot, dry climates the high ventilation intensities during night time are arranged by means of a so called wind scoop (figure 3.3.1b) facing the prevailing wind. As can be seen from the figure the equipment can also be used for evaporative cooling.

Mechanical ventilation is of course also possible as well as artificial refrigeration of the ventilation air. These measures are normally undertaken for office buildings etc. in hot and dry climates.

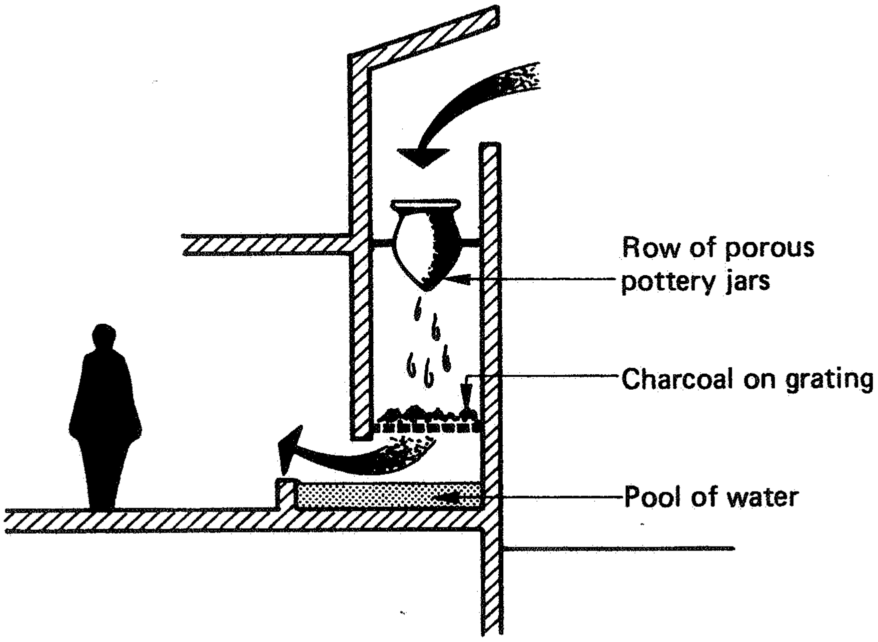


Figure 3.3.1b "Wind scoop". After Markus & Morris (1980).

3.3.2 Hot and wet climate

Reference place: Singapore

Climatic conditions: Cf. Figure 3.1.b. There are almost no variations in outdoor air temperature and relative humidity throughout the year. The yearly mean values describe the conditions quite well. They are:

Outdoor temperature	27 °C
Outdoor relative humidity	84%

Also the diurnal variations are small, mainly due to very high frequency of cloudiness.

Traditional building design in this area involves, Markus & Morris (1980):

- light-weight structure and roof construction
- ventilated space and/or insulation between roof and ceiling
- roof-overhang to shade the walls from sunshine
- possibilities to open up large parts of the facade to increase ventilation
- placing the house on poles above the ground

Analysis

As the light-weight constructions used do not give rise to any larger time-lag, which anyway had not been of any use because of the small diurnal variation of temperature, almost the same air temperature is, in principle, to be expected inside a house as outside it.

If so, analyses for hygro-thermal indoor comfort and durability can be carried out.

The combination 27°C and 84% RH of calm air cannot be regarded as a comfortable situation. Cf. Figure 1.1! However, the human comfort can be highly increased if the air is in motion. According to figure 1.1 an air velocity of around 0.5 m/s or more seems to provide acceptable comfort for most people.

Hitherto the influence of moisture supply to the indoor air has been neglected. The outdoor vapour concentration is not far from saturation point. For the yearly mean case, for example, the vapour concentration is 21.3 g/m^3 as the saturation point corresponding to +27°C is 25.8 g/m^3; a difference of 4.5 g/m^3.

If RH = 90% is chosen as an absolute limit for indoor comfort the highest permissible moisture addition is $25.8 \times 0.9 - 21.3 = 1.9$ g/m^3. For a dwelling with a volume of 250 m^3, this corresponds to maximum moisture supplies according to table 2.3.2a. ($G = 1.9\ V\ n$).

Ventilation intensity h^{-1}	Max moisture supply kg/h
1	0.5
2	1.0
4	1.9

It seems possible to take care of considerable moisture supplies, due to the high temperature, without reaching higher relative humidity than 90%. This, however, would seem to be very uncomfortable and it can also be criticized from durability aspects.

If compared with the criteria quoted in part 1.2 for mould growth, i.e. RH = 70% or more, it would seem impossible to avoid such growth, unless dehumidification is used. Mould growth is also a great problem in this climatic zone. From time to time it is necessary to clean walls, ceilings etc from mould, Huy Anh (1986).

