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Published in:
Journal of Physics: Conference Series (Online)

DOI (link to publication from Publisher):
10.1088/1742-6596/2654/1/012144

Publication date:
2023

Document Version
Publisher's PDF, also known as Version of record

Journal of Physics: Conference Series

PAPER • OPEN ACCESS

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To cite this article: Kim B. Wittchen *et al* 2023 *J. Phys.: Conf. Ser.* **2654** 012144

Journal of Physics: Conference Series **2654** (2023) 012144 doi:10.1088/1742-6596/2654/1/012144

Influence of window recess on solar loads, heat loss and external condensation

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Abstract. The current architectural preference for the recess of windows is in line with the forefront of the building facade. The recess of a window has consequences for: solar loads, heat loss, and risk of outside condensation. This paper presents an analysis of these issues in relation to variations in recess depth and differences in orientation of the window. The solar load in buildings is highly influenced by the depth of the window recess, depending on the orientation. Solar gains both contribute to heating the building during the heating season, but also to overheating in other periods. The latter being especially important for other buildings than residential buildings. This is analysed for different window orientations and size (height and width) as wells as the recess depth. Recess depth also influences the overall heat loss though the facade and window and is analysed through detailed calculations. Last, but not least, condensation on the external face of modern low energy windows causes a serious issue regarding visual comfort in the mornings during periods with clear weather and low outdoor temperatures. Analyses of the recess depth influence on the outside condensation risk is presented. The issues regarding the recess depth for facade windows is analysed using dynamic simulations of different window and recess depths in different orientations in combination with 2D static calculations of the overall heat loss coefficient for the total window and facade construction in typical highly insulated facade constructions.

1. Introduction

In many new buildings the outer glass layer is placed in line with the façade. This solution results in higher levels of solar gains and thereby a higher risk of the building overheating but also more hours with external condensation. Finally, this placement will also increase the extra heat loss from the thermal bridge around the window.

The need for reducing building energy use has resulted in higher levels of thermal insulation, and the result is walls with a thickness of 40-50 cm or even more. The windows have also been improved. New types of windows have resulted in lower U-values by introducing more layers of glass, low emissivity coatings and gas fillings. In Denmark, regular windows produced today have three layers of glass and a centre U-value of around 0.6 W/(m²K). This, however, gives rise to problems with condensation on the outer pane of the glass in the form of dew or ice that impairs the view through the window after cold clear nights. This was never a problem with the traditional two-layer glass window since heat loss through the window would remove any risk of outside condensation.

Traditionally the windowpane has been placed around 5 cm behind the wall façade. This reduces the risk of problems with driving rain. With the new thick wall of 40-50 cm the window could be placed even deeper into the wall, which would also reduce the effect of the thermal bridge. Furthermore, this would also reduce the risk of external condensation as the view angle to the sky is reduced. Finally, the placement deeper into the wall would also influence the solar radiation and the energy use in a room behind the windows.

For the design of new buildings is it important to know the effects of placing the windowpane with a smaller or larger recess. Reducing the number of condensation hours has a positive effect but there could be negative effects from the reduced solar radiation entering the building. The different aspects of recess depth in relation to window sizes, orientation etc. are analysed, e.g., demonstrating how choices influence number of hours with outside condensation and the energy use for the building.

Most previous research on external condensation relates to calculation methods in theoretical studies. A good overview of previous research on external condensation is found in [4]. This and other articles show that it is possible to reduce the number of condensation hours by using a low energy coating with an emissivity of 0.2 on the outer glass pane. An alternative is to place the window deeper into the wall as demonstrated in this paper.

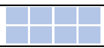
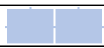
The study aimed at investigating the influence of window location in the facade on solar gains/cooling demand, risk of external condensation on the glass, and the thermal bridge.

