EFFECT OF PASSIVE SOLAR GAIN ON THE HEATING ENERGY CONSUMPTION AND PEAK LOAD OF THE SYSTEM

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ABSTRACT

Total heating energy need in its entirety equals to the heat loss. It is covered by utilised passive solar gain, internal gains and the heating system. The last can be decreased offsetting by passive solar gain. At peace with higher peak load considerable energy saving is possible – low built-in capacity does not guarantee low heating energy consumption. The effects of orientation, glazed ratio and heat storage have been analyzed, applying strict elementary requirements of current national regulations. Simulations prove that concepts of classic passive solar architecture are efficient in the case of superinsulated new buildings as well. Interpretation of "renewable share", passive solar gain and heating energy is discussed in the light of European directives.

KEYWORDS: *passive solar gain, glazed ratio, renewable share, regulation.*

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Introduction

The Energy Performance of Building Directive [EPBD 2010] as well as the national regulations implemented according to its concept aims at low non-renewable energy consumption including that of the heating. Besides this final requirement most of the national regulations has further ones, related to the elements of the building and about half of them (according to the state on June 2019) prescribe an obligatory „renewable share".

The elementary requirements are formulated typically as the thresholds of *U* values, sometimes they are accompanied by a threshold of overall heat loss coefficient or the transmission heat loss of a notional or reference building.

Aiming at low heating energy consumption and low built in capacity the elementary requirements are very strict. The strict elementary requirements result in a low heating peak load and suggest on one hand, that the low peak load is their reason, on the other hand create the impression that the low peak load leads to low heating energy consumption. This expectation however seems to be in contradiction with the experiences of classic passive solar architecture. It should be notified that the buildings of classic passive solar architecture exhibit quite good energy performance as far as the heating energy consumption is concerned although they were not well insulated, moreover some of their characteristic constructions (mass wall, Trombe wall) simply excluded the thermal insulation.

Pondering the above facts it seems to be interesting to analyse the interrelation of heating peak load vs. heating energy consumption. In other terms (anticipating our assumption): is it worth to accept higher peak load if it leads to lower energy consumption?

Our analysis focuses on the followings:

– how the lessons of classic solar architecture be applied in super insulated nearly zero energy buildings (in the followings nZEB);

– what is the interrelation of heating energy consumption and peak load;

– how to interpret and account the renewable energy share and the passive solar gain.

Literature review

This literature review is unconventional and brief. Certainly there are several publications on the heating energy consumption of buildings as well as on the utilisation of passive solar gain. Separately these topics are well known and there is no sense to refer the sources since the methods used in the followings do not differ from the long standing ones.

The question of built in capacity for heating is less popular – conventional calculation methods seem to be accepted and free of problem. This general attitude is justified: heat generators' (boilers, heat pumps) power scale is not continuous, the difference between the capacity of two subsequent products is quite big: certainly the only possibility is to select the capacity which exceeds the calculated peak load. Oversizing of heat generator is not favourable (although improves the designers' sense of security), but condensing boiler relieve this problem.

Our analysis focuses on the interrelation of the energy consumption and built in capacity. This question itself is worth of interest however provokes an other one: how to take the solar gains into account in the national regulations and energy certificates?

The actuality of the last question is underlined by the recent directives of the EU. The preambulum of the [EPBD 2010] mentions a crookedly worded "definition" of the nZEB suggesting that significant amount of renewable energy should be used. Some studies of institutes which can be considered as "background" ones of the EU published detailed analysis proving that the "renewable share" should be 50-90% in case of residential and office buildings in many Member States [BPIE 2011a, BPIE 2011b, Ecofys 2012, Boermans T. at al].

We consider their statements as subservience to the expectations of policy makers – effectively realistic only if exclusively biomass is incinerated wherever heat is needed, keeping its primary energy conversion factor at an unrealistic low level.

As a consequence some national regulations interpreted this suggestion as an obligatory requirement and prescribed unrealistic „renewable share". According to [Hermelink A, et al. 2013] Member States distinguish renewable sources for heat production: solar, geothermal, biomass, heat pump. Although this classification is not considered consistent, these forecasts are available (Figure 1.).

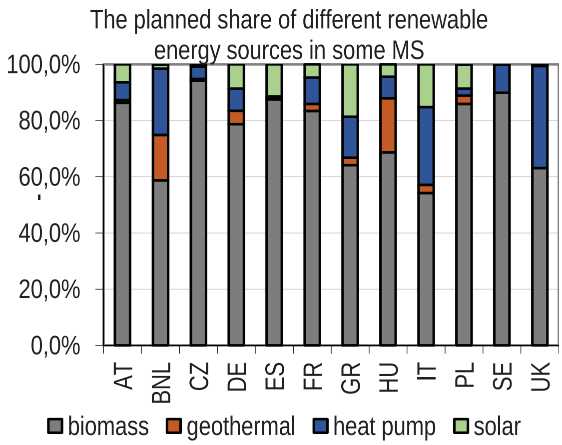

Figure 1. The planned share of different renewable energy sources in some Member States

The predominance of biomass is at least solicitous. Whilst solar energy is inexhaustible on human scale time horizon the reproduction of biomass needs human activity and the available growing area is limited (and is to be shared for fuel and food production). Transport and storage of solid fuel may be a problem in urban area unless district heating is spoken of.