A proper ventilation strategy for buildings in hot and wet climate could be:

- Keep ventilation at a minimum level, primarily for moisture control, as long as the indoor temperature is below outdoor temperature.

- Ventilate as much as possible as long as outdoor temperature is below inside temperature.

- Do cooking and other moisture generating activities, as far as is possible, outside the building itself.

- If higher hygro-thermal comfort is necessary, use artificial cooling for the building. If so, take good care with the design and construction of the building. (Vapour barriers on the hot side, air tightness etc).

3.3.3 Cold and dry climate

Reference place: Saskatoon, Sask., Canada

Climate conditions: Cf. figure 3.1c. The daily mean temperature varies between -18°C in January and around 20°C in July. The diurnal variations are relatively large, especially in the summer-time. The relative humidity is low at summer-time.

Building design and ventilation system: Due specially to cold outdoor conditions in the wintertime, at least newer buildings are well insulated and air tight. Many newer buildings are equipped with mechanical ventilation; otherwise natural ventilation is used.

Analysis

In order to achieve an acceptable indoor temperature it is necessary to run the heating system most times of the year except in the summer. With a proper temperature control, by means of thermostats, it is possible to keep a relatively constant indoor temperature.

For this, a complete thermal analysis of the building is not necessary in order to predict indoor surface temperatures, relative humidities etc.

Hence, the analysis procedure outlined in part 3.2 is completely applicable.

1. Outdoor conditions:
   These are taken from the appendix. As condensation risks etc. are greatest when the outdoor temperature is at daily minimum, this temperature is chosen. Though meteorologically not completely correct (Geiger, 1965) the daily mean outdoor vapour concentration is treated as constant during the day. However, if this leads to saturation, a value of RH of 97%, at temperature minimum, is chosen. Four season-representative months (January, April, July and October) are chosen for the analyses.

2. Moisture supplies:

   Three levels are investigated; 0.2 (low), 0.4 (medium) and 0.8 kg/h (high).

3. Damage criteria:

   No condensation on the inside of window glasses is allowed. There should be no opportunity for mould growth on the wallpaper behind sofas etc.

4. Indoor temperatures:

   Two indoor air temperatures are investigated: +20^{o}C and +18^{o}C.

Such analyses as these outlined above are quite easily made solely by means of the multi-diagram (figure 2.1a) However, if a great number of calculations are to be made it is easier to perform the calculations using a computer.

The results of such calculations for Saskatoon are shown in table 3.3.3 .

Conclusions

The low indoor temperature case, 18^{o}C, is excluded for summer-time, which seems to be reasonable, because of the relatively high outdoor temperature at this time of the year.

In all cases except summer-time it is the "no condensation on windows" criterion that governs the ventilation need. It varies between 0.43 ac/h (spring and autumn) and 0.65 ac/h (winter) for the 20^{o}C-case at medium moisture supply (0.4 kg/h) and double glazed windows. Corresponding values for triple-glazed windows are 0.26-0.31 ac/h.

Table 3.3.3

SASKATOON
MINIMUM VENTILATION INTENSITIES (ac/h)

MOISTURE (kg/h)	WINDOW DOUBLE	TRIPLE GL.	WALL BEHIND FURNITURE U=1.0	U=0.4 W/m2/K
WINTER, INDOOR TEMP 18 DEGC				
0.2	.36	.17	.16	.1
0.4	.71	.34	.32	.21
0.8	1.42	.68	.64	.41
SPRING, INDOOR TEMP 18 DEGC				
0.2	.24	.15	.19	.14
0.4	.48	.29	.39	.28
0.8	.96	.58	.78	.56
AUTUMN, INDOOR TEMP 18 DEGC				
0.2	.24	.15	.2	.15
0.4	.48	.29	.41	.29
0.8	.96	.59	.82	.59
WINTER, INDOOR TEMP 20 DEGC				
0.2	.33	.15	.14	.09
0.4	.65	.31	.28	.18
0.8	1.31	.61	.57	.37
SPRING, INDOOR TEMP 20 DEGC				
0.2	.22	.13	.16	.12
0.4	.43	.26	.33	.23
0.8	.86	.51	.66	.47
SUMMER, INDOOR TEMP 20 DEGC				
0.2	.23	.17	.68	.41
0.4	.46	.34	1.35	.81
0.8	.93	.67	2.7	1.63
AUTUMN, INDOOR TEMP 20 DEGC				
0.2	.21	.13	.17	.12
0.4	.43	.26	.34	.24
0.8	.86	.52	.68	.49

In summer-time, however, it is risk of conditions for mould growth behind furniture that settles the ventilation need. For example in the "well-insulated" case (U_{loc} = 0.4 W/m^2K) the ventilation need is 0.81 ac/h.

