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Stavebně energetické koncepce budov jako nástroj udržitelného rozvoje

Building-Energy Concepts as a Tool for Sustainability

Summary

The potential for improving of energy related performance of buildings is enormous, long-time present, and partially achievable at today's economical conditions. Very promising practical results in respect to energy for space heating were reached at so called of low-energy buildings and passive buildings
On the way to such building design it is crucial to pay the extra attention to several physical phenomena, which were mostly already known but often neglected. Even small irregularities in placing of thermal insulating boards and/or open joints or cracks in supporting or covering layers could lead to significant reduction of overall insulating effects. The presence of leakages in the building envelopes seems to be one of the reasons, why the actual measured energy use for heating is often higher than calculated. Long-wave radiation between surface of building structure and sky as a natural phenomenon could create a serious troubles especially by high insulated ventilated (cold) roofs. The external surfaces may cool down below the dew point of the air and the condensation may form. In general, only correct building physics calculation can be advantageously used as a base for design decisions.

In the early design stage, the roughly estimated primary energy (operation) of several alternatives of the designed buildings can be used as a base for decisions. The necessary link between energy based calculations and overall sustainability assessments and the principles of integrated building design are discussed here.

Renewable energy systems can be effectively used in buildings. Some of components will be directly integrated into the building envelopes (solar collectors of different types). Their overall performance should be analyzed including traditional building physics approach: thermal transmittance of such a new envelope, risk of water vapor condensation at the back surface (mostly metallic, not permeable layers), thermal bridges due to installation and fastenings, etc.

Three examples of consequent real design with respect to building-energy concept are discussed here: two family houses with a different concept, environmentally friendly building for education having large multi-layer earth heat exchanger, and finally the photovoltaic system. Part of this system is building integrated on ventilated SW orientated facade. The CFD simulations and first measurement results are shown.

Souhrn

Potenciál zlepšení energetických vlastností budov je enormní, dlouhodobě přítomný a zčásti dosažitelný i za současných ekonomických podmínek. Velmi slibných výsledků je dosahováno u tzv. nízkoenergetických a pasivních domů. Při navrhování takových domů je mimořádně důležité se zvláště pečlivě věnovat různým stavebně-fyzikálním jevům, které byly dříve sice většinou známé, ale zanedbatelné. I malé nepravidelnosti v osazování tepelně izolačních desek a/nebo netěsné spoje a trhliny v nosných nebo krycích vrstvách mohou vést k výrazné redukci izolačních vlastností. Existence netěsností v obálce budovy, kudy může proudit vzduch, je zřejmě jedním z důvodů, proč jsou měřené hodnoty spotřeby tepla na vytápění vyšší, než se očekávalo. Dlouhovlnná radiace mezi oblohou a povrchy konstrukcí může vést k jejich podchlazení a kondenzaci vodních par v neočekávané míře. Obecně platí, že jen korektní provedené stavebně fyzikální výpočty mohou být s výhodou použity pro rozhodování během procesu navrhování.

Přibližně určená primární provozní energie již v rané fázi návrhu pro odlišné varianty řešení může být použita jako základ pro rozhodování. Je zde diskutována nezbytná vazba mezi energetickými výpočty a hodnocení širších vlastností z hlediska udržitelnosti. Jsou objasňovány principy integrovaného navrhování budov.

Obnovitelné energetické systémy mohou být v budovách použity velmi efektivně. Některé z jejich prvků jsou přímo integrovány do obvodových konstrukcí (solární kolektory různých druhů). Jejich celkové vlastnosti mají být analyzovány s využitím tradičních stavebně-fyzikálních postupů: součinitel prostupu tepla takové nové obvodové konstrukce, kontrola rizika kondenzace vodních par na zadním povrchu (jedná se zpravidla o kovové nepropustné plochy), vznik tepelných mostů v souvislosti s kotvením apod.

Dále jsou zde diskutovány tři reálné příklady důsledného návrhu s ohledem na stavebně-energetickou koncepci: dva odlišně řešené nízkoenergetické rodinné domy, budova pro environmentální výchovu používající rozsáhlé zemní výměníky tepla a dále fotovoltaická instalace. Část je integrována ve formě dvouplášťové větrané konstrukce do jihozápadní fasády. Jsou zde uvedeny první měření a CFD simulace.

Klíčová slova: Tepelné chování budov, integrované navrhování, udržitelná výstavba, nízkoenergetické budovy, provozní energie, svázaná energie, obnovitelné energetické zdroje

Key words: Thermal performance of buildings, integrated design, sustainable construction, low-energy buildings, operation energy, renewable energy sources

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Contents

1. Introduction: social context

The extremely high responsibility of construction sector in respect to energy use and overall sustainability is a well known phenomenon: Buildings in EU consume in average about 40 % of all used energy and produce approximately 30 % of CO_2 emission and 40 % of total waste. New approaches to design and constructing of buildings and to development of urban space cover several sets of criteria, which are based on general Agenda 21 UNO transformed into CIB report Agenda on Sustainable construction of buildings [1] sorted to three basic areas of sustainability:

- Environmental quality (outdoor and indoor environment)
- Economic efficiency and constraints
- Social equity and cultural issues.

This approach clearly shows the complexity of the problem. Let us concentrate on the energy problem related to buildings only, especially the *operation energy*, with a corresponding respect to the broader context of sustainability.

The potential for improving of energy related performance of buildings is enormous, long-time present, and partially achievable at today's economical conditions. The political and social context is very easy to understand: "good energy policy is the best peace policy + creating of new working places + high quality indoor conditions in the buildings". In a short time perspective, the successful implementation of the Energy performance directive (EPBD) [2] should be one of the driving forces. The dependency on energy import outside of EU today is about 50 % with strongly increasing tendency (up to 70 % within future 20 years, mainly from the politically non-stable countries). At the same time several experts confirm that the EPBD-related legislation is not consequent enough and that much more ambitious frame targets would be possible and advantageous for all. These could be expressed as necessary up to 80 % reduction of carbon dioxide emissions in 2050 as a target for the developed part of the world.