2. Methods

2.1. Model description

A simple single zone model is set up in the dynamic building energy and indoor climate simulation tool BSim [6]. The model consists of one room with a facade area of 4x3·meteres and 5 meters depth with different configurations of windows, all having the same gross window area and the same width of the frame around the glazing. Window configuration, orientation, and recess of the glass in relation to the forefront of the facade are varied in the analyses. The gross area of the windows is fixed at 2.88 m^2 and window configuration varies as shown in **Table 1**.

Table 1. Variations of window configurations in simulation model.

Configuration					
Width [m]	0.60	0.60	1.2	0.6	1.2
Height [m]	0.60	1.20	1.2	1.2	2.4
Gross area [m^2]	2.88	2.88	2.88	2.88	2.88
Glazing area [m^2]	1.55	1.83	2.16	1.83	2.33

Different sizes of the recess, i.e., the distance from the forefront of the facade to the outside face of the glazing, are analysed from 0 to 0.25 meter in 0.05 m increments.

The room is placed on the ground, with adiabatic walls towards all neighbouring rooms and 400 mm insulation on the roof. The room is kept at an operative indoor temperature between 20 and 25 °C with sufficient power of the respective systems to maintain the temperature within these limits. There is a constant internal heat load in the zone of 110 W and an infiltration rate of 0.5 air changes per hour. Key performance indicators (KPI's) for the simulation results are solar gains (qSunRad), heating need (qHeating) and cooling need (qCooling). No external shading i.e., overhangs, shading obstacles or screens was implemented in the models.

In addition to recess, the influence of orientation of the windows have been analysed for windows with no recess and windows with a recess of 0.25 meters. The building model was rotated with windows facing south to windows facing east in intervals of 15°. Only the model with a window configuration having 2 side-by-side windows sized 1.2 m · 1.2 m was analysed in this respect.

Journal of Physics: Conference Series **2654** (2023) 012144 doi:10.1088/1742-6596/2654/1/012144

2.2 Condensation risk

The surface temperature of the outer glass pane is calculated using the heat balance. Under steady state conditions the heat flow through the window is equal to the heat flow from the pane to the surrounding air and surroundings because of convection and radiation.

$$\vartheta_{se} = \frac{\frac{U_W}{(1-0.04*U_W)}\vartheta_i + \varepsilon \cdot C\left[F\left(\frac{Tse+Ta}{2}\right)^3 \vartheta_u + (1-F)\left(\frac{Tse-Te}{2}\right)^3 \vartheta_u\right] + (A+Bv)\vartheta_u}{\frac{U_W}{(1-0.04*U_W)} + \varepsilon \cdot C\left[F\left(\frac{Tse+Ta}{2}\right)^3 + (1-F)\left(\frac{Tse-Te}{2}\right)^3\right] + (A+Bv)} \tag{1}$$

where

ϑ_{se} is the calculated temperature of the outer pane, °C
T_{se} is the initial guess of the temperature of the outer glass pane, K
ϑ_i is the indoor air temperature, °C – here 20 °C
ϑ_e and T_e is the outdoor air temperature, C and K, respectively
T_a is the sky temperature, K
U_w is the U-value for the glass part of the window, W/(m²K)
ε is the emissivity of the outer glass pane (normal glass 0.837)
F is the view factor to the clear sky
v is the local wind speed at the pane, m/s
A and B are constants for convective heat transfer
C is a constant for radiation calculations ($2.268 \cdot 10^{-7}$)

The clear sky temperature for a horizontal face is calculated as: $\vartheta_{sky} = 1.2 \cdot \vartheta_e - 14$ [1], and the outdoor temperature is taken from the reference year. The view factor F is the part of the sky with radiation from clear sky to window surface: $F = 0.5 \cdot (1- CC/10) \cdot F_{recess}$. The 0.5 is the part of the sky seen from a facade window. Then a correction for the cloud cover CC from the reference year and finally the view factor for the window size and recess from Table 1. The convective heat mass transfer coefficient is: $H_{conv} = A + B \cdot v = 4 + 4 \cdot v$. The local wind speed must be calculated from wind speed in the test reference year in 10 m height: $v = v_{10} \cdot D$. The reduction factor D is normally 0.6, but for a window with a larger recess the local wind speed is reduced further.

