On Strategies to Prevent Condensation in Buildings

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INTRODUCTION

It is recognized that the occurrence of condensation in surfaces inside buildings is a major cause of indoor pollution with relevant negative effects on human health. Scientific reviews on health effects from dampness and moisture in buildings made in recent years [1, 2] present the common view that, despite intensive research efforts, the relationships between the probability of the occurrence of dampness and moulds and the building construction and operation parameters have not been fully identified yet. However, some authors [2] clearly state that "setting limits on indoor relative humidity" does not guarantee a mould-free environment.

Nevertheless, it could be stated that dampness and moulds are cases of pollution sources that could, in theory, be totally removed. This would enable the elimination of those sources and effects by the use of a source control strategy. In fact, if the control of a few physical parameters could be guaranteed, the occurrence of dampness and moulds would be prevented and the principle of source control could be successfully applied.

More than exploring the processes through which dampness and moulds are generated or emit pollutants that are responsible for respiratory diseases this paper aims at contributing to discuss the extreme conditions by which it would be possible to avoid condensation.

In terms of physics, condensation occurs in a surface of a room whenever the temperature of the surface is lower than the saturation temperature of moisture in the surrounding indoor air. Phenomena at the micro-scale may make condensation emergence dependant on the nature, microstructure and micro-geometry (roughness) of the surface material. In addition, when condensation occurs, several phenomena may take place at the microscopic scale in the microstructure of the materials behind the surface such as capillarity effects and others. Dampness effects can also be present at the surface caused by the dynamics of the moisture traveling by capillarity inside the fabrics once condensation occurred and mass transport could take place. This case is not considered in this paper.

Other causes for the occurrence of humidity in the fabrics due to leaks in pipes, infiltration of rain water, drainage or others are not considered in this paper since they can be effectively eliminated by different ways, namely, through proper maintenance and operation of the building envelope and water systems.

STRATEGIES

Preventing the occurrence of condensation requires that the temperature of the surface stays permanently higher than the temperature of saturation of the water vapour in the surrounding indoor air. In terms of Physics, this can be achieved by increasing the temperature of the surface or the temperature of the air or by lowering the humidity contents of the air, or by a mix of some of these factors.

In practical terms, this translates into one condition related to the construction of the envelope and two operational conditions associated with thermal comfort and indoor air quality, all of them ultimately interrelated with the energy use in buildings for heating:

- i) To insulate the building envelope to ensure that indoor surface temperatures are kept above a certain threshold;
- ii) To increase the temperature set-point of the indoor air in the heating mode (which consequently also increases the temperature of the indoor surface);
- iii) To increase the ventilation rate in the space to remove the moisture in the indoor air and lower its humidity by mixing it with some new fresh and dryer air and, therefore, to raise the indoor dewpoint temperature. Of course, it may be ineffective when the outdoor humidity is high and the indoor temperature is about the same as outdoors.

In fact, insulation has been justified in some regulations for two main purposes: a) enhancing comfort by avoiding temperature asymmetries and assuring energy saving by reducing heating needs for comfort in winter; and b) preventing condensation inside the fabrics in order to preserve the building structure and the cladding materials. This condensation criterion can probably become, in some cases, the first condition for insulating as it may contribute significantly for the prevention of condensation while heating, by climatie conditions, may not be a critical issue.

The new question could then be to guarantee the fulfilment of the condensation criterion while assuring the thermal comfort conditions. Besides, there is the problem of the thermal bridges that are associated to discontinuities in the insulation. Those thermal bridges are often left without insulation, and become typically the zones where condensations occur in the first place.

Raising the temperature set-points and the ventilation rates have both negative effects in terms of energy demand for heating, which represents a comfort requirement that clearly prevails in Europe over the cooling demand. Nevertheless, there are minimum requirements due to comfort and health reasons. And there are indications that going beyond the minimum requirement might be positive in terms of productivity [3], although there is no consensus on the extent of such effects.

Regarding the occurrence of condensation, it is not clear to what extent, once solved the thermal insulation problem, each of the two operational conditions indicated, taken one by one, may solve the problem or whether there is always a need for a combination of both. And, in the later case, what are the relative weights from each of the two operational conditions. Figure 1 shows a schematic diagram with the relative risk of occurrence of condensations as a function of the heating temperature set-point, the ventilation rate and the insulation of the envelope. The quantification of the boundaries is a step that could provide a significant contribution towards the assessment of the effectiveness of each measure and of their combination. This will be sought in the next section.