Very promising practical results in respect to energy for space heating were reached in the so called of *low-energy buildings* and *passive buildings* [3].

General perception of low-energy strategies finally seems to be visibly changing in the Czech Republic and several other European countries. This is not just an evident result of growing energy prices and other negative expectations, but also a result of the dissemination of information on successful built examples. This positive trend needs to be further supported at the levels of applied research, pilot projects, promotion and other informational activities and education. The limits to applying progressive technologies and approaches more quickly create intellectual stereotypes that are too often more difficult to overcome than the technical barriers.

The key and currently very natural challenge is to use this positive atmosphere to introduce *sustainability principles* into the construction sector. Finding a cost-acceptable solution is understandably very important. If during the initial planning phase a low-energy house is mentioned to a small private investor, it is automatically assumed that the increase in investment costs will be minimal or null. This elicits justifiable pressure to increase the efficiency of the overall solution to construction and design, i.e., even to optimize construction elements and principles that are not very related to the energy flows needed for the building's operation. Discussions on the selection of a suitable alternative can be advantageously supported with simpler or more sophisticated arguments obtained from using some methods to evaluate overall sustainability – in the simplest case expressed using operation and/or embodied primary energy from non-renewable sources.

A distinct situation is that of the strong investor for whom social prestige plays an important role (financial institutions, etc.) Here, non-traditional solutions (energy-saving, using renewable energy sources) are employed if they improve the investor‘s image, or confirm the investor's leading position in the sector, etc. The future investor must have all necessary information in a compelling form at the decisive time. Conceptually developed alternatives that include not only the usual visualization and construction-energy concepts along with the business-as-usual and best available techniques but also some very progressive „sci-fi“ alternative could be decisive. The advantage stems from when the hopeful alternative has some marked goal with good "marketing strength" (passive buildings, buildings that use mainly renewable energy sources, building without a normal heating system, without air-conditioning, but with guaranteed high quality indoor comfort, etc.).

The key to further marked advancement in society is still the systematic and qualified dissemination of information to and education of main target groups with an emphasis on the wider context of sustainability. The natural advantage of theory and practice in low-energy constructions may be used in this respect. All pilot projects and more significant private investments should be evaluated using sustainability assessment tools [4].

Czech technical standard on Thermal Protection of Buildings (Requirements) [5] was written partially in a new way, with certain professional overlap to enable the wider understanding of con-text of thermal protection of buildings, indoor comfort, HVAC-system and built sustainability. Even paragraphs and criteria from its informative only Annex A *Design instruction* are really used, by contractual parties, as a guideline for low-energy buildings, in public documents.

2. Energy balance of building

Energy balance of building considering all relevant energy flows is one of the key characteristic of the energy performance – see *Fig.1.* The assessment of energy quality (comparison with standard requirements, other recommendations) can be performed at different levels:

A limits for thermal transmittances (U-value) of particular building components
B limits for U mean value at system boundary
C specific heat use limits (related to m^2 or m^3 or heated space, space heating)
D specific energy use (space heating + hot water)
E specific primary energy need (space heating + hot water + service electricity)
F overall primary energy need (as E + electricity for appliances, related to m^2, m^3 or expressed per capita or production unit).

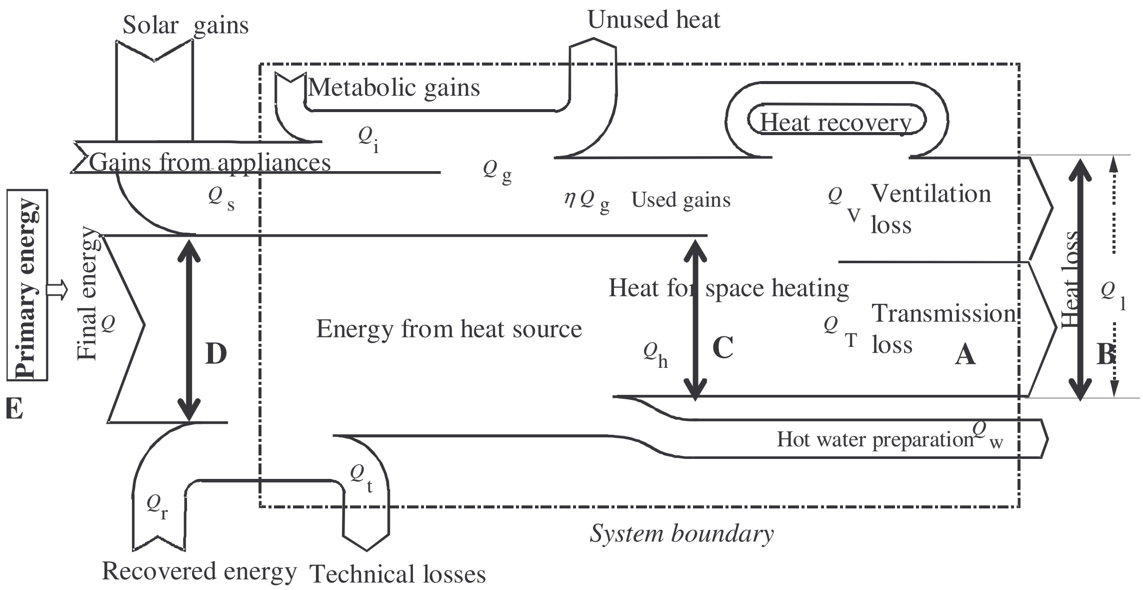


Fig.1 Principal energy balance of building (steady state for the larger time steps – typically months or weeks, or dynamical). The proportion between particular heat fluxes can vary in a wide range. The principal balance of heat losses and heat gains was extended to enable the primary energy assessments.