The condensation risk is calculated by comparing the vapour pressure in the air (calculated from outdoor temperature and the relative humidity in the reference year) with the saturation vapour pressure at the surface of the glass. If condensation is present and the global horizontal radiation is larger than zero, the condensation is set to zero as the solar radiation would remove the moisture. This is a simplified method as it could take some time before the condensation evaporates.

2.3 Thermal bridges

Window recess influences thermal bridge effects in the window/wall joint. The farther the offset between the glass in the window and the centre of the insulation in the wall, the larger the thermal bridge. To evaluate how the thermal bridge at the window/wall joint is influenced by the recess of the window HEAT2 [7] is used to determine the linear thermal transmittance at the joint. Calculations are performed in accordance with ISO 10211 [8]. The 3-dimensional effects at the corners of the windows will only have limited effect and are not included in calculations. The thermal bridge at the joint between glass and frame was not considered in these calculations since it is not influenced by the recess.

3. Materials

3.1 Climate data

The Danish Design Reference Year (DRY) used in the current analyses is based on observed data from 2001–2010. Denmark has been sectionalized into five to six climatological zones depending on the parameter, each characterized by distinct diurnal and yearly variations. The dataset consists of observed data from one station located within and representing each zone.

The parameters included in the dataset are temperature, relative humidity, wind speed and direction, atmospheric pressure, global radiation, cloud cover, soil temperature, sea temperature, diffuse irradiance, and illuminance. The time resolution is hourly except for soil temperature where the resolution is daily values [5]. The reference year is constructed from twelve typical months during 2001 – 2010. Measured data from 2005-2019 has been used for analyses of the actual variations of risk of condensation over the measuring period.

3.2 View factors

For a point on a horizontal surface as a roof the solid angle is 2π to the sky. For a wall the solid angle to the sky is π and the solid angle to the earth is also π. This is the case also for a window in line with the outer wall surface. The solid angle for the top of a pyramid can be calculated with formula (2) with length *a*, width *b* and height *d* as follows:

$$\Omega = 4 \arctan \frac{ab}{2d\sqrt{(4d^2+a^2+b^2)}} \tag{2}$$

This formula also calculates the view field for the centre of a window with width *a*, height *b* and a recess of *d*. The results in Table 2 is given as relative to the case with no recess.

Table 2. Relative view factor (F_{recess}) for different window sizes and recesses.

Recess (m)	Window 0.6 m · 0.6 m	0.6 m · 1.2 m 1.2 m · 0.6 m	1.2 m · 1.2 m	1.2 m · 2.4 m 2.4 m · 1.2 m	2.4 m · 2.4 m
0.00	1.000	1.000	1.000	1.000	1.000
0.05	0.852	0.883	0.926	0.941	0.963
0.10	0.713	0.771	0.852	0.883	0.926
0.15	0.591	0.669	0.781	0.826	0.889
0.20	0.487	0.579	0.713	0.771	0.852
0.25	0.402	0.502	0.650	0.719	0.816

The view angle is the same for a horizontal size window 0.6 m · 1.2 m and a vertical size window 1.2 m · 0.6 m. Note that these two windows will not give the same result for solar radiation.

4. Results

The depth of the recess plays an important role for solar energy entering the room, but equally important is the total transparent area in the room. **Figure 1** shows the annual heating and cooling need in combination with the annual solar gain for combinations of south facing windows. The results are thus a result of varying transparent area and varying recess i.e., an increasing number of windows result in a decrease in total transparent area. However, for all window configurations, the depth of the recess has a strong negative impact on the solar gains and the energy need for heating. Increased recess depth, on the other hand, have a positive impact on the cooling need.

Figure 2 (left) shows the variation of the same three KPI's for different orientations (south to east in increments of 15°) of two 1.2 m · 1.2 m windows with a recess depth of 0 and 0.25 meters, respectively. However, Figure 2 (right) shows the relative values and the KPIs and here is it clear that solar gains and consequently also cooling needs are less influenced by the orientation for large recesses.