There are several factors which limit the use of solar energy whether it is about heat or electricity generation. These active solar systems need energy collecting elements: even if solar access is not obstructed the roof area comparing with the floor area of a multistory building limit the allocation of enough energy collecting element (collector or PV arrays), sometimes this area is further decreased with elevator engine rooms, fans, cooling towers, boilers, installed on the roof. Other climatic and related energy aspects must not be forgotten, too: experts of urban heat island support the idea of "cool roof" however a roof covered with collectors or PV arrays is anything but not cool since the essence of energy collecting elements is the maximum possible absorbtance.

Regarding the soil as the source of heat pumps limited area of building sites in densely built urban environment allows only the application of quite costly bore holes.

We do not state that the above listed facts would normally prevent the use of the renewable energy systems however the expectable occurrences of the above listed or other barriers mean that compulsory application of any renewable share cannot be recommendable unless we are ready to accept many derogation requests.

Practically each building makes use of solar energy for heating with no technical system or other specific element. Passive solar gain is inevitable, its conscious utilisation is the most natural and simplest option. Nevertheless the role of passive solar gain in the renewable share seems to be disputable due to the inaccurate use of concepts and formal statement of the RES directive [RES 2009]. It declares that "Passive energy systems use building design to harness energy. This is considered to be saved energy."

This statement is misleading: energy for heating as such is not saved! "Only" the energy output of technical heating system can be decreased.

The heat loss of a building in a heating season is

$$Q = \left(\sum AU + 0{,}33nV\right)DH_{\text{climatic}} \qquad (1)$$

where

A – the area of the elements of thermal envelope, m^2;

U – heat loss coefficient, W/m^2K;

n – air change rate, 1/h;

V – heated volume of the building, m^3;

DH_{climatic} is the "climatic" degree hours, for each hour when $t_e < t_i$.

The precondition of the balance is that the same heat should be delivered into the building. It is the sum of different components:

– utilised fraction of direct passive solar gain;
– utilised fraction of indirect passive solar gain (mass wall, Trombe wall, air collector, double skin façade, sunspace,..);
– ventilation through buried pipe;
– heat recovery from exhaust air (heat exchanger or heat pump).

These components of the energy balance do not decrease the heat losses of the building but cover fractions of heat losses and are to be taken into account as heating with renewable energy. The rest of the heat loss is covered by internal gains from non-renewable sources and by the output of the heating system (Fig. 2.).

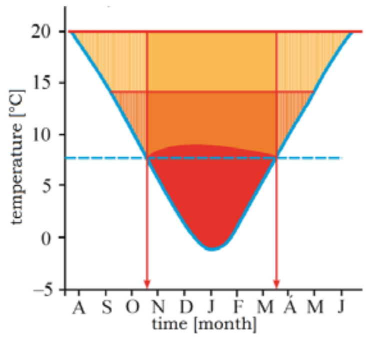

Figure 2. The full area, bordered by the indoor and outdoor temperature is proportionate to the heat loss of the building. The total heating energy need equals to the heat loss. The coloured areas (from the top down) illustrate the total heating energy from: internal gains, utilised passive solar gains and heating system. The term "heating energy need" refers to the last only

The intention of [RES 2009] is acceptable: double counting of utilised passive solar gain must be avoided. It should be considered only once, however correctly, as heating – thus as a component of the renewable share.

Regarding the unexplainable view of [RES 2009] irritating contradictions arise: heat gain from a double skin façade or from an air collector is considered as utilisation of renewable energy if air flow is run by a fan (which requires some electric energy) - why should be excluded the same if the air flow is due to the buoyancy effect?

Methodology

Certainly the problem of peak load versus energy consumption strongly depends on the thermal characteristics of the building elements. Interesting results could be obtained with those of the classic solar architecture and other buildings however currently the strict elementary requirements are to be applied to see how this relationship develops in the case of new buildings.

Attempting to illustrate the problem case studies have been carried out. A simple model has been analysed using Energy Plus v.8.4.0 software for simulation. Regarding the climatic conditions Debrecen (second largest city in Hungary {N 47° 28'} {E 21° 37'})have been considered with the data from ASHRAE HUN_Debrecen. 128820_IWEC files. To check whether the tendencies are very specific or exhibit typical features some simulations have been repeated for Bergen (Norway, {N 60° 17'} {E 5° 13'} with the data from ASHRAE NOR_Bergen. 013110_IWEC files.