Typical levels

The energy requirements on building envelopes (limits of thermal transmittance) changed in time significantly, considering the period since 1949 at Czech territory (*Fig. 2*). *Fig.3* brings an overview about typical specific heat use (space heating). According to present legislation (CZ) the specific heat demand should be in the range 80 – 140 in kWh per square meter of gross floor area and year, while the mean value of existing building stock is two-times or three time higher. The passive house [6] according its definition limiting the heat use up to

15 kWh/(m²a) can be classified as the best available technology (BAT), which represents in fact the factor 7 – 10 reduction (*Tab.1*).

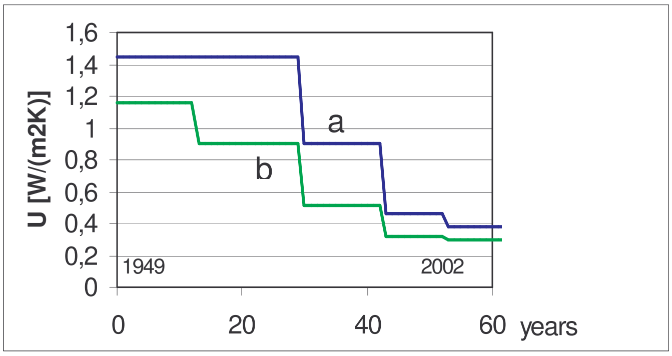


Fig. 2 Legal requirements (CZ) on energy quality of building envelopes for housing stock in last approx. sixty years expressed as required thermal transmittance (U-value) for external walls (a) and roofs (b).

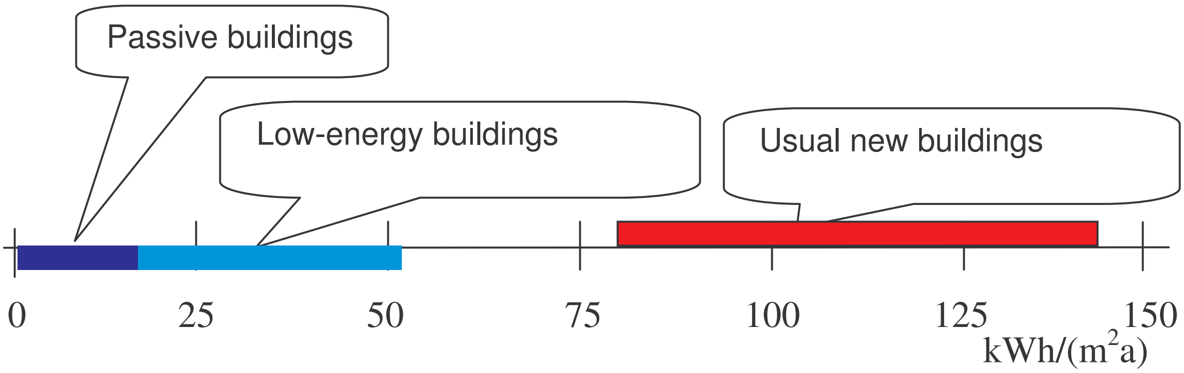


Fig.3 Typical values of specific heat use for space heating

Tab.1 Basic classification

Category	Specific heat use for space heating
Existing stock	2x – 3x higher than usual new buildings
Usual new building (requirements)	80 – 140 kWh/(m²a) depends on form factor (A/V ratio)
Low-energy building	≤ 50 kWh/(m²a)
Passive building	≤ 15 kWh/(m²a)
Zero building	≤ 5 kWh/(m²a)

The classification can be extended by *plus-energy houses*: Passive buildings having the photovoltaic system for electricity production delivered to the public grid. Such buildings produce in a yearly balance (in total) more energy than they need. Out of this classification are the totally independent energy-autarc buildings without connection to any energy supply. For passive buildings there are several other criteria to be fulfilled [6]: measured air-permeability, limits on total operation primary energy and others.

3. Challenges for building-physics

On the way to low-energy solutions of buildings described above it is crucial to pay the extra attention to several physical phenomena, which were mostly already known but often neglected. For example, due to substantial decrease of heat transmission in the building components (1D-problem), the energy effects of thermal bridges (thermal couplings as 2D or 3D-problem) become very important. The negative effects of workmanship can be also more significant at declared very good insulated building components. The *convective thermal bridges* combining both, heat transmission and heat convection due to air movement through the open joints etc. should be introduced in the analysis.

3.1 Irregularities in building envelopes

Even small irregularities in placing of thermal insulating boards and/or open joints or cracks in supporting or covering layers could lead to significant reduction of overall insulating effects.

Heat transfer through buildings envelope is calculated using thermal transmittances (U-value, 1-D) of separate building elements. The effects of thermal bridges are usually expressed by the linear thermal transmittance (Ψ-value, 2-D) and by the point thermal transmittance (χ-value, 3-D). However, the additional effects of "small" irregularities (not correct installed thermal insulating boards, different cavities, open joints, fastening, etc.) should be taken into account, too. To identify these phenomena, detailed studies were performed using a model of combined heat transfer by both, conduction and convection – see *Fig.4, 5* and followed by full-scale laboratory observations – *see Fig.6.*

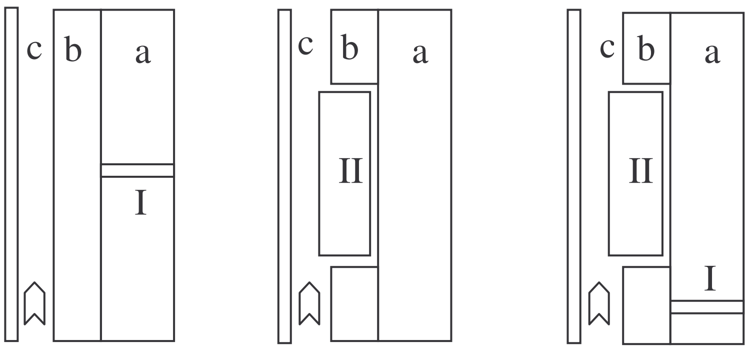


Fig.4 Scheme of studied construction – internal part of double skin facade with irregularities (a - load-bearing layer (200 mm concrete), b – insulating layer (100 mm mineral wool), c - ventilated air cavity, I – open joint with thickness of 1 mm, II – insulating board at a distance of 5 mm)