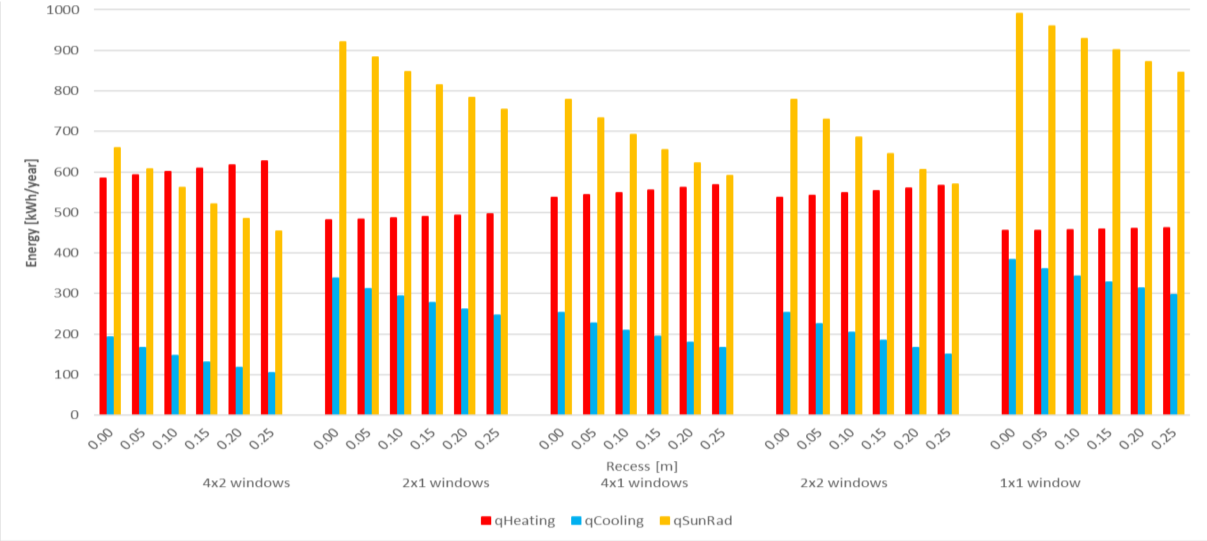


Figure 1. Impact on KPI's from varying window configurations and recesses for South facing windows.

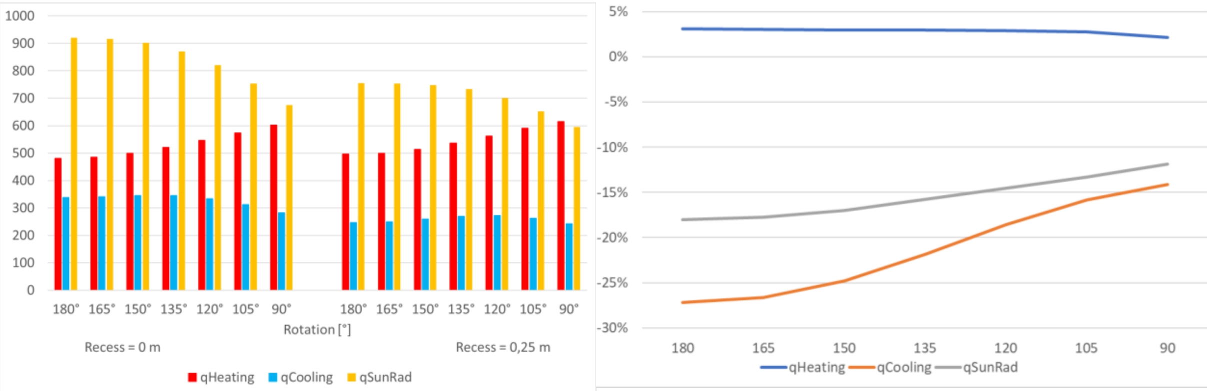


Figure 2. Impact on KPI's on two 1.2 m · 1.2 m with no recess (left) and 0.25 m recess (right) in a model with different window orientations (left) (south = 180° and east = 90°), and relative KPI's for the two different recesses (right).