The yearly heating energy need (to be covered by the heating system) has been calculated. The peak load has been selected from the hourly data.

The model is shown in Fig. 3.

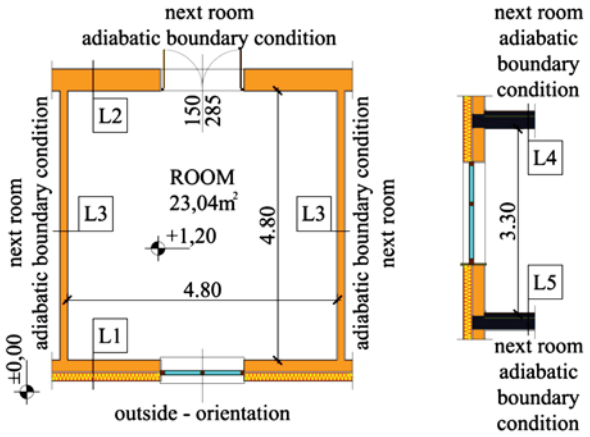

Figure. 3. The layout and section of the model

The starting version represented a massive construction, with brick partition walls, 20 cm reinforced floor slab. The layers of the external wall are masonry blocks, thermal insulation and plaster on both surfaces. The minimum glazed ratio is 4.5%. In this version the total heat capacity of the boundary constructions is 23.872 MJ/K.

The glazed ratio has been varied up to 71,7 % step by step according to the Table 1. Certainly increasing the window area the total heat capacity slightly decreases. In order to see the effect of the heat capacity it has been systematically decreased halving by each step the original or the previous one (Table 2.). Certainly not all versions correspond to a real construction however this approach facilitates to reveal the effect of heat storage in a wide range.

Table 1

Glazed ratio of the façade %	4.5	16.3	23.7	34.9	71.7
Identification on the diagrams	a	b	c	d	e

Table 2

Total heat capacity of the boundary construction with 4.5% glazed ratio MJ/K	23.872	11.936	5.968	2.984	1.492	0.746	0.373
Identification on the diagrams	1	2		4	5	6	7

Heat capacity itself was one of the parameters. It is to be mentioned in advance that the last cannot be specified with the sum of the mass of the first 10 cm of the boundary constructions if a longer weather history of 8-12 days is spoken of – during these days the “deeper layers” of the boundary construction become “active” in storing and releasing heat.

The *U* values are the followings: external wall: 0.24 W/m^{2}K, window glazing: 1.062 W/m^{2}K (Argon gas-filled, three layer 3-13-3-13-3, with Low-e coating, frame: wooden conductance: 0.13W/mK, frame thicknes: 61 mm). The g value of the glazing 0.579.

Continuous air change of 0.5/h and a user profile for residential building are taken into account and perfect automatic control of the heating is supposed.

Different orientations have been taken into account. The problem of summer overheating has been ignored considering that movable shading devices facilitate to radically decrease the cooling load.

Certainly the results gained for isolated cells illustrate well the effect of orientation however real buildings have more exposed facades. There is heat flow between two rooms or zones facing e.g. towards North and South. These heat flows are generated by the difference of passive solar gains and depends on the heat transmittance of internal partition between the zones. These heat flows partially offset the difference of passive solar gains. To demonstrate this phenomenon two cells are joined along their backwall. The heat capacity of this, now internal partition wall are changed step by step according to the change of the heat capacity of the rooms. Changing the glazed ratio the ratio of the strength of thermal connection between the rooms and environment to that between the rooms will change, too. Anticipating our assumption that glazed area may exhibit some kind of optimum which depends on orientation different combination of glazed ratio are investigated: first optimum glazed ratio for both orientations, then a set of equal glazed ratio on both facades.

Discussion

Design peak load

The traditional method of calculation of heating design peak load is based on simple steady state equations. The design external temperature is prescribed either as a conventional value based on experience or derived from statistical analysis at a given risk level. Even a simple steady state equation might include additive components for a conservative value of the daily average passive solar gain (say the diffuse radiation only) and the internal gain. (The last may seem to be risky, however if the building is occupied there *is* some internal gain, if there is no internal gain, the building is empty thus nobody takes care if the indoor temperature is a little bit below the set point.)

Neglecting the usual method of design peak load calculation the peak load of the heating system has been taken from the hourly results of simulations. It occurs in a given hour of the continuous process of the heating regime and depends on the “weather history” of the days before. Taking into account their thermal performance new buildings have a “long lasting memory”, thus the history of eight– ten days is to be considered.

