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Skarning, Gunnlaug Cecilie Jensen; Svendsen, Svend ; Hviid, Christian Anker

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INVESTIGATION AND DESCRIPTION OF EUROPEAN BUILDINGS THAT MAY BE REPRESENTATIVE FOR “NEARLY ZERO” ENERGY SINGLE FAMILY HOUSES IN 2020

G.C.J.Skarning[1]; S.Svendsen[1]; C.A.Hviid[1]

1: Department of Civil Engineering, Technical University of Denmark, Section of Building Physics and Services, DK-2800 Kgs. Lyngby.

ABSTRACT

As part of European energy politics and strategies for reduction of fossil fuels all new buildings should have a “nearly zero” energy consumption in 2020. This creates a strong need for research in cost-effective technologies and solutions that will contribute to the fulfilment of the ambitious energy reductions without compromising desirable daylight conditions and indoor climate. This development requires knowledge about the demands and possibilities of the low energy building mass of the future. An important basis for the research within this field will therefore be the establishment of a set of reference parameters that can be expected to be representative for the behaviour of the “nearly zero” energy building of 2020 in different European climatic zones. This paper provides an overview of how single family houses with a very low energy demand for space heating and cooling can be approached by rational and conventional means in three different European climates: Rome, Bratislava and Copenhagen. Special attention is paid to the role of windows and their contribution to solar gains in these well-insulated buildings of the future. By a neutral treatment of the window configurations towards different orientations, where the windows in all rooms are dimensioned based on the diffuse daylight access at the specific location, it is shown that an equal window distribution will allow fulfilment of an ambitious energy target, while simultaneously enabling a balanced daylight access across the building and a comfortable indoor climate. Furthermore, the analyses indicate that the ability of these well-insulated buildings to utilise solar gains is highly restricted, even at the location of Copenhagen. Window panes with a solar control coating seem to be an appropriate protection against overheating for all three locations.

Keywords: Building parameters, European climates, energy, daylight, windows, solar gain.

INTRODUCTION

The establishment of cost-optimal levels for energy requirements is a task requiring several considerations, spanning from future energy prices and discount rates to local possibilities. According to the guidelines accompanying the Commission Delegated Regulation (EU) No 244/2012 on the energy performance of buildings, it is the responsibility of the member states to set minimum energy performance requirements for their buildings with a view to achieving cost-optimal levels. This paper aims at providing an example of how buildings with a low energy demand for space heating and cooling can be achieved based on a selected target. The analyses are the first step towards a more detailed study on how windows with optimal properties for the energy frame in 2020 can be developed. For this reason, special attention is paid to the link between the building behaviour and the windows. The overall building performance must be transparent to the effect of orientation, window configuration and room distribution, and it must be possible to trace both the heating and cooling demand back to a specific room with a specific orientation and window fraction. Furthermore, daylight conditions, energy demand and thermal environment must be evaluated at room level and the behaviour of rooms with different orientation must be comparable.

The daylight access is considered an unquestionable aspect of the building performance, thus all solutions are created in accordance with an ambitious daylight target. The analyses will lead to a suggestion on low energy solutions for each location, followed by parameter variations on how these solutions are affected by different glazing properties.

METHOD

In accordance with the criteria above, the symmetrical building set up in Figure 1 is chosen.

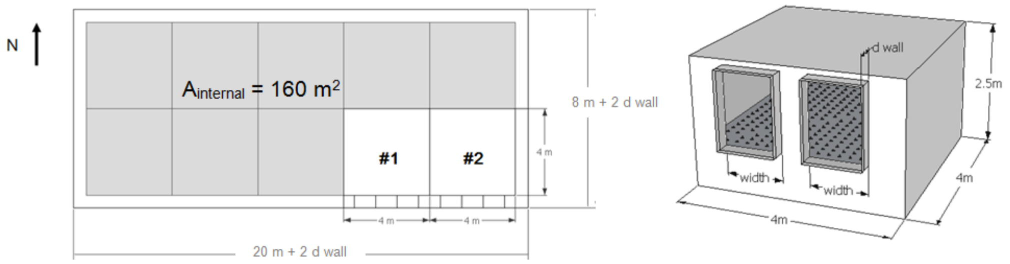


Figure 1: Building set up. The building is composed by equal quadratic rooms and oriented South-North for neutral treatment of room composition, window distribution and orientation.

