ENERGY EFFICIENT BUILDINGS – DESIGN AND ENERGY CALCULATIONS IN VARIANTS

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Summary

The paper deals with calculating assessment of thermal behaviour of energy efficient buildings and its approaching to real building operation. It summarizes aspects influencing energy balance and points out the uncertainty of some input data which affects a calculation result error and decreases its information capability.

One of the possible solution methods to treat with this uncertainty is to work with variants, or a spread of input data that allows to gain a notion of possible result spread in dependence on entered inputs and its sensitivity to selected parameters.

The very design that should consider and assess different variants by various criteria is not less important.

In the extended paper on the DVD there is an example of variant solution and assessment of sports complex study from the point of view of energy need for heating and summer overheating risk in the initial stage of the project, when with respect to the documentation stage there was not enough information available and therefore lack of the input data. Furthermore, it allowed the results to influence decisions in subsequent stages of design.

Keywords: energy efficient buildings, energy need for heating, summer overheating, simulation, variants of calculations, uncertainty of input data

1 Introduction

To be able to design and assess energy efficient buildings correctly, it is necessary to understand not only building calculation assessment but also buildings themselves, their behaviour and sensitivity and to be aware of some aspects which are often ignored.

Energy efficient buildings are more sensitive to certain parameters then usual buildings. Due to considerable reduction of the heating loss, openings, building operation, locality and others gain the importance. It is impossible to say unambiguously what solution is the optimal one for the house especially if there are various, often competing points of view to be assessed (energy need for heating, good indoor climate, primary energy use, financial aspects...). That is why it is advantageous to design in variants. As early as at the initial stage of the design, it is possible to process a simple energy study that can help with the decision on the most appropriate variant.

When the design or building has been already finished and the energy behaviour of the building is only monitored, usually there are some missing data necessary for the calculation which might have a strong influence on the result. In such case it is advantageous to make the calculations in variants as well to cover all the possible ranges of the uncertain input data.

2 What influences the energy balance

Some parameters influence the energy behaviour of the building more, some less. If there is enough time, which usually is not in real design process, a sensitivity analysis could be done and further, on the basis of its results, most influencing factors optimized. But a sensitivity analysis is mainly processed for some experimental calculations done for research purposes, in common practice it is a rare case. So let's summarize basic factors significantly influencing the energy balance.

- quality and thermal properties of the building envelope (heat loss)
- airtightness of the external envelope (heat loss)
- glazing – size and orientation (both heat losses and solar gains)
- air change rate and ventilation mode (heat loss)
- operating mode and occupancy (internal and partially solar gains, heat loss)
- appliances and equipment (internal gains)

Heat losses by transmission can be calculated quite accurately and besides, their dependence on building operation is marginal. When the construction and openings properties are known, their contribution to heat balance can be determined quite easily.

On the contrary, internal and partially solar gains and heat losses by ventilation are very uncertain because of their dependence on user behaviour, way and mode of building operation and occupancy. They enter the calculation with great uncertainty, but are also one of the most considerable parameters from the energy balance point of view. Accurate determination contributes to obtaining relevant results.

2.1 Heat gains

Thermal gains, an important item of thermal balance, can influence energy need for heating in winter and transitional period and also can imply a possible necessity of further provisions or even cooling in summer period. Therefore they cause computational difficulties because of its variability and uncertainty that affects results of energy balance.

User – produces metabolic heat in term of his presence and furthermore he influences the operation of some appliances (see below). But the user also affects a thermal loss, he need to be supplied by a sufficient amount of fresh air, so the occupancy is strongly related to heat loss as well.

Appliances and lighting – amount and energy efficiency appears. A part of appliances' thermal production is independent of a building operation mode (technology, fridge,...), a part is in correlation with it (lighting, computing and office equipment, kitchen appliances,...).

Shading – is the next factor which can be influenced by a user or by design with respect to user – for example if the office work place is inconveniently situated by the window, the user will protect himself from an excessive amount light and glare on the display e.g. by drawing curtains. This behaviour reduces part of solar gains included in thermal balance.

Heating – Rooms are commonly heated on a higher temperature than it is considered in the calculation. These forced gains from the heating system can be undervalued in the calculation and can misrepresent the result as well.

As can be seen, a numerous amount of factors on the side of gains (and also part on the side of looses) is considerably dependent on building use, way and operation mode, occupancy and last but not least on a degree of mature behaviour of the users themselves. Therefore correct determination of occupancy and related factors and way of its inclusion into the calculation is very important because of its influence on high amount of other parameters. That is why simulation of different possible situation and study of building behaviour in dependence on various variants of operation is of great significance.

3 Design and calculation variants

3.1 Design

During correct design procedure, especially in case of integrated design, when a lot of aspects enter into the design process, more variants necessarily emerge which shall be assessed and the better one chosen. Sometimes it can be chosen on the basis of consideration only, but sometimes the effect of some parameters cannot be estimated correctly, especially for buildings atypical in operation. It depends on the chosen criteria. Especially when assessing competing aspects, for example the quality of internal environment in summer period and the energy need for heating in winter period, some things can be ambiguous. Then simulation of various variants can help.