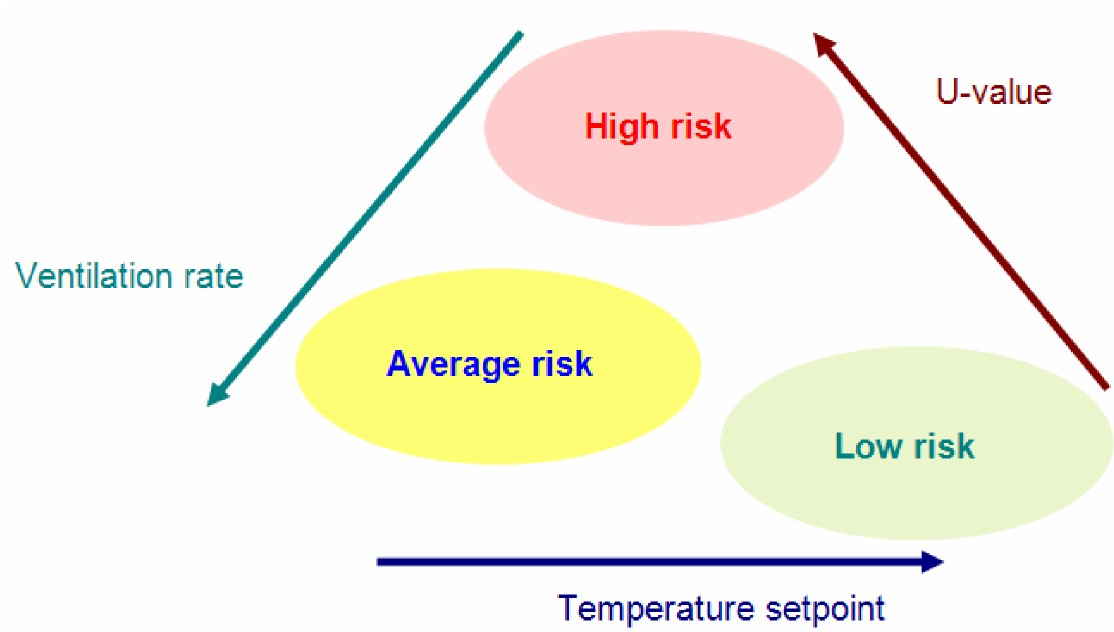


Figure 1: Diagram of risk the occurrence of condensations as function of the insulation (U-value), heating temperature set-points and ventilation rate.

A PARAMETRIC STUDY OF THE CONDENSATION OCCURRENCE

Geometry

A exploratory exercise was made taking as a reference model a room with 15 m^2 of floor area and 3 meters high. The West and the North facades are external; all the other envelope surfaces are considered as connected to similar zones of the building. The room is connected to the exterior through 13 m^2 of opaque wall and 1.65 m^2 of window facing West, plus 8.4 m^2 of wall and 0.6 m^2 of window facing North. A thermal bridge with 0.9 m^2 was considered in the North facade.

Constructions

In terms of construction, the external walls are composed by three layers: an external insulation, an 11 cm thick brick and an internal coating. A thermal bridge made of concrete without any insulation, and with a U-value of 2.7 $W/m^{2o}C$ is considered. The width of the insulation in the main wall is adjusted to vary corresponding to the U-values between 0.8 and 0.2 $W/m^{2o}C$.