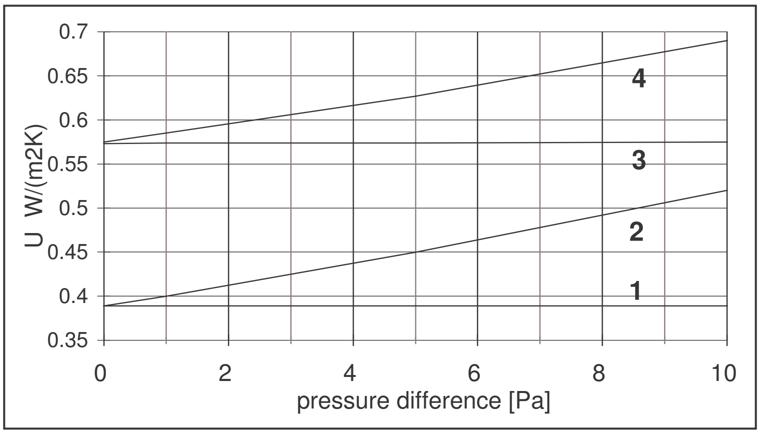


Fig.5 Thermal transmittance of constructions with irregularities corresponding previous fig. Result of numerical simulation (1-ideal, 2-open joint in load-bearing layer, 3-insulating board at distance 5 mm, 4-combination: open joint + insulation without contact)

To documents this, the full size model of internal part of a double skin facade with artificially created irregularities was placed to the front side of the cold box. The surface temperature was investigated using both, thermocouples and infrared thermography. The temperature profiles in the area of irregularity looks similar for both situations presented here - (a) adjacent insulating boards at a distance of 16 mm and (b) open joint 1 mm in gypsum board - see *Fig.6*.

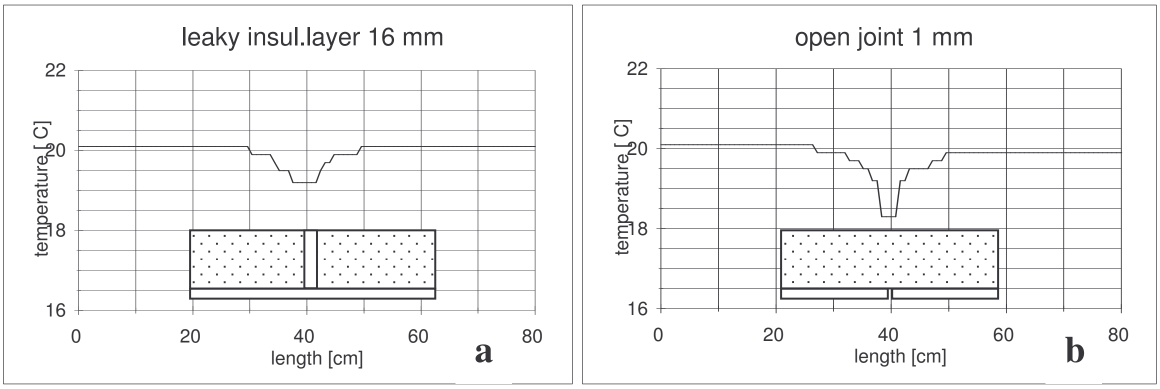


Fig.6 Decrease of internal surface temperature on 1:1 scale model of the internal part of a double skin construction with irregularities - laboratory measurement,

a) gypsum board, 100 mm polystyrene with 16 mm distance between adjacent boards

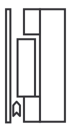
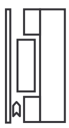
b) gypsum board with 1 mm open joint, 100 mm mineral wool

The irregularities can be treated like thermal bridges (*linear thermal bridges* for open joints etc., *point thermal bridges* for not well placed boards). The commonly accepted approach could be easily extended as follows:

$$\boldsymbol{L} = \underbrace{\sum \boldsymbol{U}_i \boldsymbol{A}_i + \left(\sum \Psi_k \boldsymbol{l}_k + \sum \chi_j\right)}_{\text{usual scheme [3]}} + \underbrace{\left(\sum \overline{\Psi}_k \boldsymbol{l}_k + \sum \overline{\chi}_j\right)}_{\text{effects of irregularities}}$$

Corresponding data from the numerical studies are collected in *Tab.2*. This method is to be used for: a) draft analysing of real situation on site, and b) for creating safety factors related to the type of construction in the future.

Tab.2 Additional linear and point thermal transmittances of irregularities

Irregularity	**Description** (assumed 10 Pa air pressure difference)	**Additional linear thermal transmittance Ψ [W/mK]**	**Additional point thermal transmittance χ [W/K]**
	distance 5 mm between adjacent insulating boards	**0,18**	
	open joint (gap) in supporting layer 1 mm	for mineral wool **0,13** for EPS **0,01**	
	insulating board at distance 5 mm from supporting layer, cold air penetration		**0,14**
	insulating board at distance 5 mm from supporting layer, cold air convection		**0,27**

3.2 Thermal transmittance in 3D

In some cases it is necessary to use more-dimensional heat transfer model for evaluation of thermal transmittance. The simplification of the real situation can lead to un-acceptable high differences between the reality and estimated values used further as the inputs for overall energy assessments of particular building. In the example in *Fig.7* the overestimation of insulating effects by simple 1-D calculation was about 100 %! In such cases the water vapor condensation risks should be assessed more-dimensional, too [7].