It is a well-known experience that the coldest day of the winter usually occurs in clear windless days when the long wave radiation towards the sky is intensive. (The effect of the wind is low if the building is well insulated and airtight.) It can easily be imagined that if such days are preceded by overcastted days the building will lose its stored heat even if the external temperature is mild. This expectation proved to be correct: regarding the Hungarian test reference year the peak load occurred in the process of such a "weather history" (Fig. 4.). Obviously the date of the occurance of the peak load depends on the building (orientation, glazed ratio, thermal mass) however the tendencies are similar.

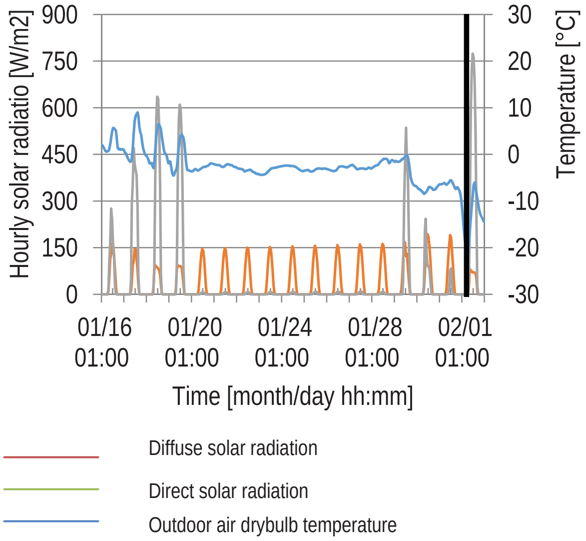

Figure 4. Example of the „weather history" before the occurance of the peak heating load (marked) in Debrecen

Similar phenomenon can be observed in Bergen (Fig. 5.)

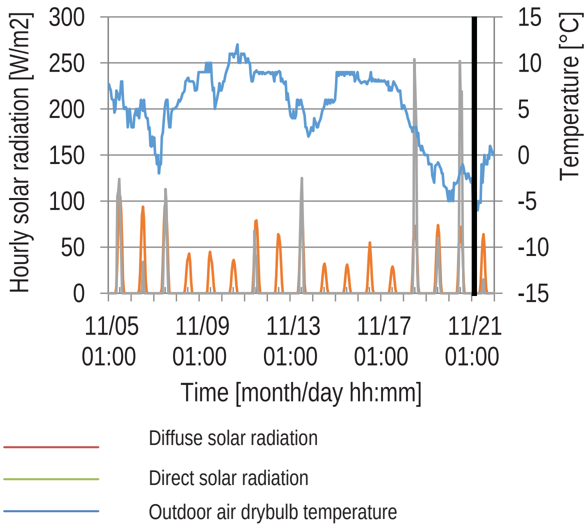

Figure 5. Example of the „weather history" before the occurance of the peak heating load (marked) in Bergen

Certainly different "weather histories" of the whole heating season determine the heating energy consumption.

Energy consumption – orientation and thermal mass

To prevent any misinterpretation it is to be emphasized that the total heating energy need in its entirety equals to heat losses - in the following context the "heating energy need" relates to the energy, required from the heating system. Increasing the glazed ratio of the façade results in higher transmission heat loss and higher solar gain. With given *U* and *g* values. it depends on the orientation whether the augmentation of loss or gain is more intensive. If the augmentation of gain prevails, increasing the glazed ratio from a very low starting value at the beginning the energy need decreases since the excess solar gains will exceed the excess heat loss whilst the gain/load ratio remain modest and most of the gain will be utilised. Further increasing the glazed ratio the solar gain will continuously exceed the heat loss however due to the higher gain/loss ratio less and less fragment of the gain will be utilised. At a given glazed ratio the heating energy need exhibits minimum. In the North-East sector this is at 15-25% glazed ratio however the energy saving is quite modest. For Northern orientation the minimum might occur at an unrealistic low glazed ratio. Nevertheless moving towards East and South the increasing glazed ratio is accompanied by considerable energy saving parallel with increasing peak load (Fig. 6).

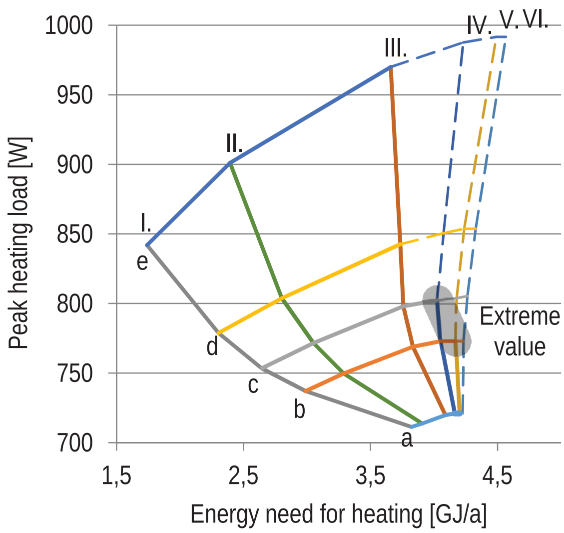

Figure 6. Heating energy need vs heating peak load (Massive building, Debrecen) Orientation: I. – South, II. – South- ast, III. East, IV. East - North-East, V. North-East, VI. – North. Glazed ratio of facade: a – 4,5%, b – 16,3%, c – 23,7%, 34,9%, e – 71,7%.