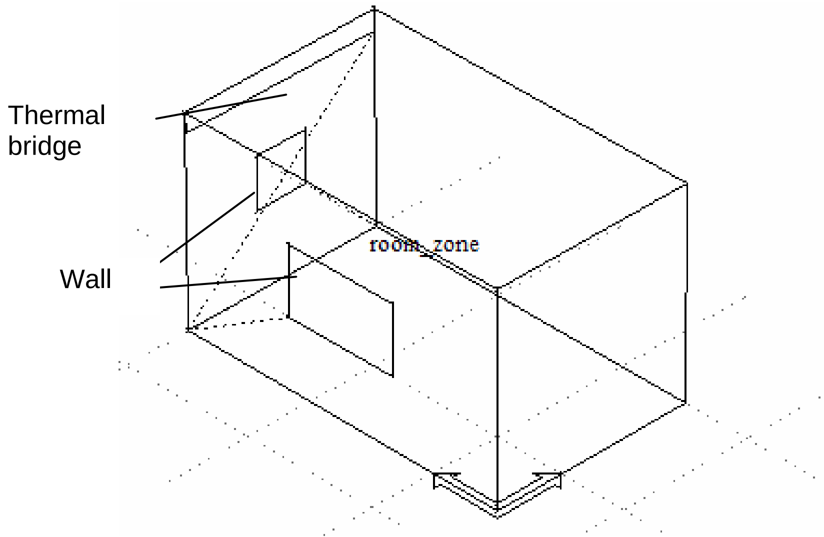


Figure 2: Geometry of the reference room used in the study

Internal gains

The room is considered to be occupied by two persons with a metabolism rate of 115 W/person (70W sensible and 45W latent) from 23 to 24 h and at 70 W/person (50W sensible and 20W latent) from 0 to 8 h. In addition, a general internal gain of 4 W/m^2 due to equipments and lighting is considered.

Software and climate

The thermal behaviour of the room was studied by performing an hourly simulation with the software ESP-r [4]. In order to make the study more representative of an `European average` (and, thus somehow immediately accessible to all), the room was considered to be located in Brussels, with the irrespective geographic coordinates and climate.

Parameters

The parametric study considered variations in the following parameters:

i) U-values of the wall (between 0.2 and 0.8 W/m^2.ºC);
ii) Ventilation rates (between 0.1 and 1.2 air changes per hour);
iii) Temperature set-point (heating mode). Two scenarios were studied for this item:
   a. A control ensuring a minimum of 14ºC at anytime;
   b. A control ensuring a minimum of 18ºC during the occupied period and of 14ºC during the unoccupied period;

By explicitly including a thermal bridge in the model, it was also be possible to assess its effect and therefore compare a "scenario with thermal bridges" and a "scenario without thermal bridges".

The results of the study, shown in tables 1 and 2, are expressed in number of hours in which condensation might occur for that particular climate and those specific conditions.

Table 1: Number of hours in the year with probable condensation. (temperature set-point at 14 ºC)

U W/m^2.ºC	air exchange rate									
	0.1		0.2		0.4		0.6		1.0	
	wall	th.bridge	wall	th.bridge	wall	th.bridge	wall	th.bridge	wall	th.bridge
0.8	1403	1967	466	902	93	163	41	65	23	32
0.5	1073	1934	302	766	55	127	29	47	19	25
0.2	656	1489	161	613	33	95	22	37	7	18

Table 2: Number of hours in the year with probable condensation. (temperature set-point at 18ºC)

U W/m^2.ºC	air exchange rate									
	0.1		0.2		0.4		0.6		1.0	
	wall	th.bridge	wall	th.bridge	wall	th.bridge	wall	th.bridge	wall	th.bridge
0.8	417	1184	55	140	6	11	0	0	0	0
0.5	256	1110	23	100	0	1	0	0	0	0
0.2	84	912	3	58	0	0	0	0	0	0

The results show that, to prevent the physical conditions favourable to the occurrence of condensations at the surface indoors, it is necessary to act simultaneously at the three components: insulation, temperature set-point and ventilation. However, there seems to be a hierarchy in the influence, where the temperature set-point is the factor that influences most, followed by ventilation and finally by the level of insulation.