3.2 Calculations

Some aspects are included in the calculating assessment of energy balance even though they cannot be determined exactly. User behaviour and building operation mode that are always individual are typical examples. The influence of those to the thermal behaviour of energy efficient buildings is very considerable, and the more reducing the energy need for heating the more considerable it is. In the declarative calculations there are some typical inputs used. But if we want to have a detailed picture how the building could behave form the energy point of view and not only to declare some level, e.g. for office use, we should try to include various possibilities that can occur, try to simulate various situations and way of use and possibly some other uncertain aspects as precisely as we can.

A variant solution cannot be necessarily knotty. For the basic picture a simple reflection about potential limits of given parameter and the calculation in those boundary limits suits the purpose. The more those uncertain parameters there are the more complicated the calculation is because of the combination of their effects. In dependence on needed accuracy of calculation we can sometimes focus only on those parameters whose impact the building is the most sensitive on and to disregard the remaining. The result still has higher information capability than at calculation without variants.

3.3 Benefit of the variants

If we “play”, more information can be obtained than in common procedure.

In case of a new building design when computationally assessing various variants we can obtain better picture of the influence of various parameters on final energy building behaviour. Also on the basis of this calculations a financial pay-back study of some provisions can be done, it can be better decided what can comply more with investor’s preferences or which design is better than the others from the point of view of energy balance at given time interval.

In case of assessing calculations of already finished design or existing building a picture about spread of building energy behaviour in dependence on its operation mode, user behaviour etc. can be obtained and real needs and risks better predicted.

4 Conclusion

There are always many uncertain parameters which enter the energy calculations. Further, by reducing the heat loss, the influence of internal heat gains increases and buildings and calculations change their sensitivity to other parameters that were insignificant in building stock with high heat demand. Therefore the resulting thermal balance of energy efficient building, especially passive buildings or better ones, is the result from the subtraction of two similarly large numbers (heat loss and thermal gains) and error of result can be relatively high. The error also depends on the user performing the calculation (source and more information see in [6]), on the choice of the calculation model, extent of simplification, on the uncertainty of inputs etc. It is also advantageous to think about situations that can come and to elaborate the calculation or assessment with respect to these possibilities. The result is never a single number but a range driven by a range of inputs entered with some relative error.

5 Example of energy study solved in variants

Within the study the group of students with various technical orientation deal with the design of sports complex Smilovice in Mladá Boleslav district, based on the real project documents. The complex consists of a main building with gymnasiums, sports facilities and a restaurant with its facilities; the next two buildings serve for accommodation of the sports workshops and outdoor courts with possibility to be covered by pneumatic hall in the winter period. All the available documentation was at the level of planning permission and the amount of information corresponded to that fact.

Within the group we have been working using the principles of integrated design, since the beginning of the work we had discussed the options from the various points of view and worked out several alternatives of the buildings based on these discussions. Those variants including their evaluation and assessment were presented to the investor as a basis for later decision at further continuation of the project.

Elaboration the energy study of the main building and accommodation houses – energy need for heating and thermal stability in summer period (risk of summer overheating) is shown in the following text.

5.1 Calculation model

Energy need for heating was determined by standard monthly method [7]; the software [5] was used. The thermal comfort was evaluated by a simple simulation model. The internal air temperature was calculated by:

$$T_a(t) = T_a(t-1) + \left(\frac{G - U_{tot}(T_a(t-1) - T_e)}{C} \right) \Delta t \tag{1}$$

where

$T_a(t)$ is internal air temperature in the actual time step [°C];
$T_a(t\text{-}1)$ is internal air temperature in the preceding time step [°C];
T_e is ambient temperature [°C];
Δt is time step of calculation (3600 s);
G are total heat gains into zone (internal and solar), [W/m^2];
U_{tot} is total thermal transmittance (transmission and ventilation), [W/(m^{2}K)];
C is effective thermal capacity of zone [J/(m^{2}K)]

The parameters are related to the cooled area of the building envelope (system boundary).

5.2 Accommodation buildings

Accommodation consists of two houses, see Fig. 1. The larger building has 4 dwelling units each for max 4 or 5 persons, the smaller building is for max 4 persons. Seasonal use was assumed (summer plus transitional period) but no more information about occupancy spreading over the day, week and year was available, that is why the buildings were solved in 3 basic occupancy variants (see Tab. 1). For summer stability calculation it was further considered the internal air temperature dependent ventilation variants (natural ventilation for all), see Tab. 3, and solar radiation dependent curtains possibility, see Tab. 2. Further, it was impossible to pre-estimate the effect of thermal properties of the building envelope to heat demand when seasonal use and summer overheating, whether it has impact to design the object on an passive or low-energy level or if even with common parameters of envelope structures the heat demand would be so low to additional cost not would be economical. That is why the variants of envelope structures (thermal properties) were considered in calculations too (see Tab. 4).