Figs. 7.-9. exhibit the interrelation of peak load and consumption for Hungarian reference year, for South, East and North orientation. The parameter of the curves is the thermal mass, the crossing trajectories belong to a given glazed ratio.

It can be observed that due to the orientation the augmentation of solar gain is stronger than that of the heat loss for South and – in a less extent – for East orientation. It cannot be applied for North orientation, when the augmentation of the loss is stronger than that of the solar gain.

Analysing the results for South and East orientation it can be seen that a local extreme value occurs which shows a kind of optimum glazed ratio, resulting in a minimum of heating energy consumption at the cost of higher peak load. For massive constructions the glazed ratio can be increased up to the technical limits: the consumption decreases continuously whilst the augmentation of the peak load is relatively slow.

For North facing facades however the smallest glazed ratio – not surprisingly – results in the lowest energy consumption and peak load.

It is obvious that the thermal mass has decisive role in this process. Figurs. 7, 8 and 9 shows the results for Debrecen for different orientations. The parameter of the curves is the heat capacity, that of the trajectories is the glazed ratio. In case of South facing façade there are either optimum glazed ratios or the heating energy need can be decreased up to or beyond 70% glazed ratio. Not surprisingly the less is the heat capacity of the boundary construction the lower is the glazed ratio where the heating energy need is the lowest. The dashed parts of the curves show the parameter combinations which are not rational.

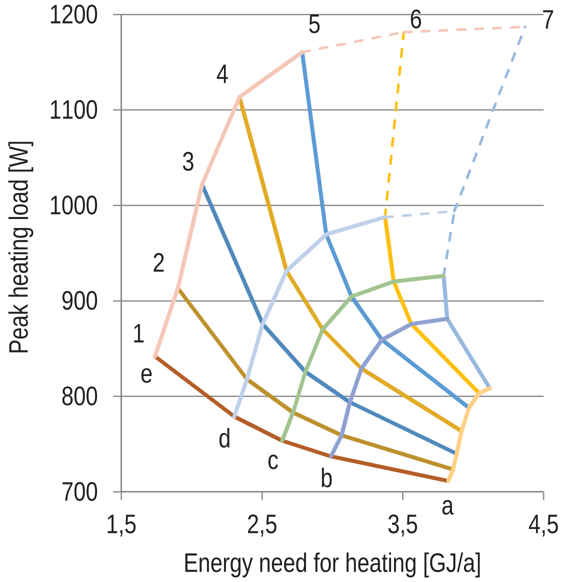

Figure 7. Heating energy need vs. heating peak load, South orientation, Debrecen. Parameters: 1…7 heat capacity (decreasing), a…e: glazed ratio (increasing), identifications are given in Tables 1. and 2.

In the case of East orientation similar phenomena can be observed. Evidently the minimum energy need belongs to smaller glazed ratio comparing to the Southern orientation.

No doubt, the “price” of the lower heating energy consumption is the higher peak load. Therefore if the slope of the curves is near to vertical this price is to be pondered since the change of the heating energy need becomes modest.

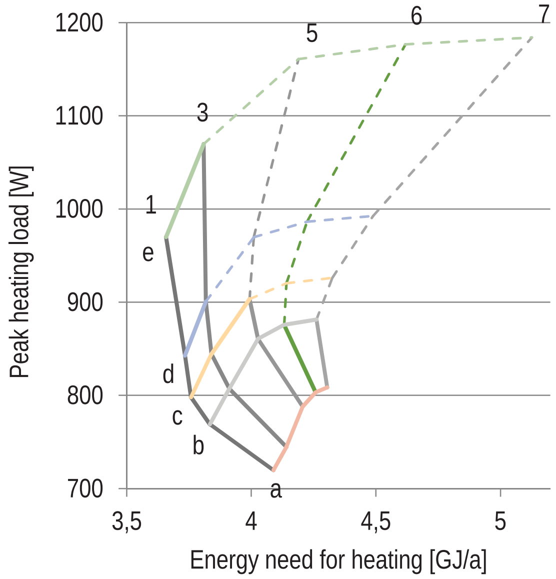

Figure 8. Heating energy need vs. heating peak load, East orientation, Debrecen. Parameters: 1…7 heat capacity (decreasing), a…e: glazed ratio (increasing), identifications are given in Tables 1. and 2

As far as North orientation is concerned increasing glazed ratio leads to higher heating energy need as well as to higher heating peak load. The same applies for any orientation if the solar access is obstructed.