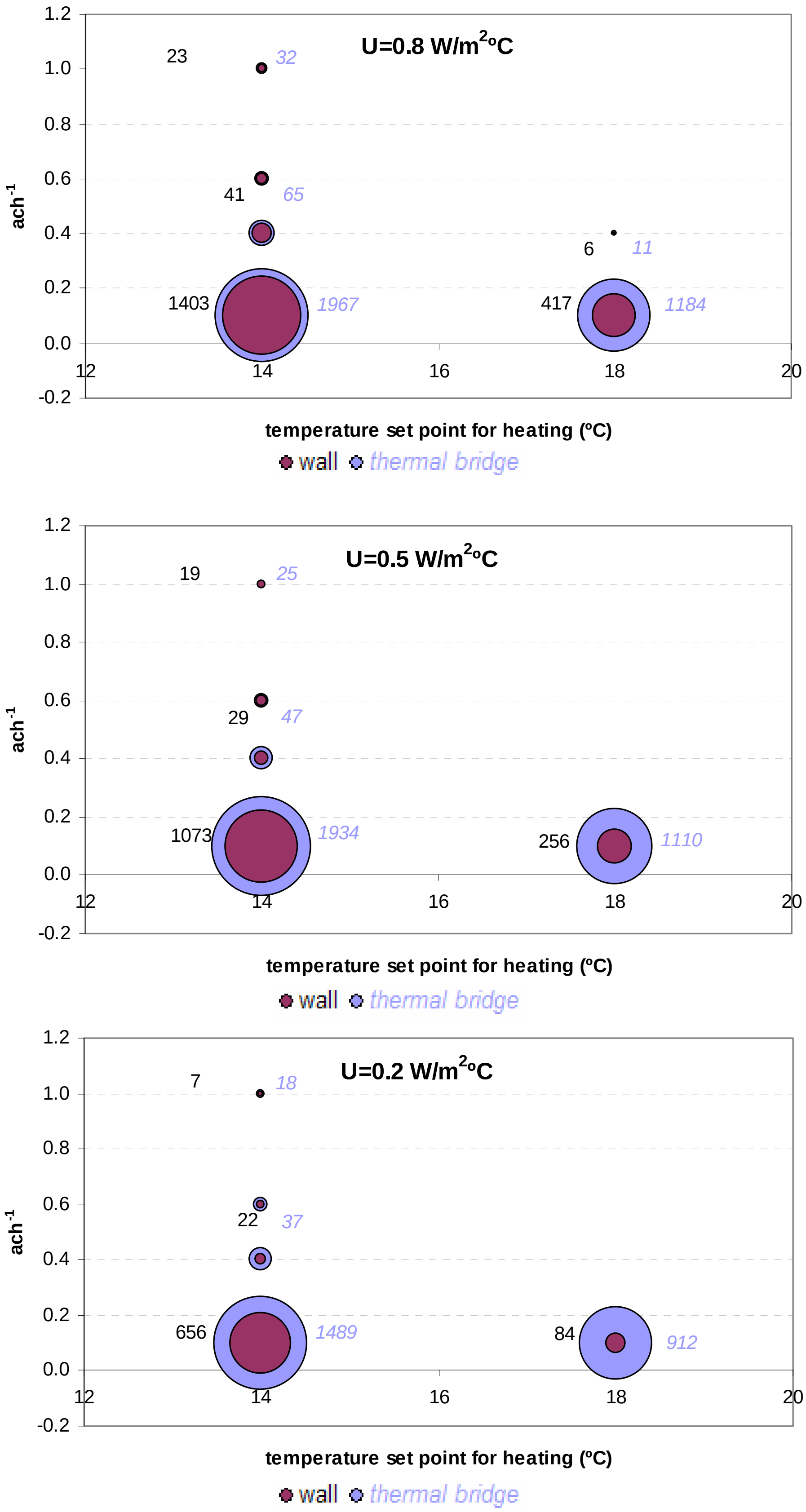
Nevertheless, given the implications in terms of the increase on the energy demand that higher temperatures and ventilation rates will imply, that does not mean that insulation is strategically the least important; on the contrary, it may just be the point where to start from.

In coherence with this framework, figures 3, 4 and 5 show the number of hours with condensation occurrence for the zones of wall and of thermal bridge, according to the different insulation levels.

A particularly important observation is that to deal with thermal bridges requires higher ventilation rates. The elimination of the thermal bridges by correct insulation of the building structure thus appears to be the first rationale alternative to adopt.

A second important observation seems to be that, with a ‘reasonable’ level of insulation and also a ‘reasonable’ temperature set-point, the ventilation rates recommended by the international standards [5] do solve the problem of condensation at the surfaces. For this room, with 45 m^3 and an occupation supposed to be of 2 persons, the 30m^3/h.person would result in an air change rate of 1.3 ach^{-1}. Therefore the results show that surface condensation could be solved even with much lower air change rates. This issue will however be analysed with further insight in the following section.

An interesting complementary observation is that the strategies to the the problem of condensation also lead to a much better behaviour in terms of the actual relative indoor air humidity. Figures 6 and 7 show the relative humidity of the indoor air for two scenarios, one with high occurrence of condensations (figure 6) and another with a strategy that enables its elimination. Comparing the two scenarios, the second does have about over 3 times more points within the 30%-70% relative humidity range, usually recommended by most international standards.