A building with internal floor area of 160 m^2 is composed by 10 equal quadratic room modules with the internal dimensions 4 x 4 x 2.5 m. All modules are side-lit by two windows and the variable dimensions are the wall thickness and window width. These will depend on the amount of insulation and window size needed in order to reach the selected targets for both energy and daylight. The building is oriented South-North and the relevant room types are evaluated separately. As the transmission area in rooms located at a building corner (#2) is significantly larger than in the rooms positioned in the middle (#1), all results will be derived from the individual area weighted performance of these two room types. The heating and cooling demands are given for the two building halves facing South and North respectively and for the building in total.

Locations and climate

The locations Rome, Bratislava and Copenhagen are selected for the study, representing three different latitudes and two different longitudes at the continental part of Europe (Figure 2).

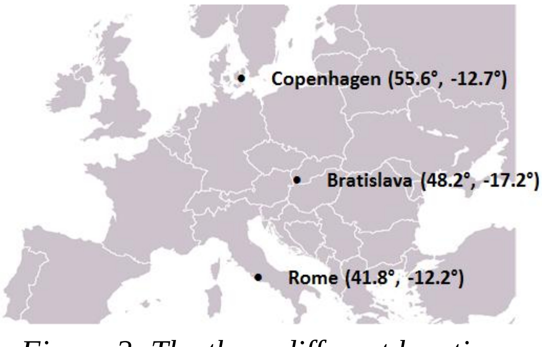


Figure 2: The three different locations.

Both a room’s heating and cooling demand and its access to daylight are climate-dependent. The access to light and solar gains decreases nearly linearly from Rome in South to Copenhagen in North, while Bratislava is positioned in between. Moreover, Rome and Copenhagen represent coastal climates with rather small temperature differences between summer and winter, whereas Bratislava, which is located in the central parts of Europe, experiences large temperature variations from -20°C in winter to 30°C in summer [1].

Windows dimensioned according to the availability of diffuse light at the location

In order to create building solutions with comparable daylight conditions across the different climates, the windows are dimensioned for an occurrence of 300 lux in 50 % of the light hours at 50 % of the work plane under the diffuse daylight availability at the given location. Target and methodology are selected with reference to the on-going discussions on how European daylight standards can be upgraded in a way that approaches climate-based daylight modelling (CBDM), which delivers daylight predictions under realistic sun and sky conditions [2]. For the purpose of these comparative studies, a simplified methodology from these proposals is chosen, where the effect of the sun and its position is neglected. Under the assumption that the diffuse light access at the locations follows the same graduation in brightness as the CIE overcast sky model, a target daylight factor (DF_{target}) can be derived for the different locations based on the median daylight level required indoors and the diffuse median illuminance available outdoors ($E_{median\ diffuse}$):

$$DF_{TARGET} = \frac{300\ lux}{E_{MEDIAN\ DIFFUSE}} \tag{1}$$

The DF target values for the different locations and the window fractions required in order to meet the selected target are given in Table 1, along with an illustration of the spatial daylight distribution in the rooms. All calculations are performed with Daysim for comparability with fully climate-based approaches. A diffuse reflectance of 70 % is assumed for walls and ceiling and a reflectance of 30 % for floors.

Heating and cooling demand based on EN ISO 13790

For comparison across the countries, all buildings are optimised with off-set in the same energy target. After subtraction of energy needed for ventilation fans, pumps and domestic hot water, the target for the annual space heating and cooling demand is set to 13 kWh/m^2.

The heating and cooling demands are calculated according to the hourly method with simplified input-parameters described in EN ISO 13790. The method simplifies the heat transfer between the external and internal environment, but distinguishes between the internal air temperature and the mean radiant temperature. This enables its use in principle for thermal comfort checks [3]. Standard set-points of 20°C and 26°C are used for heating and cooling respectively. Venting is controlled based on a set-point of 23°C and solar shadings are modelled by means of a simplified shading factor. Movable solar shadings are activated when the irradiation on the external window surface exceeds 300 W/m^2. The calculations are performed with the program WinDesign, developed at the Technical University of Denmark. Climate files are collected from the U.S. Department of Energy's homepage [2].

General building specifications and assumptions

Mechanical ventilation with heat recovery and the constant air change rate of 0.6 h^{-1} is applied all year in order to ensure an indoor air quality in accordance with EN 15251. A high heat recovery efficiency of 90 % with bypass during the cooling season favours comfortable supply temperatures and keeps the ventilation losses to a minimum. As a simplification the infiltration rate is set to 0. Natural ventilation with a maximum venting rate of 3 h^{-1} is used in order to reduce the overheating and cooling demands. The internal gains from people, equipment and lighting are 5 W/m^2 and the thermal capacity 260,000 J/K m^2. In general the building envelope holds a high quality and all connections are constructed for minimum heat losses (see footnote in Table 1).