Calculated hours of external condensation for a window with glass in line with the wall, i.e., with no recess, is seen in Table 4. For normal glass (emissivity 0.837) the U-value is the most important factor. For an old window with U=2.8 W/(m²K) the number of condensation hours is very low. For a 1.6 W/(m²K) window around 100 hours with condensation does not present a problem. But the number of hours increase for U = 1.1 W/(m²K) to around 200 and for U=0.6 W/(m²K) to 400-500 hours. Condensation is a problem for a window with a U=0.6 W/(m²K). Using a low energy coating with an emissivity of 0.2 on the outer glass pane will remove the problem as also shown in [3] and [4]. However, a low energy coating will influence the solar gains and potentially also the quality of daylight negatively. The table also shows that the number of hours will increase for a lower local wind speed.

Table 3. External condensation hours in relation to U-value, emissivity, and wind factor.

Local wind factor [-]	0.6					0.2				
Emissivity [-]	0.837				0.2	0.837				0.2
U-glass [W/(m²K)]	2.8	1.6	1.1	0.6	0.6	2.8	1.6	1.1	0.6	0.6
Number of hours [-]	6	83	185	419	0	11	110	236	552	4

It is possible to calculate the effect of the recess for all the different U-values, but we have selected the worst case with U-value of 0.6 W/(m²K) and a low wind speed factor of 0.2 as seen in Figure 3.
By increasing the recess from 0 m to 0.20 m the number of hours with condensation is reduced to 14% (or 72 hours) compared to a window in the plane with the wall. For a large window of 2.4 m times 2.4 m a recess of 0.20 m reduces condensation hours to 28%. This could still be an important reduction of the complaints from exterior condensation.

Figure 4 shows the variation of the condensation during the year for a window with no recess. There are 552 hours with condensation in total. As seen in Figure 4, June and July have many hours with condensation, but this is not a practical problem as condensation occurs around 5 in the morning and most people do not rise until 7. At that time the condensation is removed by evaporation from the rising sun. The interesting number is condensation hours after 7 which is approximately 88 hours. The problem is mostly seen in September and October where most people will see it when they rise. Using a recess will reduce the condensation hours both for the whole year and for the critical hours when people can see it after 7 in the morning.

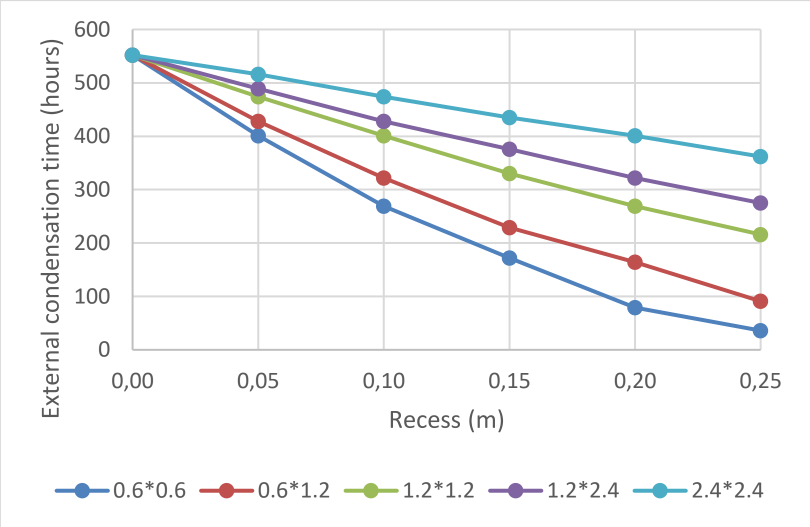


Figure 3. Number of condensation hours in the DRY year, depending on window size and recess.