Figures 3, 4 and 5: Number of hours in the year with probable occurrence of condensations for thermal bridge and wall zone, for three different insulation levels of the external wall.

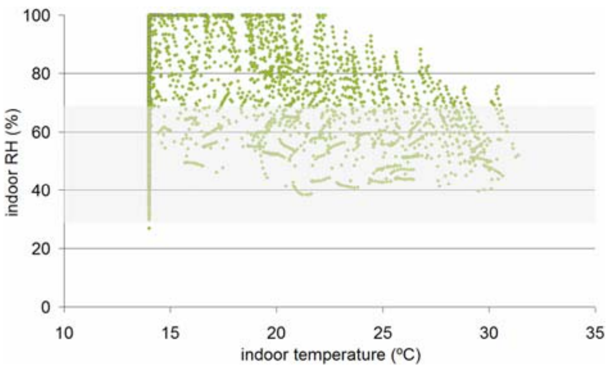


Figure 6 – Indoor temperature *vs* RH at the occupied hours, in a scenario with a U-value of 0.8 W/m^2.ºC, a ventilation rate of 0.1 ach^{-1} and a temperature set-point of 14ºC.

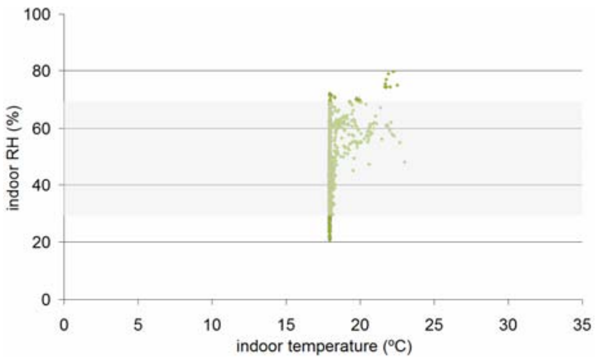


Figure 7 – Indoor temperature *vs* RH at the occupied hours, in a scenario with a U-value of 0.5 W/m^2.ºC, a ventilation rate of 0.6 ach^{-1} and a temperature set-point of 18ºC.

THE INFLUENCE OF OCCUPATION

In order to gain further insight to the influence of occupation, the analysis was extended to study the impact of the density occupation by humans. Only the "central scenario" with a U-value of 0.5 W/m^{2}ºC was considered. The pattern of occupation was shifted from night-time to day-time (8-18 h), since the higher occupation densities are more typical of offices than of domestic rooms. Two set-points, 14 and 18ºC were considered. The metabolic activity was assumed to be equivalent to a moderately office activity with a metabolism rate of 130W/person (75W sensible and 55W latent).

Varying occupation density with constant ventilation

In a first case, the occupation was supposed to vary between 2 and 6 persons (i.e., between 7.5 m^2/person and 2.5 m^2/person), while maintaining the ventilation rate at a constant value of 0.6 ach^{-1} despite the fact that it is against the good practice So this case must be seen essentially as an exploratory exercise to test the physical trends and limits.

The results in table 3 show that, as expected, there is a strong correlation between the occupation density and the likelihood of occurrence of condensations. They also show that even in the most favourable scenarios (7.5 m^2/person and set-point of 18ºC) there is a significant number of hours with probability of occurrence of condensations. This confirms that the 0.6 ach^{-1} is too low for 2 occupants (13.5 m^3/h.person), even when analysing it only from the condensation point of view.

Table 3: Number of hours in the year with probable condensation – wall with a U-value of 0.5 W/m^{2}ºC, ventilation rate 0.6 ach^{-1}

Setpoint	Occupation density (m^2/person)					
	7.5		3.75		2.5	
	wall	thermal bridge	wall	thermal bridge	wall	thermal bridge
14ºC	283	816	1449	1851	1810	2181
18ºC	59	231	1246	1764	1766	2172