RESULTS

The building parameters that are directly related to the fulfilment of the energy and daylight targets are now restricted to *insulation thickness*, *window size* and *glazing properties*. Reasonable values for these parameters are selected through iterations between window optimisation for daylight, insulation thicknesses required for energy and reasonable choices of glazing properties. The suggested set of building parameters are given in Table 1 and Figure 3 illustrates the heating and cooling demand of the solutions.

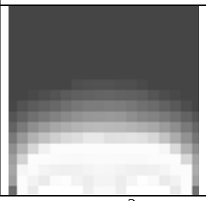
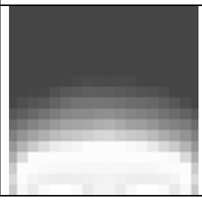
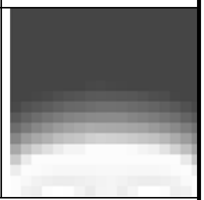
Variable building parameters		**Unit**	**Rome**	**Bratislava**	**Copenhagen**
Insulation*	Insulation thickness	mm	125	300	250
	Wall thickness	m	0.325	0.500	0.450
	U-value, wall	W/m^2 K	0.20	0.10	0.12
	U-value, roof/floor	W/m^2 K	0.14/ 0.11	0.06/ 0.05	0.07/ 0.06
Window size	Fraction of internal floor area	%	24	30	32
Glazing	Type	-	2-layer	3-layer	3-layer
	U-value	W/m^2 K	1.0	0.5	0.5
	g-value	-	0.27	0.27	0.27
	TL	%	50	50	50
Daylight	DF target	%	1.56	1.84	2.11
	Spatial distribution of daylight target. Dark area: DA $300_{diffuse}$ < 50 %				
*) Additional properties of the building envelope; U_{frame} = 1.34 W/m^2 K (width = 0.057 m, ψ = 0.33 W/m K), $\psi_{window/wall}$ = 0.01 W/m K and $\psi_{foundation}$ = 0.13 W/m K. Insulation in roof/floor is the double amount as in walls.					

Table 1: Suggested values for the climate-dependent building parameters.

Triple glazings are needed in Bratislava and Copenhagen, whereas double glazings are found sufficient in Rome. Although Bratislava is located in a southern climate relative to Copenhagen, the large variations between summer and winter force the insulation thickness to exceed Danish levels. Glazings with a solar control coating and a g-value of 0.27 are selected as a cheap mean for control of overheating. In Copenhagen, where there are no traditions for mechanical cooling, the decision is based on whether the comfort limits can be met without additional solar shadings or not. This was found possible with the selected g-value of 0.27.

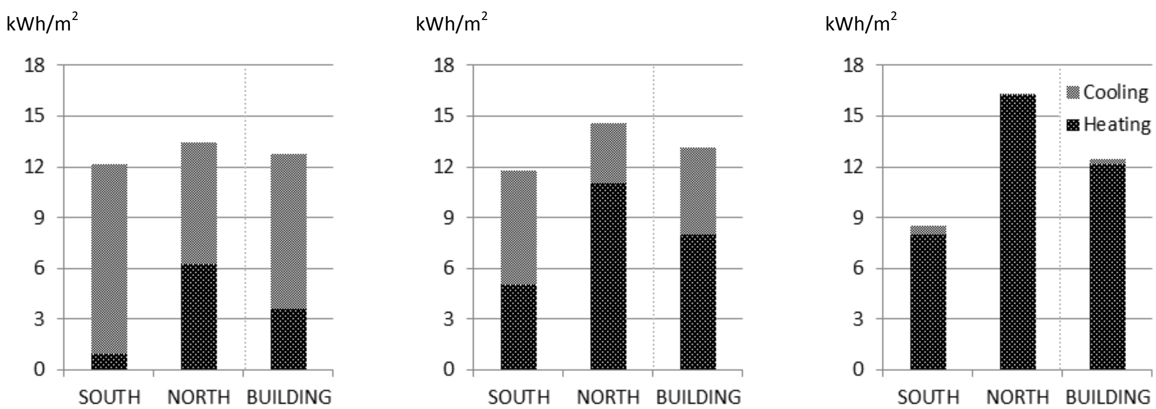


Figure 3: Energy demand of the solutions. From left: Rome, Bratislava and Copenhagen.