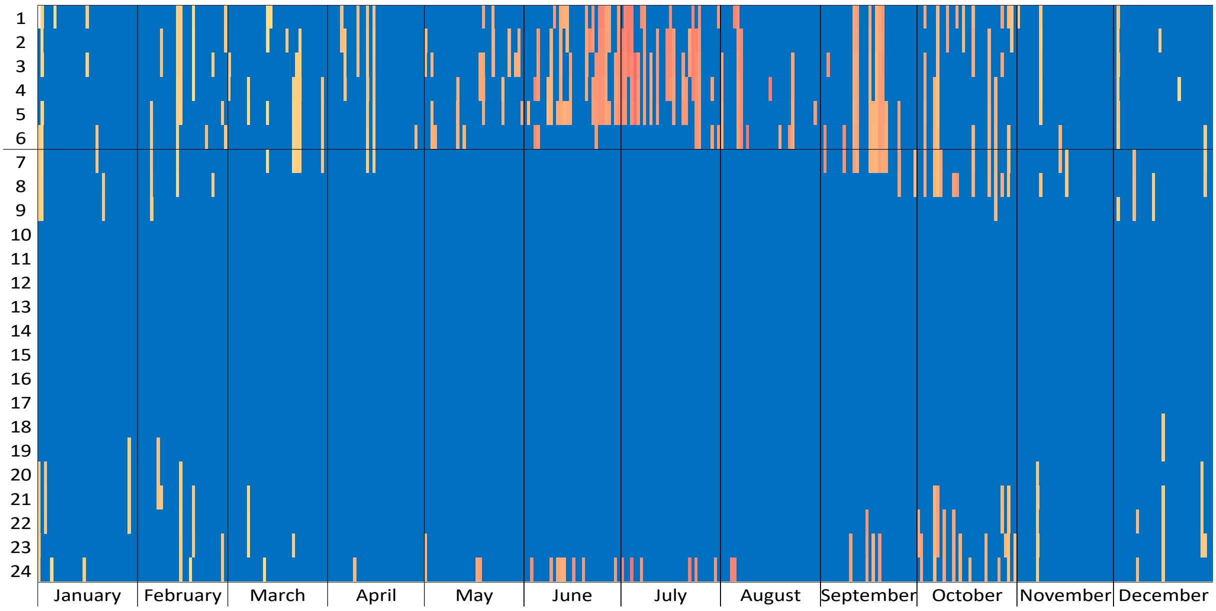


Figure 4. Variation of condensation over the year and time of day for the reference year (DRY).

4.1 Thermal bridges

Recess depth influences the thermal bridge at the window-wall joint, i.e., increased displacement of windowpane from insulation centre will increase the thermal bridge. **Figure** 5 shows the relation between the window recess and the resulting thermal bridge. Results are relevant for a traditional Danish wall consisting of (from inside) 150 mm lightweight concrete, 250 mm insulation and 108 mm brick.

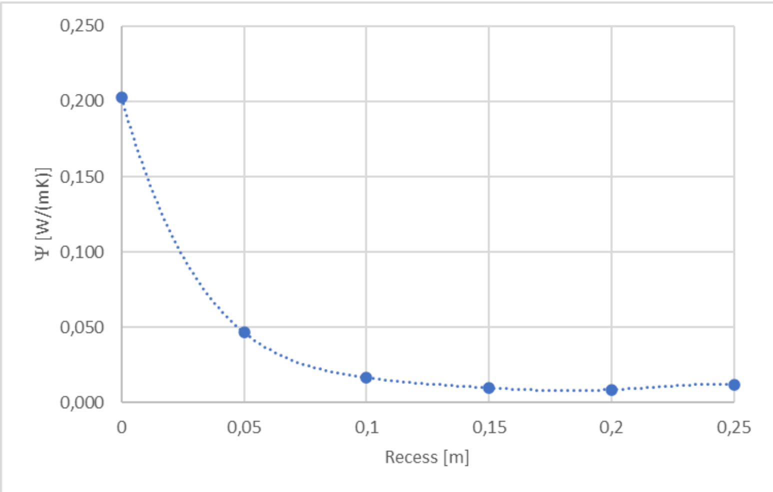


Figure 5. Thermal bridge effect at the window-wall joints as a function of the recess.