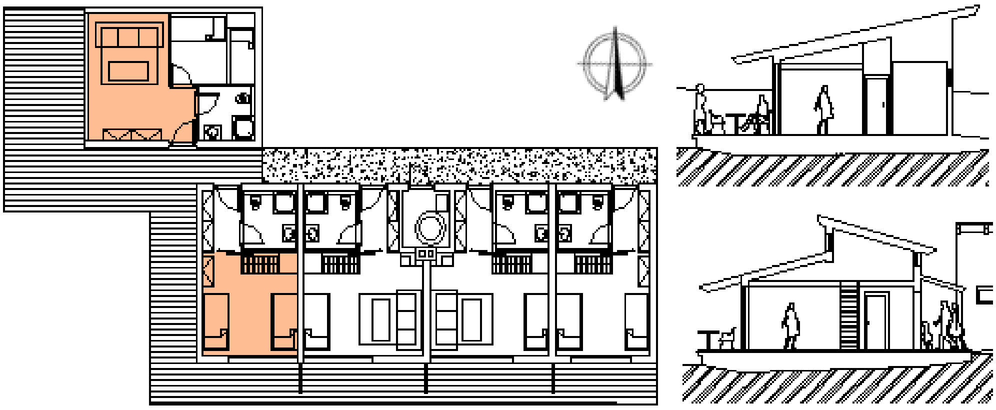

Fig. 1 Accomodation buildings, plan and sections, the rooms assessed on the aspects of summer overheating is marked

Tab. 1 Occupancy variants

variant	**b**	**c**	**d**
number of people (in the bigger + in the smaller building)	8+2	2+1	20+4

Tab. 2 Considered effect of curtains depending on irradiation

irradiation [W/m^2]	**shading factor**	**description**
< 300	1.0	no curtains
≥ 300	0.2	e.g. Aluminium-coated textiles inside or light blinds outside [7]

Tab. 3 Considered ventilation rate depending on the internal air temperature

internal air temperature [°C]	**ventilation rate** [h^{-1}]
< 23	0.62
23 - 25	4.00
> 25	8.00

Tab. 4 Variants of building envelope structures by their thermal properties

variant	**1**	**2**	**3**
construction envelope	**U_{req}** W/(m^2.K)	**U_{rec}** W/(m^2.K)	**U_{NED}** W/(m^2.K)
walls	0.30	0.20	0.15
roofs	0.24	0.16	0.11
floors	0.24	0.16	0.11
openings	1.2	1.0	0.8
thermal bridge effect	0.05	0.05	0.02
U_{em} [W/(m^2.K)]	0.41	0.31	0.22

Both energy need for heating and summer thermal stability simulation was calculated for case of continuous use of the buildings over the season. Real energy need for heating would be reduced by the month the buildings are not used in.

5.2.1 Energy need for heating

Dependence of energy need for heating on occupancy and thermal properties of the building envelope expressed by U_{em} are shown in Fig. 2. Growth the number of people caused the increase of the heat demand because the heat loss by ventilation increases faster than metabolic heat from occupants. Improving the building envelope from U_{req} (var. 1) to U_{NED} (var. 3) when seasonal use caused reduction of energy need for heating by 40 % through 63 % (depending on occupancy).

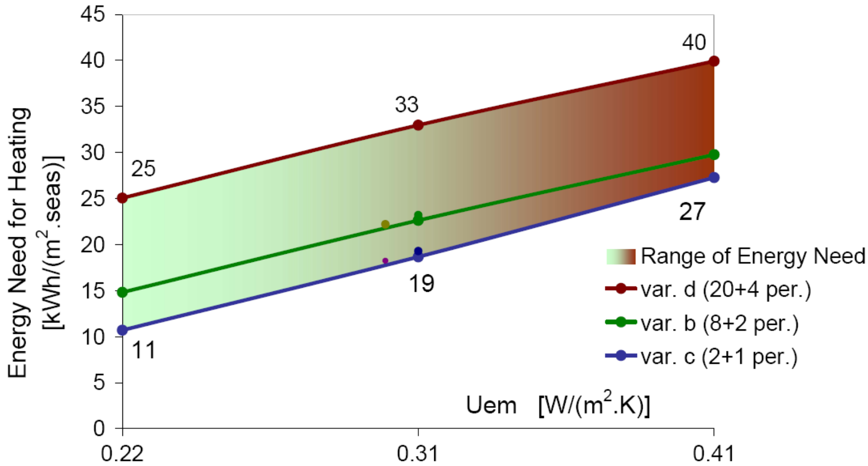

Fig. 2 Range of energy need for heating per season depending on U_{em} and occupancy

5.2.2 Summer thermal stability

From the point of summer thermal stability the room in the smaller building was proved worse than in the bigger one because of its more adverse proportion of the glazing area to the room size.

Internal air temperature in the variant with better thermal parameters exceeded 27°C (highest value required by [9]) more frequently than in the less insulated variant because of the lower heat loss by transmission in cold periods (nights). Tab. 5, Fig. 3 and Fig. 4 show that the curtains reduce the overheating rate significantly.

Tab. 5 Number of hours and days with average internal air temperature higher than 27°C without and with curtains effect on building envelope thermal properties variants

variant		**1 (U_{req})**		**2 (U_{rec})**		**3 (U_{NED})**	
without / with curtains effect		without	with	without	with	without	with
the bigger building	hours	396	109	538	125	751	142
	days	2	0	4	1	7	1
the smaller building	hours	551	227	654	272	780	332
	days	3	0	9	1	13	1