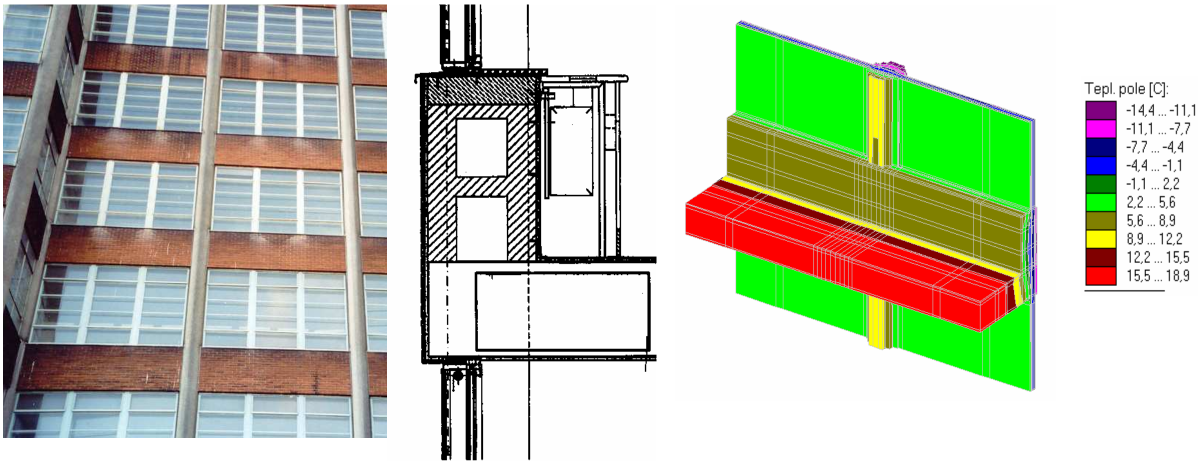


Fig.7 Examples of 3-D heat transfer models for repeated segment of the building envelope – Bata Office Building in Zlín

3.3 Overall air-permeability

The presence of leakages in the building envelopes seems to be one of the reasons, why the actual measured energy use for heating is often higher than calculated. The pressure difference between the interior and exterior leads to local air flow through the leakages. High air permeability has a negative influence on the internal thermal comfort. Under certain conditions, a significant transport of water vapour into the construction is presenting, too. The efficiency of the mechanical ventilation systems could be significantly influenced.

The driving force of the air flow through the leakages in the building envelopes is the pressure difference between interior and exterior. Most important factors are wind, stack effect and mechanical ventilation systems.

To study these problems the *fan pressurization method* is to be used (Blower-door technique) [8]. Several *in-situ* observations on buildings were carried out [9]. The fan pressurisation method can be followed by infrared thermography to make the irregularities of building envelope more visible. The air change rate by 50 Pa pressure difference n_{50} is usually much higher than recommended [5].

3.4 Long-wave radiation

Long-wave radiation between surface of building structure and sky as a natural phenomenon could create a serious troubles especially by high insulated ventilated (cold) roofs. The external surfaces may cool down below the dew point of the air and the condensation may form [10] – see *Fig.8*. Typically, the covering of cold roofs has a low thermal resistance and the condensation may form also on its downside. The amounts of condensation could be surprising high (much higher than the results of usual vapor diffusion calculation), even by temperatures of external air about 0 ^{o}C and higher. In the past, this effect was at least partially overlapped by heat loss flux coming from the interior through the lower part of the roof.

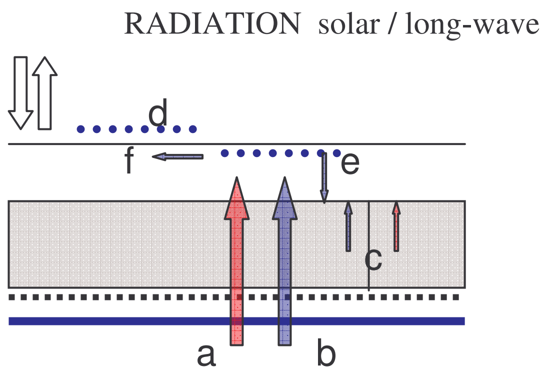
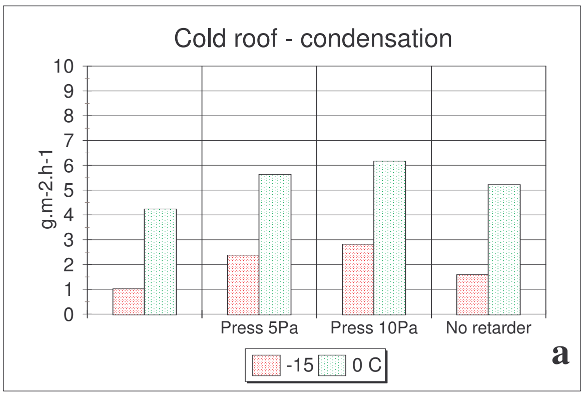


Fig.8 Scheme of a ventilated (cold) roof considering the radiation effects. (a-heat flux (heat loss), b-water vapor diffusion, c-local failure (open joint etc.), d-condensation on external surface, e-condensation on downside of the roofing, f-collection of condensed water)

Radiation heat flow (approx. 57 – 66 W/m^2 for clear sky in winter condition) was estimated and used for heat and moisture transfer including the water vapor surface condensation in the ventilated roof cavity [10]. To illustrate this phenomenon several calculation were performed for typical light-weight ventilated roof (U-value 0,16 $W/(m^2K)$) in different situations concerning the quality of water vapour retarder (ideal, without retarder and with retarder of degraded quality caused by open joints). The mean values of condensation along the air path are shown in *Fig.9a.* The amount of collected moisture in the strips 1 m wide and 10 m long (from the ridge to the gutter) is illustrated in *Fig.9b.* The situation in non-ventilated roof with identical layers is compared here. Corresponding measure should be designed for highly insulated roofs to prevent the (temporary but quite intensive) moisture problems.