Rough recommendations for minimum ventilation for moisture control could be:

Well insulated house, triple-glazed windows	
Summer	0.8 ac/h
Other seasons	0.3 ac/h

Badly insulated house, double-glazed windows	
Summer	1.4 ac/h
Other seasons	0.7 ac/h

3.3.4 Cold and wet climate

Reference place: Lerwick, Shetland Islands, UK

Climatic conditions: Cf. figure 3.1d. The daily mean temperature varies between around 3°C in the winter-time and 12°C in the summer. The diurnal variations are rather small. The relative humidity is around 90% or more throughout the year.

Building design: The more specific building design of houses on the Shetland Islands is not known to the author, but the climate in general seems to give reasons for good insulation and air tightness of the houses.

Analysis

As conditions for an analysis are similar to that of a cold and dry climate (part 3.3.3) the same procedure is used.

The results of the computer calculations for Lerwick are shown in table 3.3.4 .

Table 3.3.4

LERWICK
MINIMUM VENTILATION INTENSITIES (ac/h)

MOISTURE (kg/h)	WINDOW DOUBLE	TRIPLE GL.	WALL BEHIND FURNITURE U=1.0	U=0.4 W/m2/K
WINTER, INDOOR TEMP 18 DEGC				
0.2	.24	.15	.23	.17
0.4	.49	.3	.47	.33
0.8	.98	.61	.94	.67
SPRING, INDOOR TEMP 18 DEGC				
0.2	.25	.16	.26	.19
0.4	.5	.31	.53	.37
0.8	1	.63	1.06	.74
AUTUMN, INDOOR TEMP 18 DEGC				
0.2	.27	.17	.39	.26
0.4	.53	.35	.78	.52
0.8	1.07	.7	1.56	1.04
WINTER, INDOOR TEMP 20 DEGC				
0.2	.22	.13	.19	.14
0.4	.43	.26	.38	.27
0.8	.86	.53	.76	.54
SPRING, INDOOR TEMP 20 DEGC				
0.2	.22	.14	.21	.15
0.4	.44	.27	.42	.3
0.8	.87	.54	.83	.59
SUMMER, INDOOR TEMP 20 DEGC				
0.2	.25	.17	.49	.3
0.4	.5	.33	.97	.6
0.8	1	.67	1.94	1.21
AUTUMN, INDOOR TEMP 20 DEGC				
0.2	.23	.15	.28	.19
0.4	.46	.29	.55	.38
0.8	.91	.59	1.1	.76

Conclusions

As in the Saskatoon case, the low indoor temperature (18^oC) in the summer-time is excluded.

For the case with bad insulation (U = 1.0 $W/(m^2K)$) and double-glazed windows with medium moisture supply at an indoor temperature of 18^oC (except summer-time (20^oC)), it is, in all cases but winter, the risk for high relative humidity on walls behind furniture that settles the minimum ventilation need. It varies from 0.53 ac/h (spring) to 0.97 ac/h (summer). The winter condition is governed by the risk for condensation on windows giving a minimum ventilation value of 0.49 ac/h.

If the indoor air temperature is increased to 20^oC it is, in winter and spring, the "no condensation on window" criterion that settles the minimum ventilation need at 0.43-0.44 ac/h and in summer and autumn, the risk for high relative humidity; 0.55 ac/h (autumn) and 0.97 ac/h (summer).

For the case with good insulation (U = 0.4 $W/(m^2K)$) and triple-glazed windows with medium moisture supply at an indoor temperature of 20^oC, it is during all seasons the risk for high relative humidity near the wall behind furniture, that settles the minimum ventilation need. It varies from 0.27 ac/h in the winter to 0.60 in the summer.

Rough recommendations for minimum ventilation for moisture control could be:

Well insulated house, triple-glazed windows

Summer	0.6 ac/h
Other seasons	0.3 ac/h

Badly insulated house, double-glazed windows

Summer	1.0 ac/h
Other seasons	0.8 ac/h

3.3.5 Moderate climate

Reference place: Lund, Sweden

Climatic conditions: Cf. figure 3.1e. The daily mean temperature varies between around -1°C (January and February) and around 17°C (July and August). The seasonal variations in temperature are more pronounced than they are for Lerwick but less than for Saskatoon. The diurnal variations are moderate. The yearly mean relative humidity is 82%, i.e. in between the value for Saskatoon (71%) and Lerwick (93%).