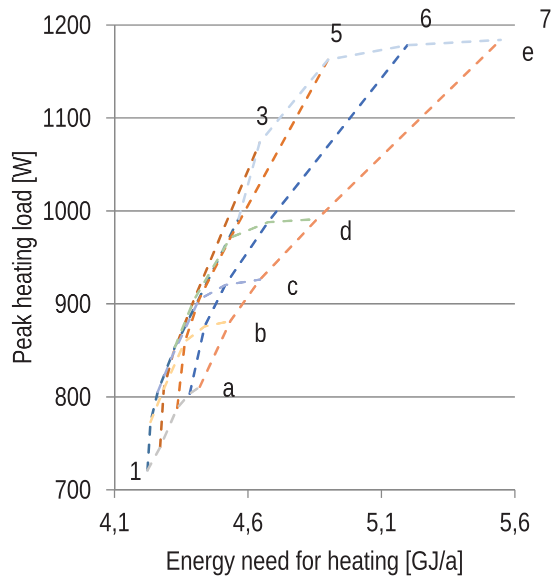

Figure 9. Heating energy need vs. heating peak load, North orientation, Debrecen. Parameters: 1…7 heat capacity (decreasing), a…e: glazed ratio (increasing), identifications are given in Tables 1. and 2

Repeating the simulation for Bergen the results are similar as it is illustrated in Fig, 10. for South orientation.

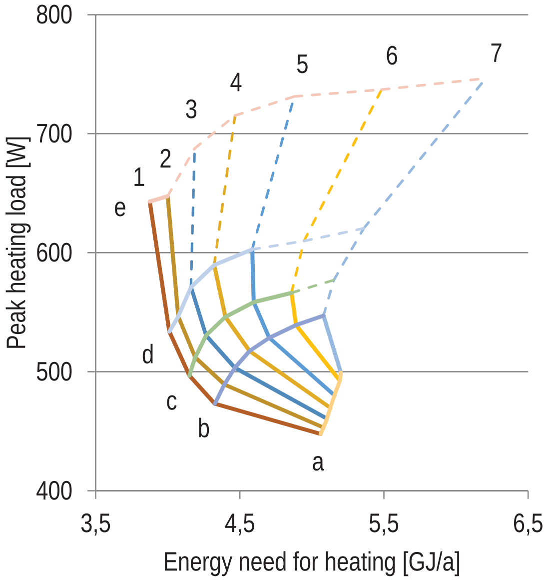

Figure 10. Heating energy need vs. heating peak load, South orientation,Bergen. Parameters: 1…7 heat capacity (decreasing), a…e: glazed ratio (increasing), identifications are given in Tables 1. and 2

Utilised passive solar gain

It is obvious that in the case of our model the only reason of the differences in energy consumption is the different amount of utilised passive solar gains. The possible saving of energy consumption depends on the orientation, glazed ratio and heat capacity of the boundary construction. Figure 11 shows the saving of heating energy need in % in the function of glazed ratio: continuous lines are for South facing façade, dashed lines belong to East orientation.

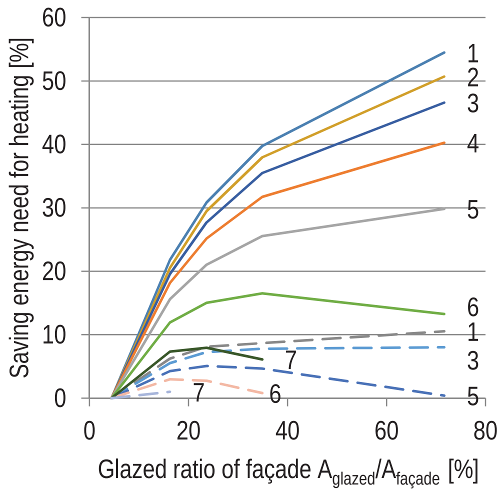

Figure 11. Saving of heating energy need. Parameters: 1…7 heat capacity (decreasing), identifications are given in Table 2

The parameter is the heat capacity of the boundary construction – its effect is decisive. Nevertheless even if a light weight construction is considered, the glazed ratio can be as high as 40% resulting in about 20% saving of heating energy need in case of South facing façade. For heavier constructions the optimum cannot be seen, only the increase of energy saving slows up.

For East orientation (dashed lines) the available energy saving does not exceed 10% and for medium weight buildings the optimum glazed ratio is around 30%. The available energy saving in light weight buildings is modest and the glazed ratio should not exceed 20 %.

