Heat Load Calculations and Passive House Requirements in Northwest European Climates

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1 Introduction

What does it mean to build Passive Houses in Northwest European climates outside of Germany? The basic idea to improve energy efficiency just so much that a separate heat distribution system is not necessary any more – and thereby reduce investment costs – holds for all climates. This limit is roughly equivalent to a maximum space heat load of 10 W per square meter living area, independent of the climate. This paper addresses the question which measures are required in order to achieve this goal in the climates of Northwest Europe.

By means of dynamic building simulation, heat load design data were established for use within the heat load calculation procedure of the Passive House Planning Package [PHPP 2004]. The procedure takes into account internal and solar gains as well as the thermal inertia of the building.

The resulting design data were then used to determine the required insulation levels of an example building for a heat load of 10 W/m², the corresponding annual space heat demand, and the effects of changing the area of the south facing windows on heat load and space heat demand. This study was performed for at least one location in the partner countries of the PEP project, i.e. Austria, Belgium, the Netherlands, the UK, Ireland, Denmark, Norway and Finland, using an identical building geometry and identical internal gains.

2 Example Building Geometry

The study was performed using the example contained in the PHPP. This example is basically an end-of-terrace dwelling unit in the first Passive House, which was built in Darmstadt-Kranichstein, Germany, in 1991. The building has a relatively good ratio of exterior area to enclosed volume (0.59 m^{-1}), is facing due south and has large south facing windows (30.4 m² gross window area, 19.9 m² glazed area in an overall 74 m² façade). Like the original house in Darmstadt, the example is assumed to be very airtight (n_{50} = 0.22 h^{-1}) and to have a highly efficient heat recovery and a subsoil heat exchanger (η_{total} = 0.87).

Figure 1: The first Passive House in Darmstadt-Kranichstein which was used as an example in this study

3 Technical Limits

3.1 Window Quality

In Germany, Passive House windows typically have overall U-values of 0.85 W/(m²K) including the thermal bridge resulting from the installation in the wall. This is achieved with highly insulating window frames and triple glazing with low-e-coating and argon gas filling. The glazing U-value would then be 0.7 W/(m²K). In northern climates, it may be necessary to use even better windows. Triple glazing with Krypton filling can achieve U-values of down to 0.51. All current Passive House frames have about the same insulation level, which is quite close to the limits imposed by the certificate “component suitable for Passive Houses”. The thermal quality of window frames can still be improved, though. First estimates showed that a standard size (1.23 m x 1.48 m) window with an improved frame, very good triple glazing and good installation in the wall ($\Psi_{inst} \approx 0$) would have a U-value of 0.56 W/(m²K). With two standard low-e double glazing layers, each in a good frame and combined to form a casement window, a U-value on the same order of magnitude is possible. The total solar transmittance g of triple glazings is typically slightly above 50 %. Glazing units with multiple plastic films or quadruple glazing would even allow for window U-values below 0.5 W/(m²K) whilst g-values will decrease to ca. 40 %.

In the following for cold climates, we assume that windows with a total U-value of 0.6 W/(m²K) and a g-value of 0.5 can easily be made available.

3.2 Insulation of opaque building elements

On rare occasions, buildings have been built with up to 60 cm of insulation in the roof. The thermal conductivity of the insulation being 0.035 W/(mK), this would result in a U-value below 0.06 W/(m²K). For walls, exterior insulation and finish systems (EIFS) with a thickness of 40 cm are registered as standard building products in Germany, resulting in a U-value of ca. 0.085 W/(m²K).

We therefore assume that U-values of 0.08 W/(m²K) for walls and 0.06 W/(m²K) for roofs can be realized.

3.3 Heat recovery

It is sometimes considered doubtful whether heat recovery works in cold Northern European climates: Due to the low temperatures, freezing of the heat exchanger might occur frequently, which would result in a reduction of the achievable annual efficiency. It appears that due to low humidity levels in the buildings, this problem is not very significant in practice. It can be overcome by using rotary wheel heat exchangers or by preheating of ambient air with subsoil heat exchangers.

4 Results

For each climate zone, we tried to identify a typical solution for a heat load of 10 W/m² (including safety margins). In a first step, this was done by adapting the insulation level of the opaque parts of the shell; if that was not sufficient, the window quality and size were also changed.