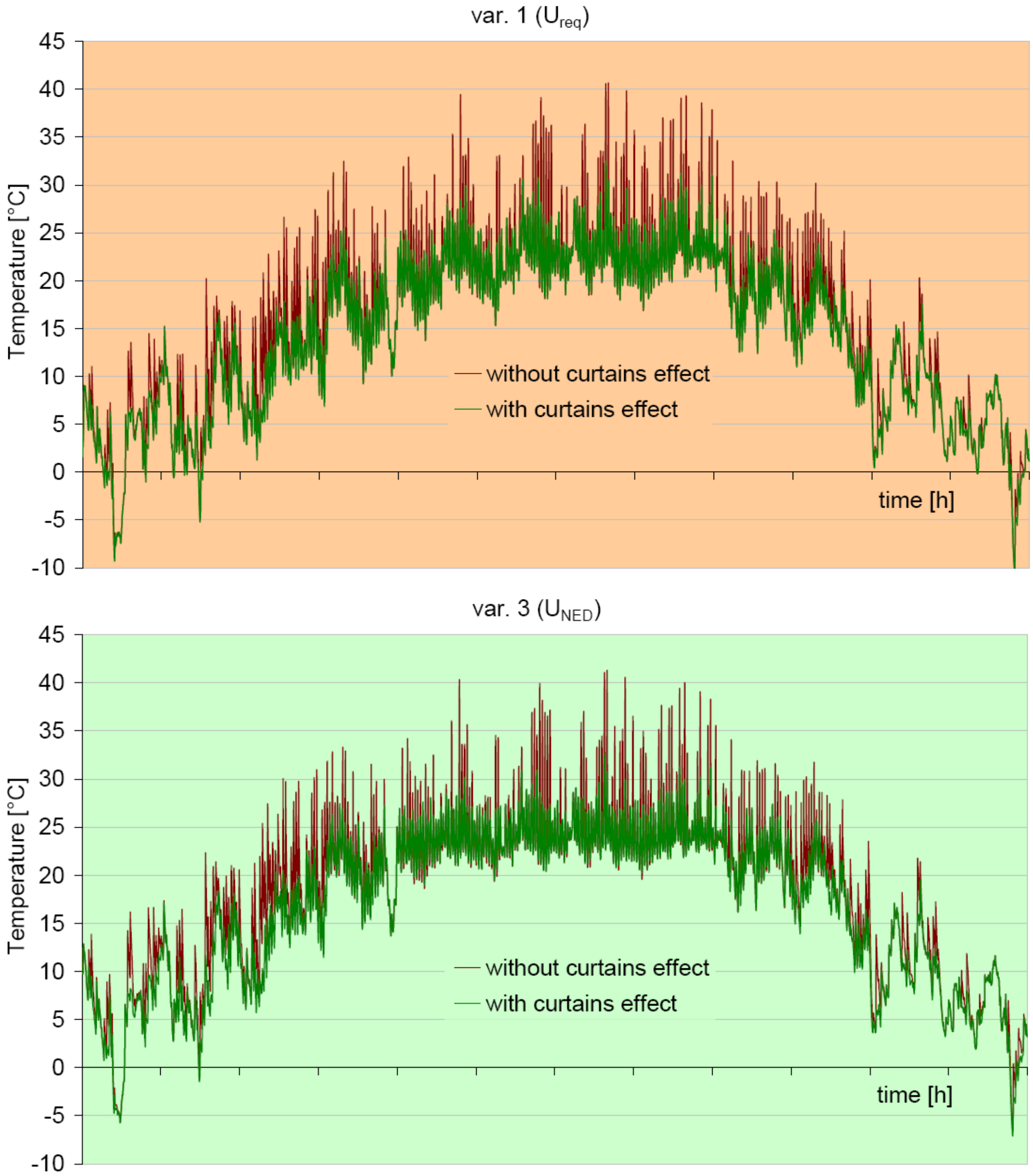

Fig. 3 Internal air temperature in the smaller accommodation building over the year – comparison curtains effect on building envelope variants (U_{req} and U_{NED})

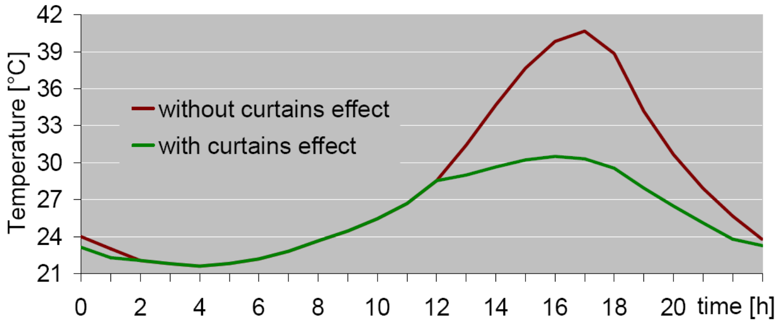

Fig. 4 Internal air temperature in the smaller accommodation building over the day, without and with curtains effect

5.3 Main building

There is a restaurant in the middle part of the main building. In the left wing of the building there is its facility, in the right wing there are gymnasiums, sauna and sports facilities (dressing and shower rooms), see Fig. 5. Building is used all the year. The heat demand calculation was 3-zones. No detailed information about the intensity of use of the parts of the building was available, only rough estimates. Therefore, for sports and restaurant the occupancy variants were considered, which determined air change need and internal gains (metabolic heat). The kitchen was calculated in variants of air change rate and internal gains in dependence on potential operation and appliance equipment. Mechanical ventilation with heat recovery was considered.