Building design: See part 3.3.3, (Saskatoon).

Analysis

The same analysis procedure as the one used for Saskatoon and Lerwick is used for Lund.

The results of the computer calculations for Lund are shown in table 3.3.5 .

Conclusions

As for the other places, the low indoor (18°C) temperature case is excluded for summer-time.

For the case with bad insulation ($U = 1.0\ W/(m^2K)$) and double-glazed windows with medium moisture supply at an indoor temperature of 18°C (except summer-time (20°C)), it is, during all seasons but winter, the risk for high relative humidity on walls behind furniture that settles the minimum ventilation need. It varies between 0.5 ac/h (spring) and 5.42 ac/h (summer).

If the indoor air temperature is increased to 20°C the minimum ventilation need varies between 0.43 ac/h (winter, spring, condensation on windows) and 5.42 ac/h (summer); see above.

Table 3.3.5

LUND
MINIMUM VENTILATION INTENSITIES (ac/h)

MOISTURE (kg/h)	WINDOW DOUBLE	TRIPLE GL.	WALL BEHIND FURNITURE U=1.0	U=0.4 W/m2/K
WINTER, INDOOR TEMP 18 DEGC				
0.2	.24	.14	.19	.14
0.4	.48	.29	.38	.27
0.8	.96	.58	.76	.55
SPRING, INDOOR TEMP 18 DEGC				
0.2	.25	.16	.25	.18
0.4	.49	.31	.5	.36
0.8	.99	.62	1.01	.71
AUTUMN, INDOOR TEMP 18 DEGC				
0.2	.26	.17	.35	.24
0.4	.52	.34	.71	.48
0.8	1.05	.68	1.41	.96
WINTER, INDOOR TEMP 20 DEGC				
0.2	.22	.13	.16	.12
0.4	.43	.26	.32	.23
0.8	.86	.51	.65	.46
SPRING, INDOOR TEMP 20 DEGC				
0.2	.22	.13	.2	.14
0.4	.43	.27	.4	.29
0.8	.87	.54	.8	.57
SUMMER, INDOOR TEMP 20 DEGC				
0.2	.29	.2	2.71	.78
0.4	.58	.4	5.42	1.56
0.8	1.16	.81	10.84	3.13
AUTUMN, INDOOR TEMP 20 DEGC				
0.2	.22	.14	.26	.18
0.4	.45	.29	.51	.36
0.8	.9	.57	1.03	.72

For the case with good ventilation (U = 0.4 W/(m^2K)) and triple-glazed windows with medium moisture supply at an indoor temperature of 20^{o}C, it is, during all seasons but winter, the risk for high relative humidity on walls behind furniture that settles the minimum ventilation need. It varies between 0.29 ac/h (spring) to 1.56 ac/h (summer). As before the winter case is governed by the risk for condensation on windows, 0.26 ac/h.

Rough recommendations for minimum ventilation for moisture control could be:

Well insulated house, triple-glazed windows	
Summer	1.6 ac/h
Other seasons	0.4 ac/h

Badly insulated house, double-glazed windows	
Summer	5 ac/h
Other seasons	0.7 ac/h

4 CONCLUDING REMARKS

The analyses carried out in the paper result in the following general recommendations for ventilation for moisture control in dwellings in different climates:

Hot and dry climate: No real problem exists from moisture point of view. The ventilation is needed more for thermal control.

Hot and wet climate: Ventilation should be kept at a minimum, primarily for moisture control, as the temperature outside the house is higher than inside. When temperature conditions are the opposite the ventilation should be as large as possible. Avoid high moisture supply within the building. In many cases artificial cooling is necessary for reasonable comfort.

Cold and dry climte: For newer houses of good quality and workmanship the ventilation need is around 0.3 ac/h except in the summer-time when 0.8 ac/h is necessary.

Cold and wet climate: For newer houses of good quality and workmanship the ventilation need is around 0.3 ac/h except in the summer-time when 0.6 ac/h is necessary.

Moderate climate: For newer houses of good quality and workmanship the ventilation need is around 0.4 ac/h except in the summer-time when 1.6 ac/h is necessary.

5 APPENDIX

PHOENIX, ARIZ.
Latitude 33 deg, 26 min N, longitude 112 deg 01 min W
Elevation 340 m.