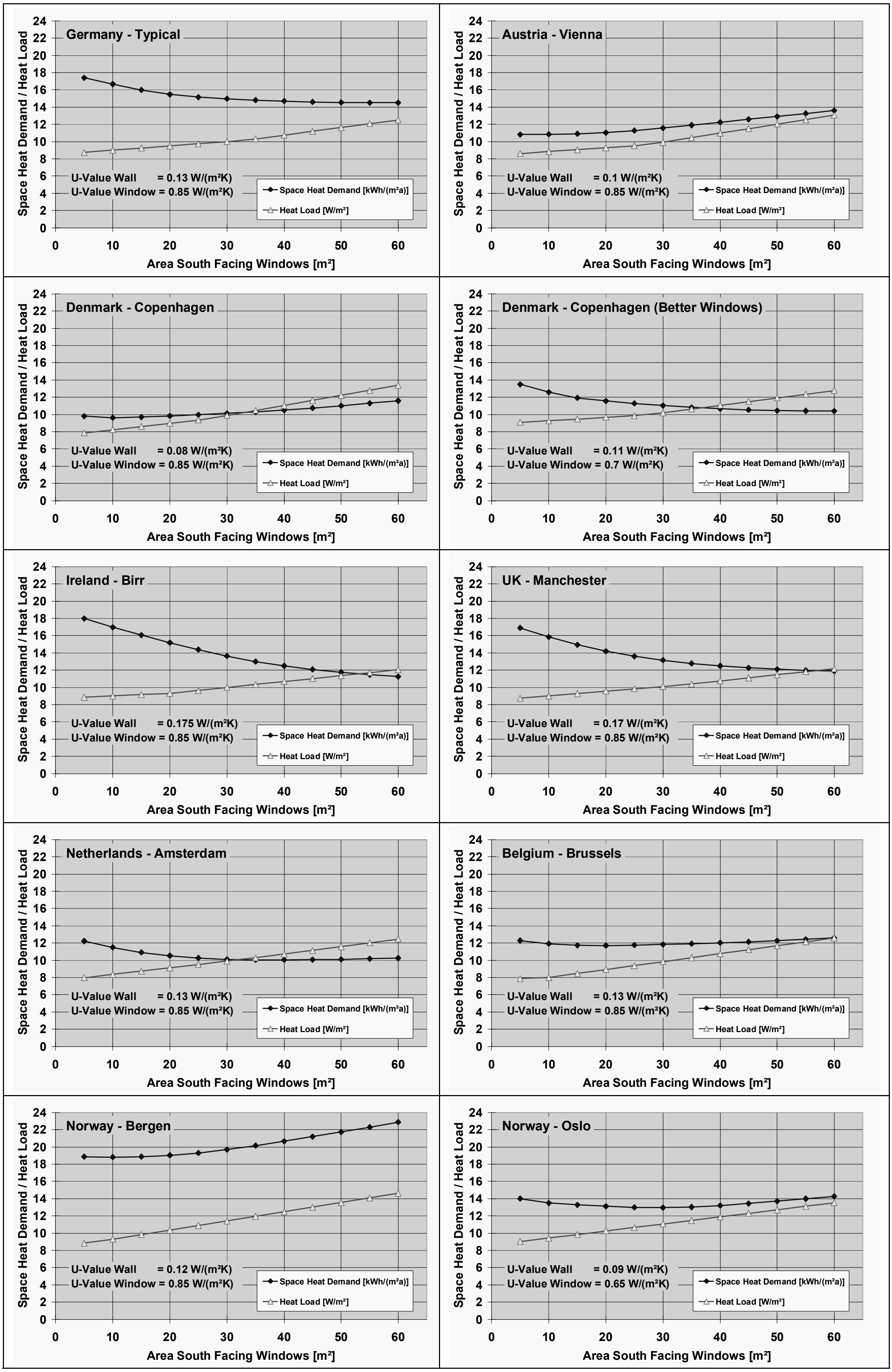
In the following diagrams, for reasons of simplicity, the U-values of the floor are always the same as for the walls, whereas the roof U-value is 71 % of this. Total solar transmittance of the glazing is always assumed to be 50 %.

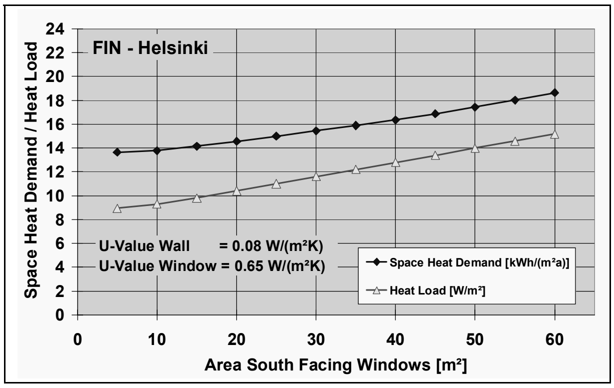
The climate data for **Germany** are based on an example climate data set from the PHPP. U-values for the walls have to be about 0.13 W/(m²K). Typical Passive House windows with an overall U-value of 0.85 W/(m²K) must be used.

With increasing window area, the heat load is also increasing, whereas the annual space heat demand is decreasing. In this example, a heat load of 10 W/m² corresponds nearly exactly to a space heat demand of 15 kWh/(m²a).

For **Vienna**, climate data from [ASHRAE 2001] formed the basis of the calculations. These data contain a relatively short period with very low temperatures down to -17 °C. Design temperatures in Vienna are therefore lower than in Germany, and more insulation is needed to achieve a heat load of 10 W/m². The standard Passive House windows are still sufficient.