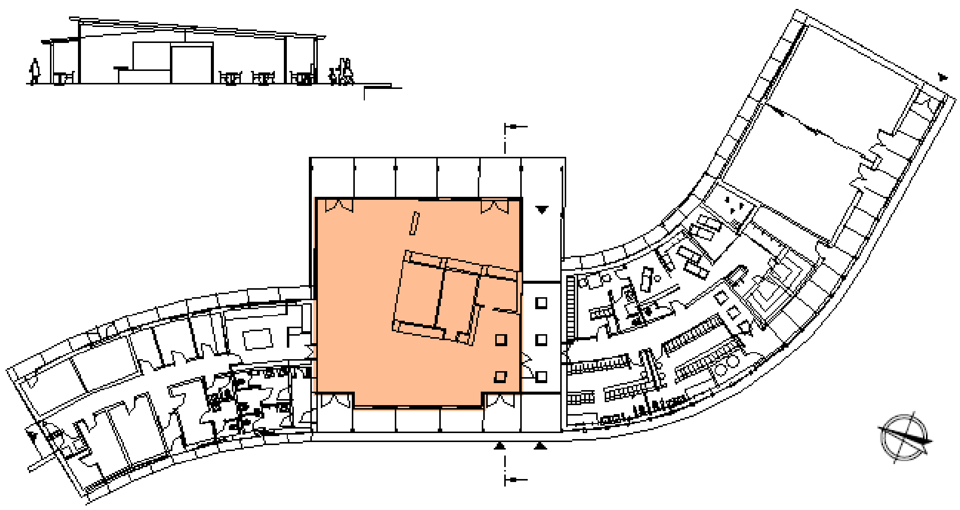

Fig. 5 The plan of the main building and section of central part (restaurant); the room assessed on the aspect of summer overheating is marked

5.3.1 Energy need for heating

Resulting energy need for heating (specific and total) calculated on the basis of individual input data variants is shown in Fig. 6.

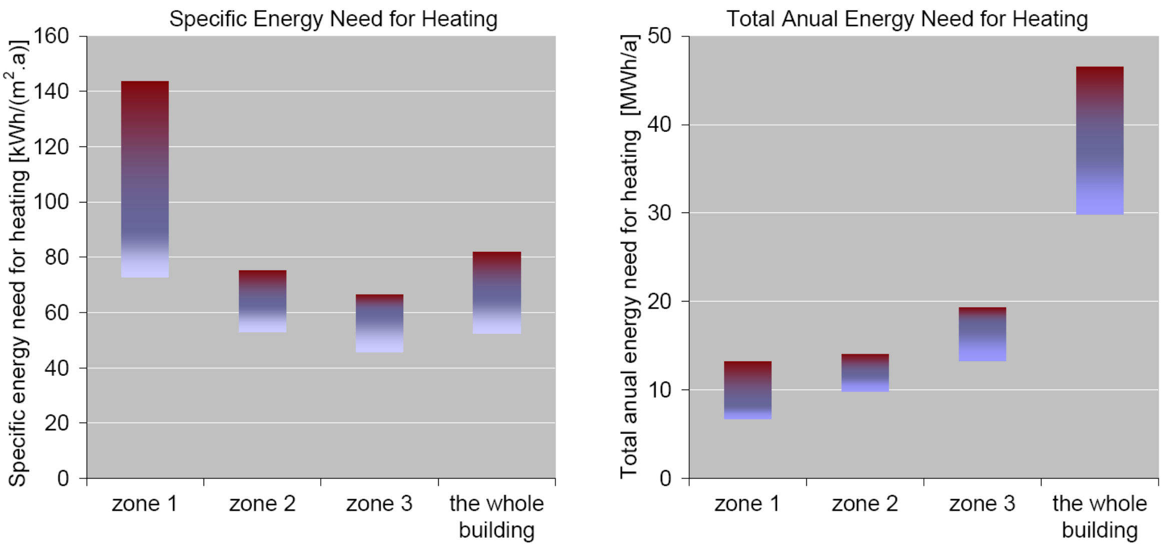

Fig. 6 Range of annual energy need for heating (specific on the left and total on the right) calculated on the basis of input data variants (zone 1 – restaurant facility with kitchen, zone 2 – restaurant, zone 3 – sports)

The highest specific heat demand and also the range are found in zone 1 (restaurant facility with kitchen) where is the highest air change rate and uncertainty of inputs as well. Growth the number of people in the restaurant as well as in sports caused increase of the energy need for heating because the heat loss by ventilation increased faster than metabolic heat from occupants. Total energy need for heating bandwidth caused by the input variants is ± 22 %. By the aspect of energy need for heating the building would be classified according to [11] between classes "very energy efficient" and "energy efficient".

5.3.2 Summer thermal stability

From the point of summer thermal stability the middle part of the building (restaurant) was assessed because there were large glazed areas almost around the whole restaurant. The calculations covered several occupancy variants (see Fig. 7). Further the impact of dynamic increase of air change rate depending on the internal air temperature (Tab. 6) and the curtains effect depending on the incident solar radiation was followed (the same way as for accommodation buildings, see Tab. 2.)