Figure 4 and Figure 5 show parameter variations on the window glazing properties, with the building solutions suggested above indicated with the grey line labelled “ref”.

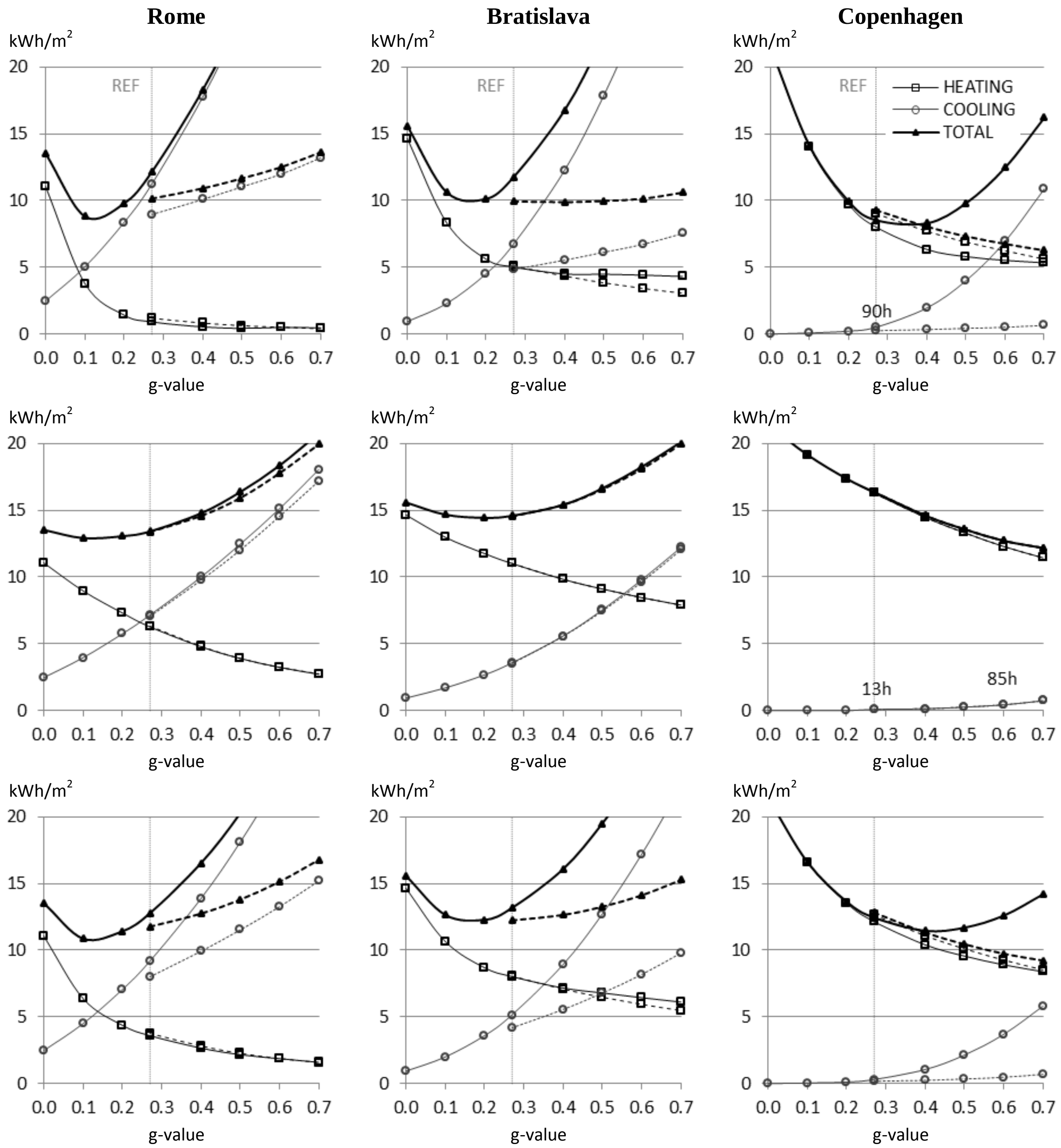


Figure 4: Heating and cooling demand as a function of g-value. From top: South, North and the building in total. Dashed lines represent the addition of movable solar shadings with shading coefficient 0.2 when activated. Equivalent overheating is indicated for Copenhagen.