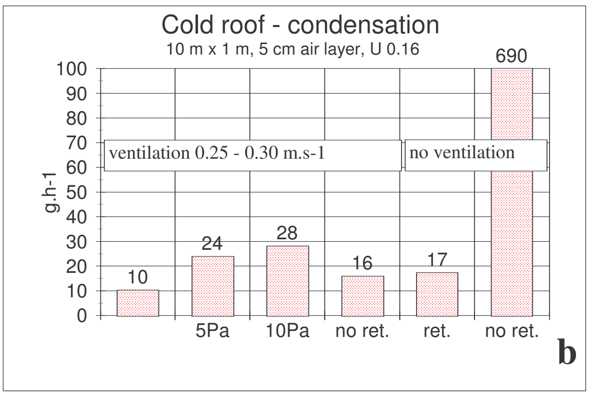


Fig.9 Condensation in cold roof – case study for different quality of water vapour retarder, by presence of 5 Pa and 10 Pa barometric pressure difference when the cracks or open joints are present. a) amount of condensed water in g/(m2.h), b) collected amount of condensed water.

4. Building-energy concepts in the design procedure

In the early design stage, the roughly estimated primary energy (operation) of several alternatives of the designed buildings can be used as a base for decisions – see level E, F in *Chapter 2*. The more precise assessment can be added later together with the extension on embodied energy values (*Fig.10*), and overall environmental loadings (c) using relevant scheme [4].

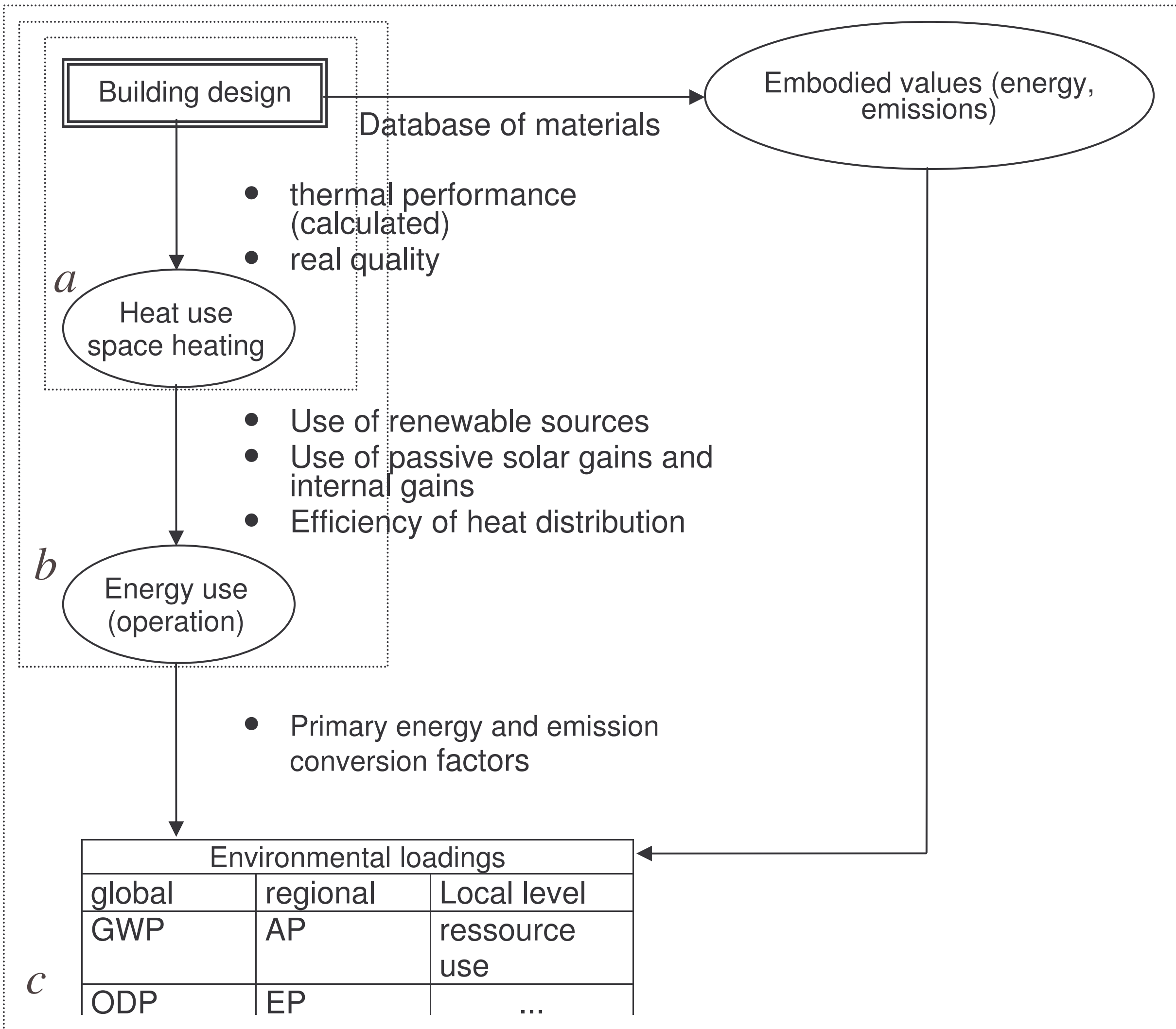


Fig.10 Scheme of more complex multi-level approach for assessments of designed alternatives (GWP global warming, ODP ozone depletion, AP acidification, EP eutrophication potentials, etc.)