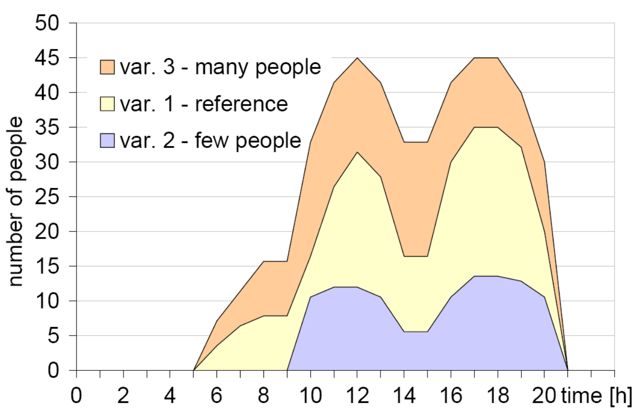

Fig. 7 Variants of hourly occupancy of the restaurant

Tab. 6 Multiply increasing of ventilation depending on internal air temperature

internal air temperature [°C]	multiplier of air change rate [-]
< 22	1
22 - 24	2
> 24	5

Fig. 8 shows the internal air temperature dependence on considered occupancy variants, with no other temperature decreasing provisions. Further the impact of the provisions on the internal air temperature was followed; see Fig. 9, Fig. 10 and Fig. 11. As shown in those charts and Tab. 7, at chosen calculation model the ventilation increase has larger influence to reduce summer overheating than the curtains but their combination is the best. Furthermore, the results of such simulation can induce designers to a reflection of suitability or necessity of some another provision to reduce summer overheating, e.g. pre-cooling the ventilation air in the ground heat exchanger, as with considered provisions high incidence of exceeding standard limit of the internal air temperature still occurs.

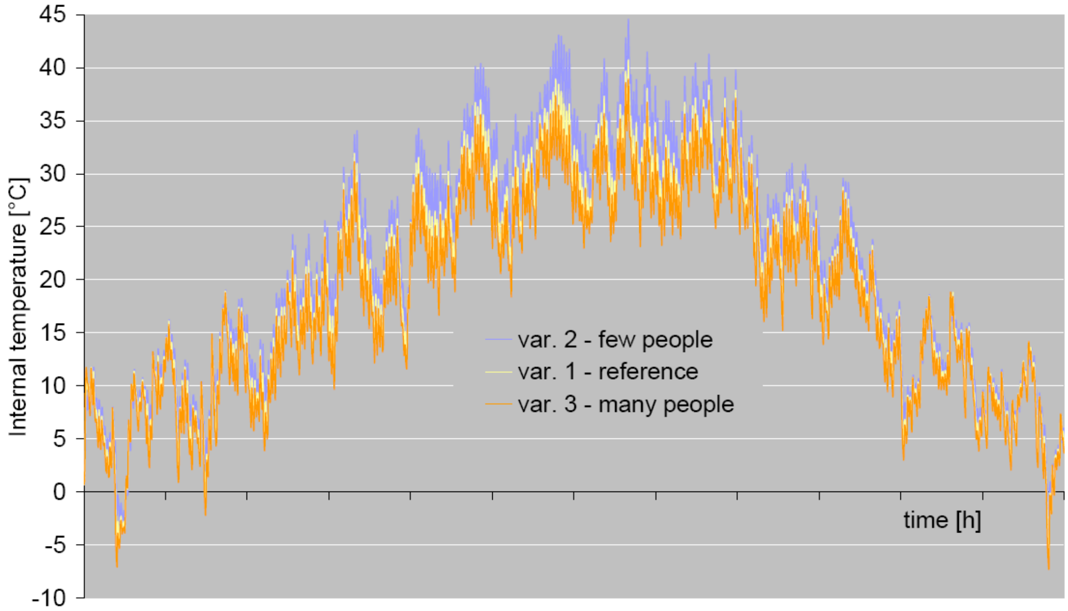

Fig. 8 Internal air temperature in the restaurant over the year – comparison occupancy variants