DISCUSSION

In Rome and Bratislava the optimal g-values are found in the range of 0.1 - 0.2 for both orientations. This indicates that even the diffuse solar gains in rooms facing North contributes to more overheating than they reduce the need for space heating. The g-value’s effect on the heating demand stagnates around this level in rooms facing South. Furthermore, the positive effect of low g-values seems to override the potential energy saving by choosing smaller windows with higher light transmittances. Smaller windows would however be favourable if the solar loads could be kept down by movable solar shadings or other means. For this purpose a potential may be found in the use of fully climate-based methods for daylight optimisation. This may allow further reductions of window area in the rooms that are most exposed to direct and indirect sun. In Copenhagen the optimal g-value is found at 0.4 for the building in total. This contradicts the current practice in Denmark, where high g-values are favoured by the energy rating system for windows. Furthermore, the flexible range of this optimum may open new development possibilities for the related glazing parameters. In a room oriented towards the North, higher g-values are still favourable and movable solar shadings may in general enable energy savings in Copenhagen. For further conclusions, the cooling demands must be verified by a reliable program. Moreover, the robustness of the findings to changes in internal gains and other building parameters must be investigated.

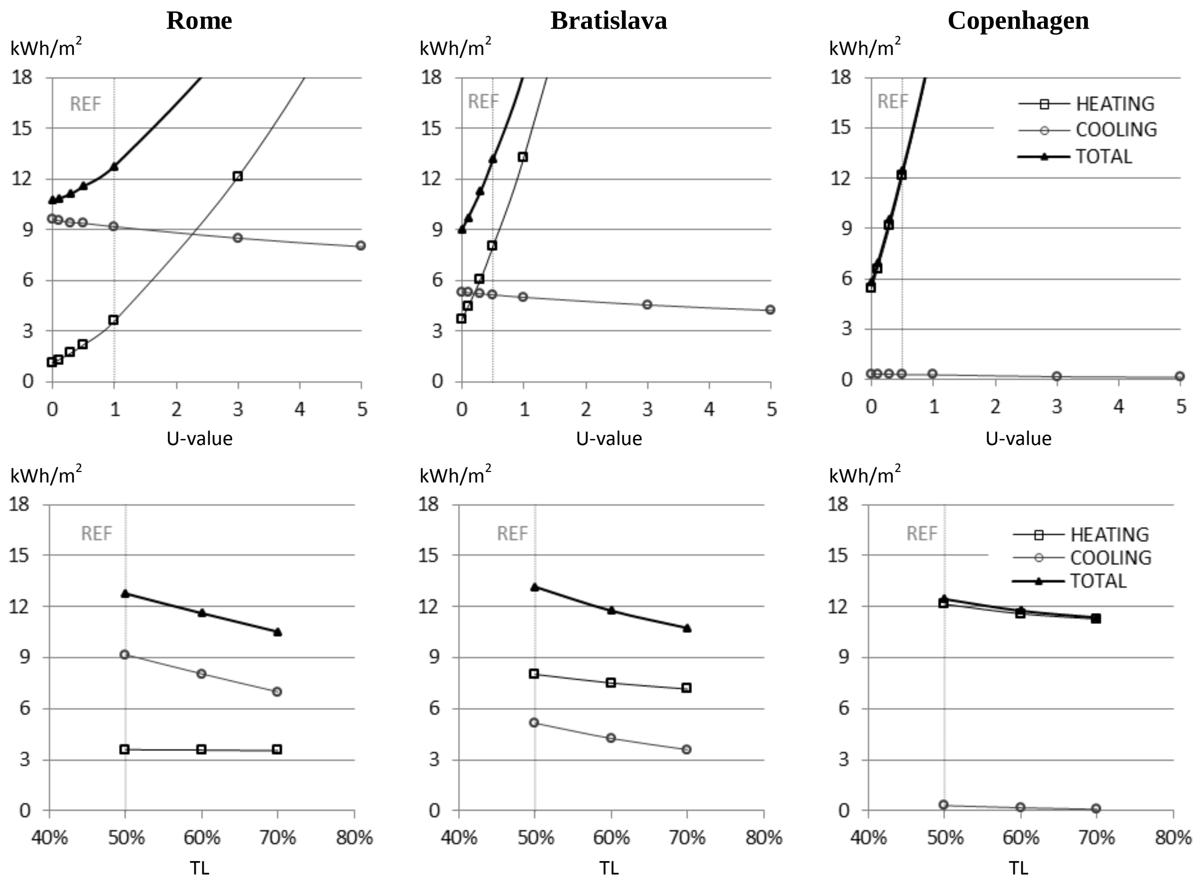


Figure 5: Building heating and cooling demand as a function of glazing U-value (top) and light transmittance (bottom), given that the window fraction is adjusted for sufficient daylight.

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