A recess of 21.5 cm would mean that the windowpane was placed in exact alignment with the centre of the insulation in the wall, i.e., corresponding to the minimum thermal bridge effect. For the wall segment analysed in this paper with a total area of 3 x 4 meters and a window area 2.88 m^2, the resulting extra heat loss per year due to thermal bridges can be determined as shown in Table 4.

Table 4. Window/wall joint thermal bridge annual heat loss (Danish climate).

Recess [m]	0.00	0.05	0.10	0.15	0.20	0.25
Heat loss [kWh]	271	62	22	13	11	16

Comparing the numbers in Table 4 shows that the minimum annual heat loss through the joints is approximately 11 kWh and the maximum is approximately 271 kWh. For comparison the annual 1-dimensional heat loss through the wall segment is approximately 80 kWh, i.e., the thermal bridges can increase the total heat loss through the wall by up to 340% if the window is placed in line with the façade. To compensate for this extra heat loss, e.g., window U-value would need be decreased by 1.4 W/(m^2K), which is not possible for typical windows used today.

5. Discussion

The results in this paper are based on the Danish reference year and for a window with a glass centre U-value of 0.6 W/(m^2K) placed without a recess – in plane with the wall.

Measurements of condensation in Borås [2] shows that there are large variations from year to year as the number of clear days depend on the actual climate for each year. Laukkarinen et al [4] has made calculations for different locations in Finland with different climate data. This again demonstrated large variations in external condensation from year to year.

Using measured meteorological data from the Danish weather station Sjælsmark (north of Copenhagen) from 2005 to 2019 it is possible to give an indication of the variation as a count of hours with the relative humidity is above 98% and when there is no global radiation. The number of hours per year is also given as relative to the average value. One year (2012) have 85% more hours with possible condensation and another have 68% less (2010) the average. So, it is impossible to predict how many hours of condensation will occur in a year. Predictions of energy use are much more reliable, as the variations in important parameters from year to year are much lower.

Table 5. Number of hours with external condensation in different years from which the design reference year is created.

Year	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	Avg.	DRY
Hours	487	688	619	993	896	190	638	1115	885	353	258	487	672	320	427	602	594
%	81	114	103	165	149	32	106	185	147	59	43	81	112	53	71	100	99

Solar gains and risk of external condensation on windows are closely connected, though the two have no direct connection. Windows with a high degree of solar gains are typically located with no or very limited recess and/or with a large contiguous glass area. The calculated need for cooling to maintain a uniform thermal summer comfort is also closely connected to the solar gain, resulting in an increased energy need for cooling or increased risk of summer overheating. On the other hand, increased solar gains will decrease the need for heating during the heating season.

6. Conclusion

Modern houses often have large glass areas placed in line with the external facade with limited or no overhang and that in combination with the high level of insulation in general and the low U-values of the windows specifically will increase the risk of overheating the building during summer. In addition, this configuration significantly contributes to an increased risk of external condensation on the windows and increased heat loss from thermal bridges.

Placing the window with a recess of 10 cm or more will give a reduction in the cold bridge of more than 90% (see Table 5). Using a deeper recess for the windows will also reduce the solar radiation and the overheating and at the same time reduce the number of external condensation hours. For instance, for a wall with two south facing windows of 1.2 m · 1.2 m with a recess of 20 cm the solar radiation is reduces by 15% and the cooling load is reduced by 23% (see Figure 1) compared to the same window configuration with no recess and the times with external condensation by 29% (see Table 2).

Deepening the recess is a practical method to improve the thermal comfort in the building with less overheating, reduce the thermal bridge at the window/wall junction and reduce the time with external condensation. The actual hours will depend on the climate in the particular year.

7. References

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