It should be noted that the base of the % calculation is the minimum glazed ratio (4.5 %), not the windowless wall.

Heating energy need is to be covered by the heating system. The results show that utilised passive solar gain can cover a considerable part of heating energy need.

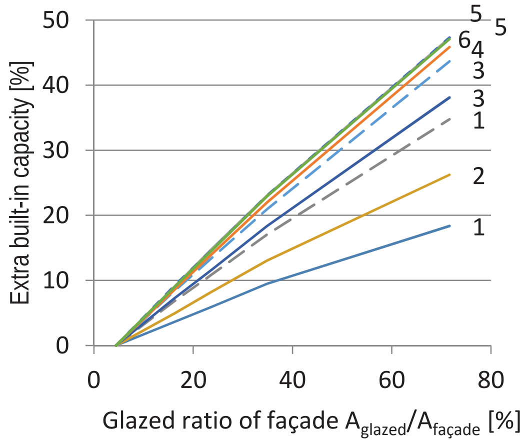

Figure 12. Increaese of heating peak load. Continuous lines: South, dashed lines East orientation. Parameters: 1…7 heat capacity (decreasing), identifications are given in Table 2

The price of the lower heating energy consumption is the higher peak load (Fig. 12.), consequently the higher built-in capacity. Although the data may seem to be shocking some facts should not be forgotten:

– the built-in capacity is typically oversized, partly due to the discrete selection of boilers, heat pumps, partly because designers intend to be on the "safe side";

– many times heat for space heating and domestic hot water is generated in the same system. The last is a given value, thus the change of the total built-in capacity is relative smaller.

Balancing effect of thermal zones

Real buildings have more facades. The passive solar gains for different orientations lead to significantly different thermal balance in differently oriented rooms – particularly if North-South pairing is spoken of. Nevertheless there is thermal connection, thus heat flow between these North and South facing rooms.

Its balancing effect depends on the ratio of the strength of thermal connection between the room and the environment to that between the differently orientated rooms.

As far as glazed ratios are concerned two approaches can lead to interesting results. The first is to have optimum glazed ratio for both orientations. Such a solution can be applied in residential buildings if the building is not very deep. In this case living rooms and similar ones where the insolation and daylight is of importance can be oriented toward South whilst the others (bath, kitchen, wardrobe, staircase...) towards North, Not surprisingly the lowest energy need occurs when on both sides the optimum glazed ratio is applied. Increasing the glazed ratio towards North both the energy need and peak load increase. Having lower glazed ratio on the Southern façade the same tendency can be seen: the energy need is higher, the peak load is lower. The results are influenced by the heat capacity, see Figure 12 for massive, Figure 13. for light weight buildings. Certainly in the last case both the energy need and peak load are higher.

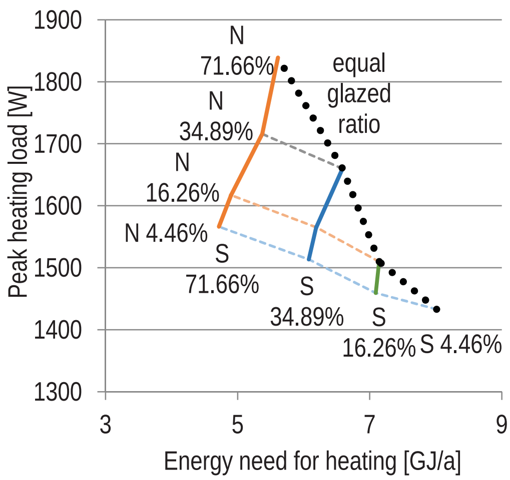

Figure 13. Sum of heating energy need vs. heating peak load of a pair of North and South facing room, high heat capacity

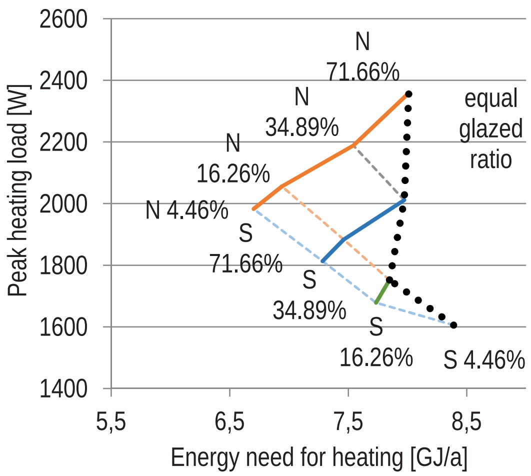

Figure 14. *Sum of heating energy need vs. heating peak load of a pair of North and South facing room, low heat capacity*

The different uses of premises justify the significant differences in the glazed ratio together with the different appearance of the facades. This is the well proven design strategy of buffer zone concept in the classic solar architecture.