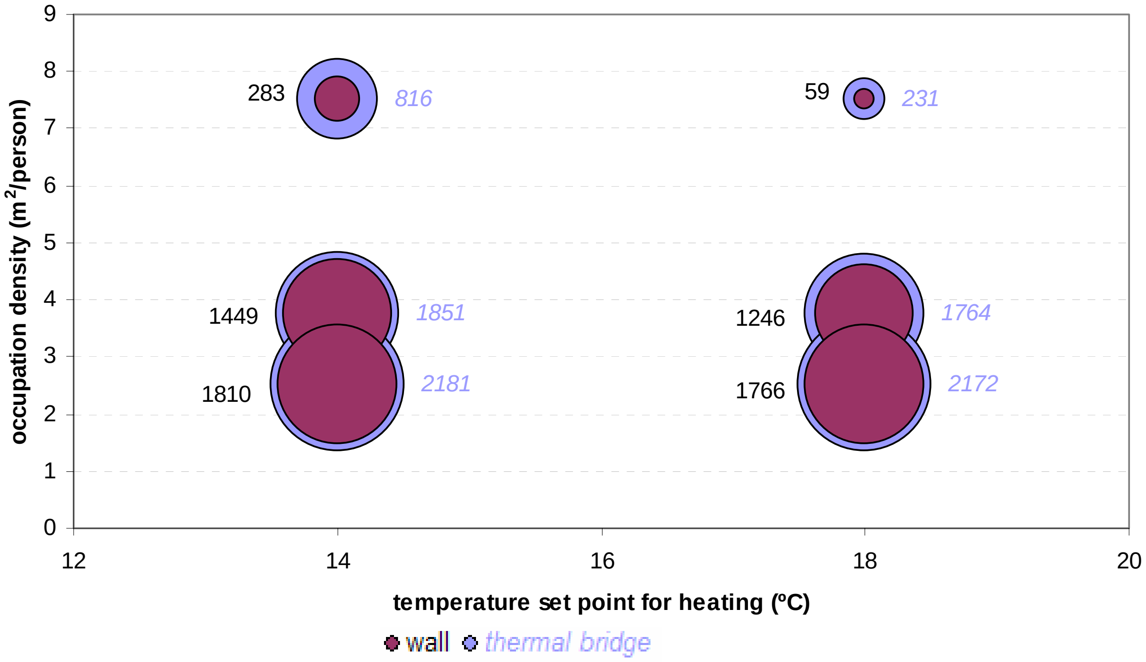


Figure 8: Number of hours in the year with probable occurrence of condensations for thermal bridge and wall zone, for two temperature set-points and three different occupation densities, with a constant ventilation rate of 0.6 ach^{-1}.

Varying occupation density with variable ventilation

A more realistic and in accordance to the good-practice situation consists in adjusting the ventilation rate to the occupation density. This scenario was studied, considering a reference value of 30 m^3/h.person.

The results, in table 4, clearly show that, the adoption of the ventilation rates recommended by the good-practice, guidelines and standards, almost solve the condensation problem. In fact, it seems to be solved if, in addition the walls are well insulated and with the thermal bridges eliminated, and an appropriate level of ventilation is provided.

Table 4: Number of hours in the year with probable condensation – wall with a U-value of 0.5 W/M^2.ºC, ventilation rate of 30 m^3/h.person.

Setpoint	Occupation density (m^2/person)					
	7.5		3.75		2.5	
	wall	thermal bridge	wall	thermal bridge	wall	thermal bridge
14ºC	27	69	27	56	17	40
18ºC	6	9	5	7	2	7