Month	Temperature (deg C)			Mean rel. humid. (%)	Mean vapour conc. (g/m3)
	mean	mean daily max.	mean daily min.		
Jan.	10.4	17.8	3.0	39	3.8
Febr.	12.5	20.1	5.0	35	3.8
Mar.	15.8	23.9	7.7	28	3.8
Apr.	20.4	28.9	11.9	29	5.2
May	25.0	33.9	16.2	22	5.1
June	29.8	38.7	20.9	18	5.7
July	32.9	40.3	25.5	33	11.3
Aug.	31.7	38.7	24.7	35	12.1
Sept.	29.1	36.9	21.4	26	7.9
Oct.	22.3	30.4	14.2	30	5.9
Nov.	15.1	23.3	7.0	35	4.5
Dec.	11.4	19.0	3.9	37	3.8
Annual	21.4	29.3	13.5	31	5.9

SINGAPORE
Latitude 1 deg, 21 min N, longitude 103 deg 54 min E
Elevation 8 m.

Month	Temperature (deg C)			Mean rel. humid. (%)	Mean vapour conc. (g/m3)
	mean	mean daily max.	mean daily min.		
Jan.	25.6	29.9	22.9	85	20.3
Feb.	26.1	30.8	23.1	83	20.4
Mar.	26.5	31.1	23.6	84	21.1
Apr.	27.1	31.2	24.1	85	22.0
May	27.3	30.9	24.5	84	22.0
June	27.6	30.8	24.7	83	22.1
July	27.3	30.6	24.7	82	21.5
Aug.	27.1	30.5	24.4	83	21.5
Sept.	27.0	30.4	24.2	83	21.4
Oct.	26.7	30.4	23.9	84	21.3
Nov.	26.2	30.1	23.7	86	21.2
Dec.	25.7	29.9	23.2	86	20.6
Annual	26.7	30.6	23.9	84	21.3

SASKATOON, SASK.
Latitude 52 deg, 08 min N, longitude 106 deg 38 min W
Elevation 157 m.

Month	Temperature (deg C)			Mean rel. humid. (%)	Mean vapour conc. (g/m3)
	mean	mean daily max.	mean daily min.		
Jan.	-17.6	-12.9	-22.4	92	1.0
Feb.	-14.9	-9.7	-20.2	79	1.1
Mar.	-7.9	-2.8	-13.1	83	2.1
Apr.	3.6	9.7	-2.5	65	4.0
May	11.2	18.3	4.1	54	5.5
June	15.4	22.1	8.7	59	7.7
July	19.3	26.6	12.1	59	9.6
Aug.	17.6	24.8	10.4	63	9.5
Sept.	11.6	18.3	5.0	62	6.4
Oct.	4.9	11.1	-1.3	71	4.8
Nov.	-5.8	-1.4	-10.2	86	2.6
Dec.	-13.2	-8.8	-17.6	74	1.2
Annual	2.0	7.9	-3.9	71	4.6

LERWICK, SHETLAND ISLANDS, UK
Latitude deg, min N, longitude deg min
Elevation m.

Month	Temperature (deg C)			Mean rel. humid. (%)	Mean vapour conc. (g/m3)
	mean	mean daily max.	mean daily min.		
Jan.	3.1	5.0	1.2	93	5.6
Feb.	2.9	5.0	1.9	93	5.5
Mar.	3.9	6.0	1.8	91	5.8
Apr.	5.4	8.1	2.8	88	6.1
May	7.8	10.5	5.1	88	7.2
June	10.0	12.6	7.4	88	8.3
July	12.0	14.4	9.7	92	9.6
Aug.	12.1	14.4	9.7	92	9.9
Sept.	10.6	12.9	8.4	93	9.1
Oct.	8.2	10.1	6.2	92	7.7
Nov.	5.9	7.8	4.1	93	6.7
Dec.	4.4	6.2	2.7	94	6.1
Annual	7.2	9.4	5.0	93	7.3

LUND, SWEDEN
Latitude 55 deg, 43 min N, longitude 13 deg 12 min E
Elevation 73 m.

Month	Temperature (deg C)			Mean rel. humid. (%)	Mean vapour conc. (g/m3)
	mean	mean daily max.	mean daily min.		
Jan.	-0.7	1.6	-3.0	89	4.1
Feb.	-0.8	1.6	-3.3	88	4.0
Mar.	1.3	4.7	-1.7	84	4.4
Apr.	6.2	10.4	2.2	76	5.6
May	11.3	16.1	6.1	71	7.2
June	15.2	19.7	10.2	73	9.5
July	17.4	21.7	12.7	78	11.6
Aug.	16.8	21.0	12.3	79	11.3
Sept.	13.5	17.4	9.6	84	9.8
Oct.	8.7	11.9	5.5	87	7.5
Nov.	4.8	7.0	2.5	89	5.9
Dec.	1.9	3.9	-0.1	91	5.0
Annual	8.0	11.4	4.4	82	7.4

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