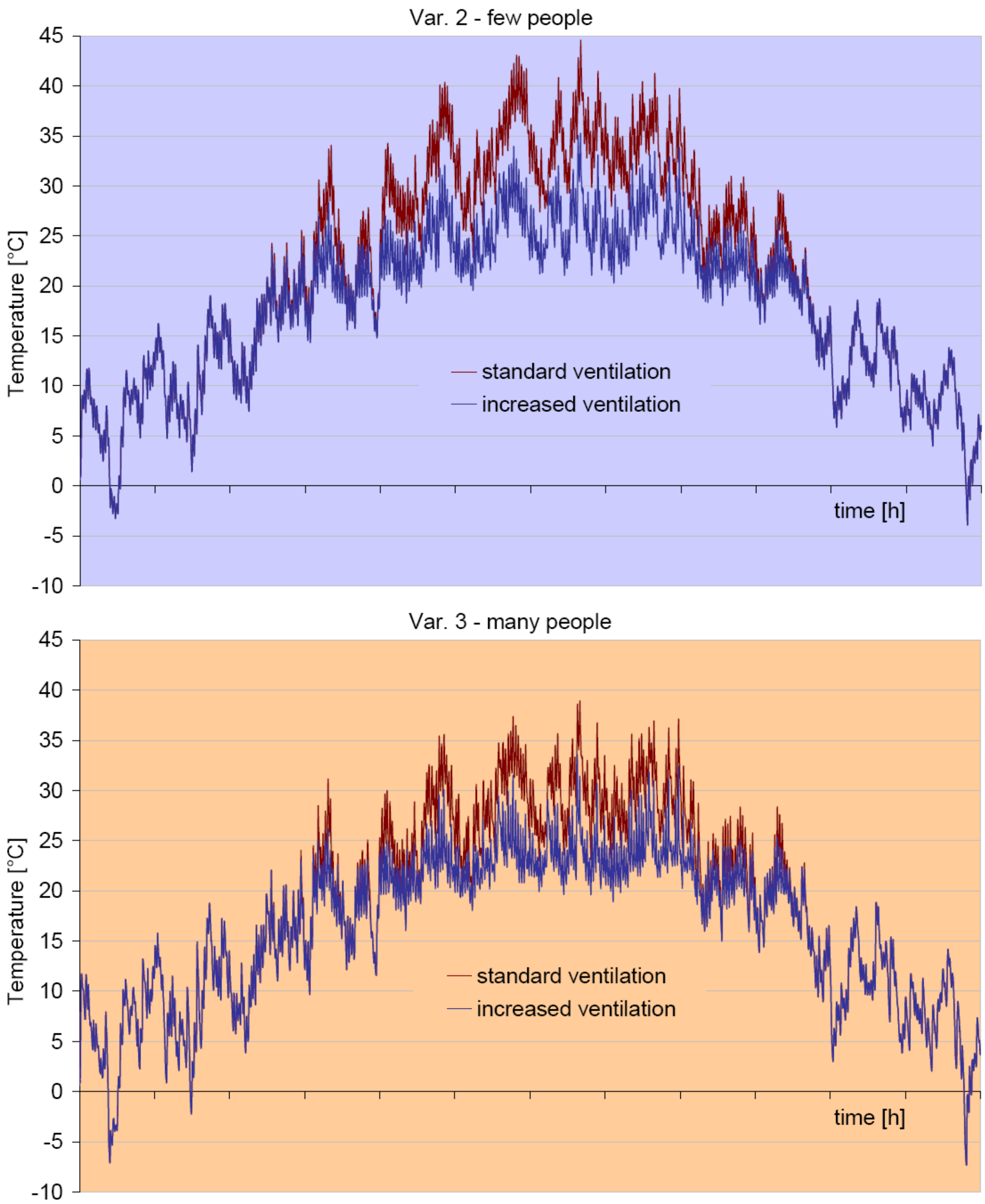

Fig. 9 Internal air temperature in the restaurant over the year – comparison the ventilation effect on occupancy variants (var. 2 – few people on the top, var. 3 – many people at the bottom)