Fig.11 brings typical values of conversion factors between heat demand and primary energy from non-renewable sources together with the energy use reduction expressed in the same way (annualized embodied energy in insulating materials resulting in decreased operation energy use). Naturally, the "*ideal strategy*" will be the following – reduction of energy demand as much as possible (using components and techniques close to BAT –level) and covering the by renewable sources (solar + biomass). Such solutions bring probably the shortest *energy-pay back time*. Similar arguments can be achieved using the operation and embodied carbon dioxide values. *Real strategy* will differ from the ideal one from several reasons: individual priorities of stake holders, local and financial conditions, results of overall sustainability assessments considering broader sets of parameters etc.

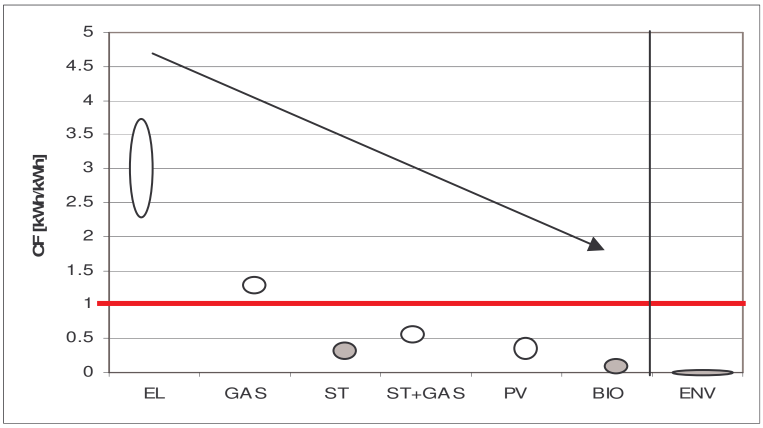


Fig.11 Primary energy conversion factor for different energy carriers together with energy saving measures (EL electricity from public grid, GAS natural gas, ST solar thermal systems, ST+GAS typical yearly value for hot water 60% covered by solar system, PV photovoltaic system, BIO wood, wooden pellets, etc., ENV demand reduction due to better envelopes)

The energy performance calculations can be used as a real design tool very effectively. As an example, the *Fig.12* presents the building of kindergarten in Ostrava - Proskovice in original stage (2001) and after refurbishment (2003). Several alternatives were analyzed in advance (*Fig.13*). The extension of the building (approx. doubling the floor area) at low-energy level, with almost 100 % use of renewable energy for heating and hot water was finally performed [11].

Fig.12 Kindergarten in Ostrava-Proskovice before and after refurbishment (pitched roof is covered by roof integrated solar collector- 120 m^2)

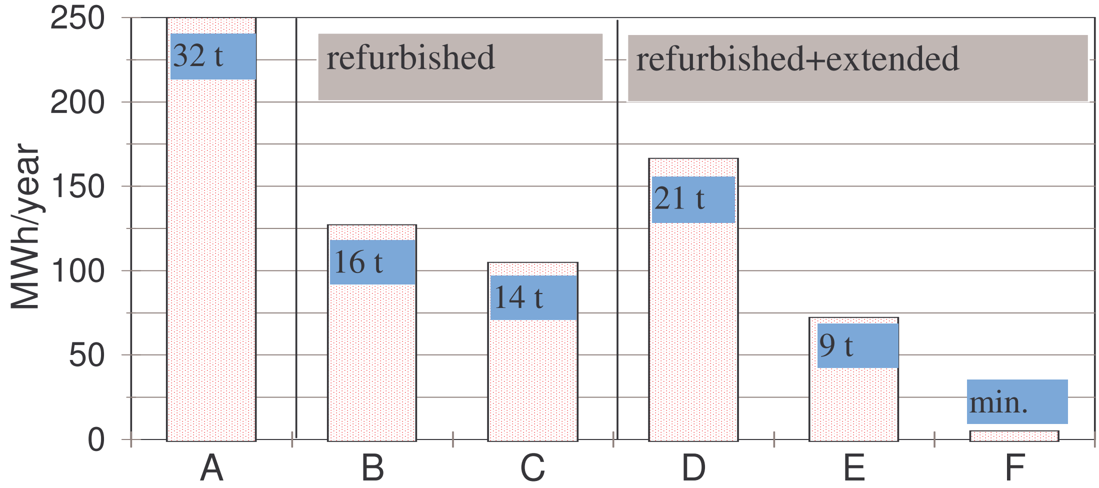


Fig.13 Kindergarten in Ostrava Proskovice. Comparison of several alternatives and sub-alternatives expressed in primary energy use for heating (A for existing building, B-C energy refurbishment of building envelope at different but traditional level, D-F for refurbishment of existing part + new attic area with flats, D according to requirements on thermal transmittance, E-F for low-energy building with mechanical ventilation system and heat recovery, A-E with gas boiler, F large solar system roof integrated + biomass heating. Additionally, the yearly amount of carbon dioxide emissions related to heating (in tons). The alternative F was performed

As already mentioned in *Chapter 2* passive house standard can be understood as an overall BAT-level in respect to space heating. Hundreds of built examples are clearly showing that such excellent values can be reached:

a. without penalizing the indoor quality,
b. without negative influence on the architectural quality,
c. with fully competitive construction costs (additional costs up to 0 - 7 %).

To be sure that also the broader environmental qualities are at corresponding high level the primary energy assessment is obligatory here [4]. Typically, the energy for space heating doesn't play the most important role in the energy balance: space heating, hot water and energy for appliances are in the final energy approx. in the same range. Assuming that usually 60-70 % of hot water energy need is covered by the solar thermal system, the energy balance can perform as presented in *Fig.14, 15*.

It seems to be possible and environmentally correct to build a house at close-to-zero energy level, considering overall energy demand – not only space heating according *Tab.1*. The principle for residential buildings could be described as follows:

a. passive house level (space heating)
b. solar thermal system covering 60-70 % hot water energy demand
c. large PV-system (grid-on). For single family house approx. 60-70 m^2

The total final energy demand can be covered in year total by PV-electricity production delivered to public grid.