In case of deep residential buildings (where complete flats have windows only on one facade or if the use of rooms is identical on both sides (e.g. office building) it is an understandable expectation that due to the identical use the facades should be identical or at least of similar appearance. Therefore sets of identical glazed ratios on both sides have been analysed. Here at the first sight it may be surprisingly that the higher glazed ratios results to the lower heating energy need, no doubt at the cost of high peak loads (Figs. 12. and 13), thus the effect of balancing heat flow is very strong. This is the consequence of the fact that the thermal connection between the rooms is multiple times higher than that between the rooms and the environment in superinsulated buildings.

Conclusion and Policy Implications

Interpreting correctly the energy performance of building the aim is to decrease the non renewable primary energy need for heating. It should not be confused with low built-in capacity which does not guarantee low heating energy consumption: on the contrary at peace with higher peak load considerable energy saving is possible.

The essence of this phenomenon is that passive solar gains cover a part of the heat losses, thus decreases the necessary heat output of the technical heating system. This experience is long ago well known and has been exploited in classic solar architecture. Nevertheless in the era of superinsulated buildings this experience seemed to be forgotten. Even with the high quality contemporary windows the transmission heat loss of building increases with the glazing ratio and this seemed to contradict the nZEB concept.

Our analysis illustrate that the passive solar gain countervails or exceeds the increase of transmission losses and in case of Equator facing orientation significantly decreases the energy consumption of technical heating system. More modest but not negligible saving can be achieved in case of less favourable orientations. Certainly the utilisation of passive solar gain depends on the heat capacity of the building, too. For several input combinations optimum glazed ratio can be defined.

Not surprisingly favourable results have been obtained by pairing rooms of opposite orientations. Providing the depth, the layout and the use of premises facilitate the application of buffer zone concept and the radically different glazed ratio of different facades are acceptable the lowest energy need can be achieved if the glazed ratio on both sides is optimum. Providing the use of rooms is similar on both sides and therefore identical glazed ratios are applied the higher ones are better in case of North-South pairing.

Man-made formal rules make confusing the consideration of passive solar gain as heating with renewable energy.

The question of interpretation would not have any importance if some of the national regulations would not require (sometimes unrealistic) "renewable share" of which utilised passive solar gain, however, is excluded.

Those national regulations of Member States which are ready (concept accepted or already implemented) exhibit wide variations regarding renewable energy. Some of them do not use "renewable share" as compulsory indicator. Others "softly" encourage the use of renewable energy but rank the building as nZEB even if (pro forma) no renewable energy is applied, providing the specific non renewable primary energy consumption doers not exceed the threshold. ("Pro forma" since all buildings exposed to the Sun use renewable energy disregarding the formal man made rules.) Interesting example is the Estonian regulation which does not define the minimum of renewable share rather B energy class has to be achieved without renewable energy.

Other national regulations cannot break away from the hasty wording of the EPBD.

Bulgaria and Ireland prescribe renewable share, 15 and 20% respectively with no further specifications. In Southern Member States (IT, ES, PT) compulsory renewable share (30-70%) for domestic hot water supply is typical. Considering the climate it is understandable and seems to be justified – the questions are the unobstructed solar access and the ratio of available roof area to the total floor area.

In Austria different options are possible:

– by solar thermal energy net final energy yields at least 10 % (up to 20%) of the final energy demand for domestic hot water or

– through heat recovery least 10% (up to 20%) net final energy yields for heating or;

– by photovoltaic the net final energy yields at least 10 % (up to 20%) of the final energy demand for *household* electricity or operating current.

The last option needs clarification since "household electricity" is not taken into account in the EPBD labelling systems. Nevertheless the extension of "renewables" with heat recovery is a salutary and justifiable concept.

As a frightening example the Slovak regulation is to be mentioned which prescribe 50% renewable share (parallel with the maximum pay back time of 15 years!).

It can be seen that the implementation of new national regulations is in the process of long lasting parturition. Likely the unclear regulation is one of the reasons which make harder the agreement of policy makers and professionals. Clear interpretation of heat losses and heating energy will create a clear situation. Even if a Member State insist on renewable ratio as compulsory or informative indicator consideration of utilised passive solar gain as part of the renewable share may make easier the fulfilment of this (otherwise disputable) requirement. Agreeing with the statement of [RES 2009] that passive solar gains must be accounted only once it is evident that heating with solar energy is to be included in the renewable share.

Regulation should be clear, realistic and convincing, free of contradictions and ambiguous guidance. The Commission and the Parliament are more often than not blamed with exaggerated bureaucracy and over-regulation. The current situation in the analyzed subject area raises the suspicion of lack of cooperation between decision-making bodies themselves as well as between policy makers and the professional society.

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