Average solar radiation levels are lower than in the German reference case. Given the window quality used here, larger windows then result in larger space heat demand.


Germany - Typical
U-Value Wall = 0.13 W/(m²K)
U-Value Window = 0.85 W/(m²K)
Austria - Vienna
U-Value Wall = 0.1 W/(m²K)
U-Value Window = 0.85 W/(m²K)
Denmark - Copenhagen
U-Value Wall = 0.08 W/(m²K)
U-Value Window = 0.85 W/(m²K)
Denmark - Copenhagen (Better Windows)
U-Value Wall = 0.11 W/(m²K)
U-Value Window = 0.7 W/(m²K)
Ireland - Birr
U-Value Wall = 0.175 W/(m²K)
U-Value Window = 0.85 W/(m²K)
UK - Manchester
U-Value Wall = 0.17 W/(m²K)
U-Value Window = 0.85 W/(m²K)
Netherlands - Amsterdam
U-Value Wall = 0.13 W/(m²K)
U-Value Window = 0.85 W/(m²K)
Belgium - Brussels
U-Value Wall = 0.13 W/(m²K)
U-Value Window = 0.85 W/(m²K)
Norway - Bergen
U-Value Wall = 0.12 W/(m²K)
U-Value Window = 0.85 W/(m²K)
Norway - Oslo
U-Value Wall = 0.09 W/(m²K)
U-Value Window = 0.65 W/(m²K)
Space Heat Demand [kWh/(m²a)]
Heat Load [W/m²]
Space Heat Demand / Heat Load
Area South Facing Windows [m²]



The climate data set for **Copenhagen** we used (TRY Copenhagen) contains a cold spell with temperatures below -20 °C. This appears rather exceptional if compared to the typical climate on the German coast of the Baltic Sea with -15 °C. This results in relatively low annual space heat requirements at a heat load of 10 W/m². Using the typical window quality, very good insulation of the walls, etc., is required.

In Copenhagen, less solar radiation is available during the heating season than in Germany. Therefore, with the same window quality, larger windows lead to a larger space heat demand. If, on the contrary, windows with U = 0.7 W/(m²K) instead of 0.85 W/(m²K) are used, increasing the area of the south facing windows results in a smaller annual space heat demand. Better windows allow for a substantial reduction in the insulation level of the opaque envelope elements, too. This example shows that for successfully planning a Passive House, a calculation that takes all these effects into account is highly recommendable - simple rules of thumb will not do.

For **Ireland**, measured data from a year which was claimed to be typical for Birr were used. The Irish climate, like others which are strongly influenced by the gulf stream and the thermal buffer effect of the sea, is a lot milder than the German one. Solar radiation levels in winter, on the other hand, are comparable to Germany. Therefore, a lot less insulation than in Germany is required. Under favourable boundary conditions, south facing windows may achieve high net solar gains.

Climate conditions in the **UK** (TRY Manchester) are very similar to Ireland. The results for Manchester are therefore nearly identical to those of Birr.

For the **Netherlands**, Amsterdam data were taken from [ASHRAE 2001]. Insulation requirements turned out to be quite comparable to the German reference case.

The IWEC data for Brussels (**Belgium**) are very similar to those for Amsterdam. In general, there is a little less solar radiation; depending on window size, the space heat demand in Brussels may be up to 20% higher than in Amsterdam.

For **Norway**, two "Representative Design Years for Solar Energy Applications" from IEA-SHCP, Task 9, were available. The first location, Bergen, is renowned for its high amounts of annual precipitation. Being situated at the North Sea, the climate is a lot milder than at other locations at the same latitude. Insulation levels may therefore be chosen similar to Germany. Due to the low solar radiation, though, small windows are advantageous for minimizing the space heat demand.

In Oslo, although it may be reached by large, seaworthy vessels, the climate is substantially less maritime than in Bergen. Minimum temperatures during the night may be as low as -25 °C, but there is more solar radiation available than in Bergen. In order to limit the heat load to 10 W/m², very good insulation and further optimized windows are required.

Helsinki (**Finland**, IWEC data) combines the difficulties of Oslo and Bergen: Minimum temperatures are comparable to Oslo, but radiation levels are close to zero in December and January. In order to build Passive Houses, extremely good insulation, small, highly insulated windows and a compact building shell will be required.

5 Conclusions

The results indicate that in most of the respective climates, Passive Houses can readily be built with components that are available on the market. In Ireland, the UK and the Benelux countries the climate turned out to be less challenging than in Central and Northern Europe. Only inland climates in Northern Scandinavia, with design temperatures down to -20 °C, appear to pose some difficulties: They may require very compact thermal envelopes, wall and roof U-values significantly below 0.1 W/(m²K) and windows with overall U-values of about 0.65 W/(m²K).

6 Acknowledgements

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7 References

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