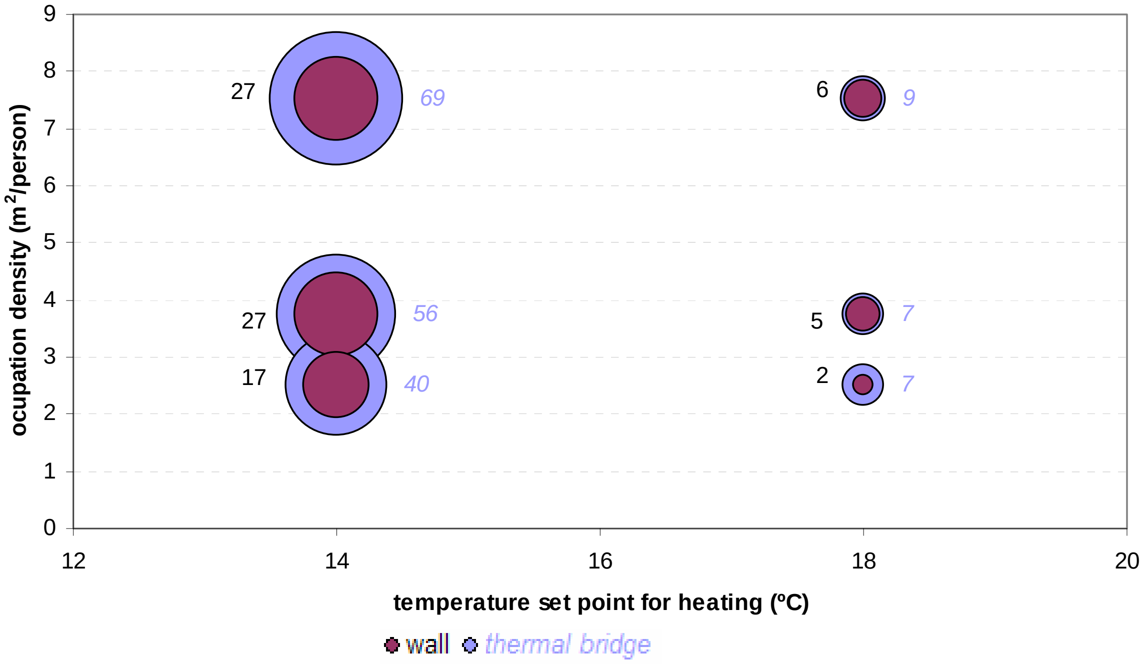


Figure 9: Number of hours in the year with probable occurrence of condensations for thermal bridge and wall zone, for two temperature set-points and three different occupation densities, with a ventilation rate of 30 m^3/h.person

LESSONS FOR POLICY-MAKING

The results of this analysis seem to allow three main conclusions with possible implications on strategic planning and policy-making regarding the elimination of dampness and moulds and consequently eliminate a cause of health effects with an extremely wide and negative impact:

- The prevention of the occurrence of condensations requires combining measures on the insulation, ventilation and temperature heating set-point. Acting on one of the factors alone may not ensure enough good results. For a "central scenario" there is, however, a hierarchy in the effectiveness of measures, increasing from the level of insulation to the ventilation rate and to the temperature set-point. It seems to be wise to take the actual good practices in building construction and in the heating and ventilation systems as a background for the selection of the best combinations for every particular climate condition.

- The existence of thermal bridges in the envelope significantly increases the risk of condensations what implies the need for a particular care in what regards the continuity of the insulation. That may suggest a preference to be given to the external insulation. It is always possible to decrease that risk by increasing the heating set-point and/or the ventilation rate, but this likely means a (unnecessary) significant impact upon the energy demand.

- The ventilation rates around 30 m^3/h.person stated by good-practice guidelines and standards are, combined with reasonable insulation and set-points and with the absence of thermal bridges, compatible with the removal of the vapour produced by the occupants and the prevention of condensations. In fact it seems that even lower ventilation rates would be compatible, so the prevention of condensations doesn't seem to be the critical parameter to set the ventilation rates.

REFERENCES

1. Bornehag, C.G., et al., *Dampness in buildings as a risk factor for health effects, EUROEXPO: a multidisciplinary review of the literature (1998-2000) on dampness and mite exposure in buildings and health effects.* Indoor Air, 2004(14): p. 243-257.
2. Moon, H.J. and G. Augenbroe. *Development of a performance indicator for mould growth risk avoidance buildings.* in *Heatthy Buildings 2003*. 2003. Singapore.
3. Seppanen, O., W.J. Fisk, and D. Faulkner. *Control of temperature for health and productivity in offices*. in *American Society of Heating, Refrigerating and Air-Conditioning Engineers, ASHRAE 2005 Annual Meeting, Jun 25-29 2005*. 2005. Denver, CO, United States: Amer. Soc. Heating, Ref. Air-Conditoning Eng. Inc., Atlanta, GA 30329, United States.
4. ESRU, *The ESP-r System for Building Energy Simulations: User Guide Version 10 Series*. 2002, Energy Systems Research Unit, University of Strathclyde: Glasgow, Scotland.
5. ASHARE, *ASHRAE 62-2001 - Ventilation for Acceptable Indoor Air Quality*. 2001, ASHRAE: Atlanta, USA.