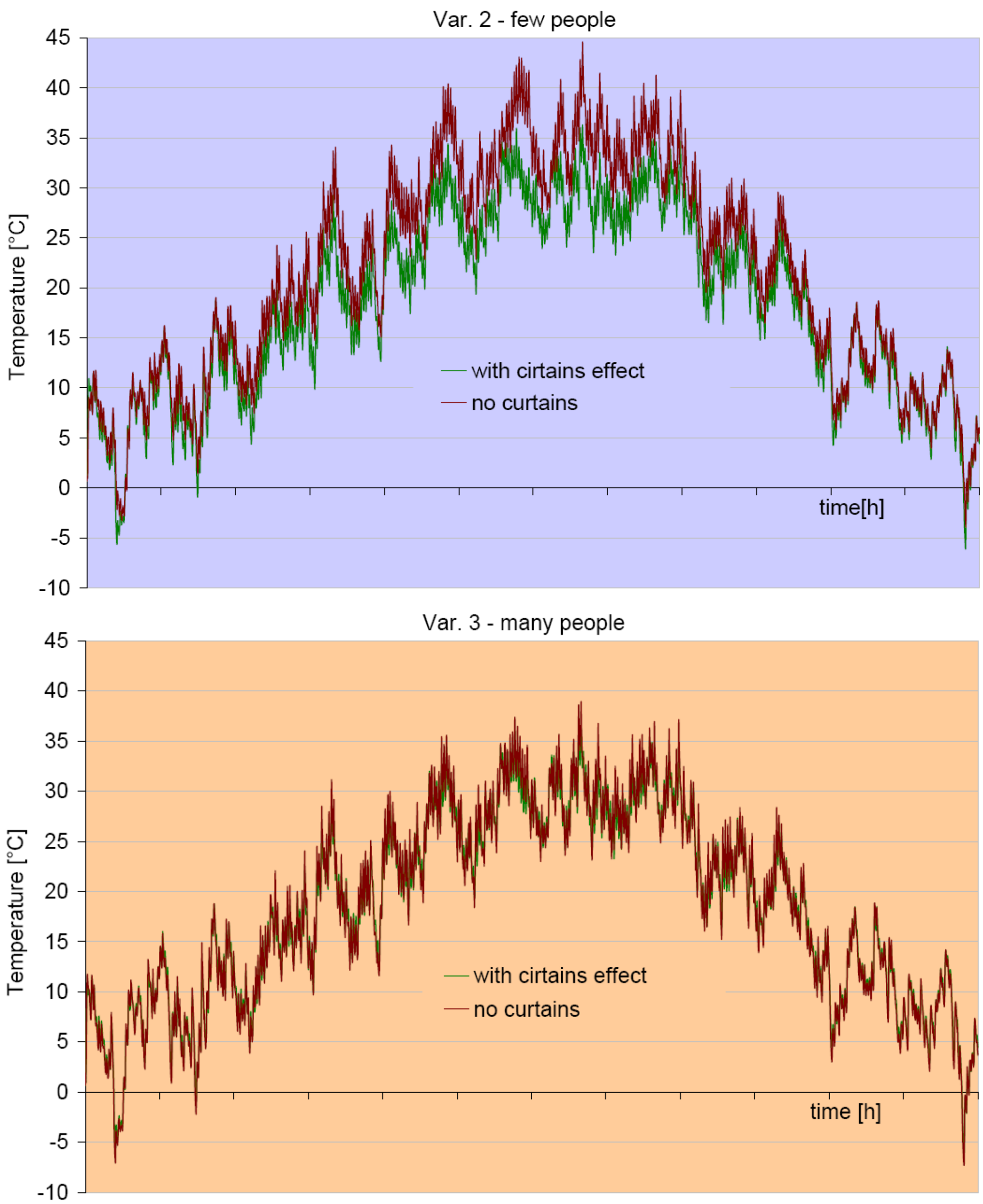

Fig. 10 Internal air temperature in the restaurant over the year – comparison the curtains effect on occupancy variants (var. 2 – few people on the top, var. 3 – many people at the bottom)

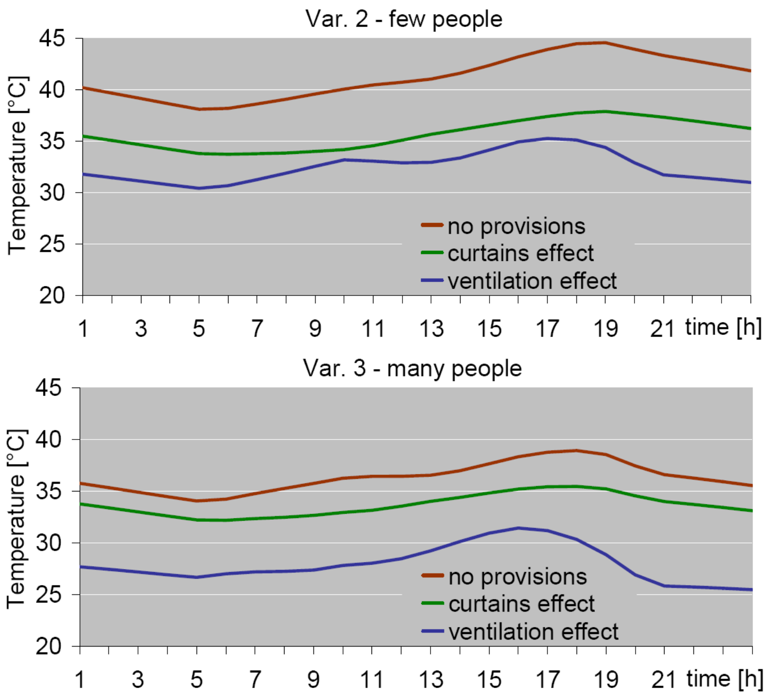

Fig. 11 Internal air temperature in the restaurant over the day – comparison no provisions variant, the curtains effect and the ventilation effect on occupancy variants (var. 2 – few people on the top, var. 3 – many people at the bottom)

Tab. 7 Number of hours and days with average internal air temperature higher than 27°C with no provisions, with the curtains effect and the ventilation effect on occupancy variants

variant	**var. 2 – few people**			**var. 1 – reference**			**var. 3 – many people**		
no provisions / curtains / ventilations	no	curt.	vent.	no	curt.	vent.	no	curt.	vent.
hours	3197	2553	944	2449	1997	343	2029	1632	259
days	134	105	38	106	86	6	89	68	3

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References

[1] TYWONIAK, Jan, *Nízkoenergetické domy. Principy a příklady*. Grada Publishing, a.s., 2005, 200 p. ISBN 80-247-1101-X

[2] TYWONIAK, Jan et al., *Nízkoenergetické domy 2. Principy a příklady*. Grada Publishing, a.s., 2008, ISBN 978-80-247-2061-6

[3] The project documentation of the sports complex Smilovice in Mladá Boleslav district for zoning decision, Atelier Klose s.r.o., September 2008

[4] KOPECKÝ, Pavel. Calculation tool for parametric analysis for MS Excel "calc13790simout3.xls",

[5] Software Energie 2008, Svoboda software

[6] KOPECKÝ, Pavel; STANĚK, Kamil; ANTONÍN, Jan. Přesvědčivost výsledků výpočtu potřeby tepla na vytápění pasivních domů. In *Pasivní domy 2008: sborník příspěvků konference Pasivní domy 2008, Brno 30–31 October 2008*, Ed. Jan BÁRTA, Juraj HAZUCHA: Centrum pasivního domu, 2008, p. 337–344. ISBN 978-80-254-2848-1

[7] ČSN EN ISO 13790. *Tepelné chování budov – Výpočet potřeby energie na vytápění*, 2009 (ISO 13790:2008)

[8] ČSN EN ISO 13789. *Tepelné chování budov – Měrné tepelné toky prostupem tepla a větráním – Výpočtová metoda*, 2009 (ISO 13789:2007)

[9] ČSN 73 0540-2. *Tepelná ochrana budov. Část 2: Požadavky*, 2007

[10] TNI 73 0329. *Zjednodušené výpočtové hodnocení a klasifikace obytných budov s velmi nízkou potřebou tepla na vytápění - Rodinné domy*, 2009

[11] Regulation no.148/2007 Sb. *o energetické náročnosti budov*, Ministry of the Interior of the Czech Republic, 2007