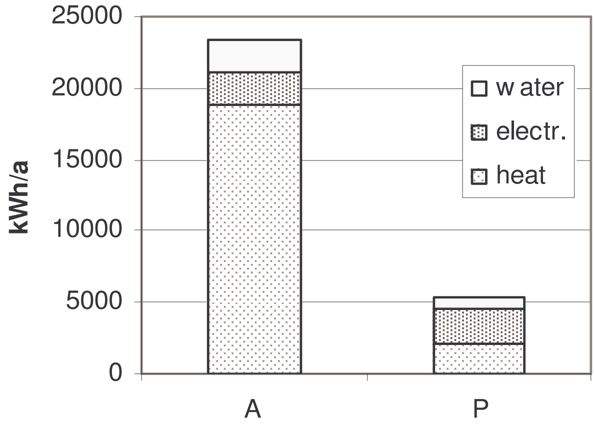


Fig.14 Delivered energy for a typical family house. (A common solution, standard according to legal requirements, P passive house (heat use 15 kWh/(m^{2}a), 60 % energy for hot water covered by a solar thermal system).

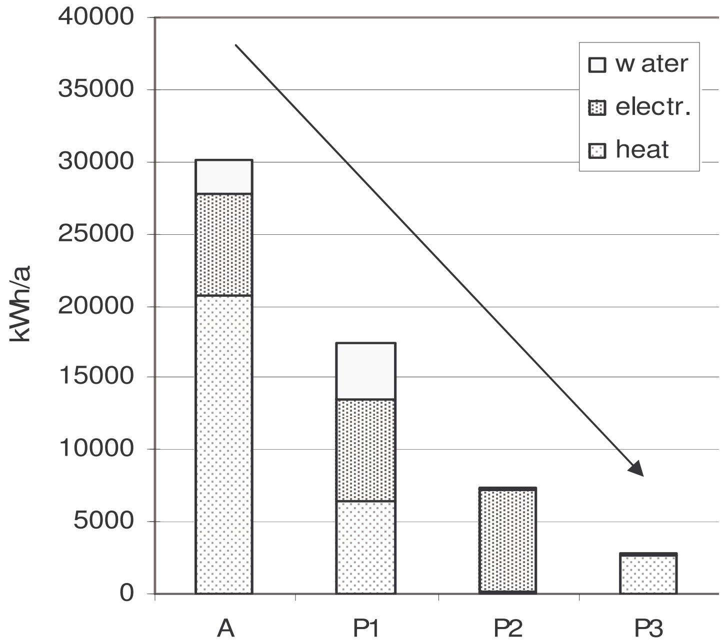


Fig.15 Case study of primary energy (see Fig 14). (A common house with gas heating, P passive house with a solar thermal system for hot water preparation and with different energy sources for heating +for the 40% of the hot water preparation by: P1 electricity from public grid, P2 wood, biomass, bio-alcohol etc., P3 represents a zero-energy house in annual total, taking into account both delivered and produced energy by PV grid-on).

Fig.16 Study of solar-optimized solution for a passive house at close-to-zero energy level (developed from a real design of passive house [12]). The PV system covers the entrance area of the building and also the adjacent roof (independent structure guarantees good ventilation of solar panels fixed). Other smaller parts of the PV systems, i.e., those that are semi-transparent, are situated in a vertical position in front of the facade. Solar thermal system is integrated in the roof together with PV panels in strips near the gable wall.

5. Integration of renewable energy systems

Renewable energy systems can be effectively used in buildings. Some of components will be directly integrated into the building envelopes (solar collectors of different types). Their overall performance should be analyzed including traditional building physics approach: thermal transmittance of such a new envelope, risk of water vapor condensation at the back surface (mostly metallic, not permeable layers), thermal bridges due to installation and fastenings, etc.

Considering the *photovoltaic systems* (PV) for example, the term *integration* can be understood in different ways: Integration of PV-produced energy into the energy balance of building, integration as the architectural design (visual) problem, integration into investment and operation costs, etc.

The methodology of optimized solar energy use in relation to the building (solar-thermal, photovoltaic, semi-transparent photovoltaic systems, transparent insulation, system dealing with solar passive gains, etc.) is the subject of further research studies. Only a deeper understanding of the relevant phenomena could lead to a significant change in practice. It is necessary to understand all effects from integrating these systems, and the consequences of their synergy performance in terms of the building's energy balance, etc.

Earth heat exchanger (EAHX) [13] are the systems using in a very naturally way the energy in the earth for the conditioning of buildings in order to save energy and to reduce the investment costs. The correct design of such system is not simple, the empiric knowledge is missing. The operation modes respecting the local condition and building needs should differ in a wide range. New methods for simulation of the total performance of such systems were developed, solving the problems of the time depending heat transfer, dealing with condensation risks (summer conditions).

6 Examples

6.1 Two low-energy family houses

The selected examples should document the variety of solutions – in architectural form, construction and material concepts for low-energy houses.

Fig.17-19 present the wooden based low-energy, single family house built in 2003 with calculated specific heat use about 44 kWh/(m^2a) (~ 30 % of admissible value). The simple EAHX built here (one tube, 21 m in lengths, approx.2 m deep) helps efficiently to prevent overheating in extreme hot days and brings the reduction of energy use in winter condition. Solar thermal collectors are roof integrated.

Fig. 17 House W (design M.Šenberger, J.Tywoniak, et al.) built 2003. Low-energy house (44 kWh/(m^2a)) using passive house components: mechanical ventilation with efficient heat recovery, earth heat exchanger 21 m, 1 m^3 water accumulator in service room, integrated solar system (net area 8,1 m^2) + electric heating rods, additional local heat source in living space (wood).

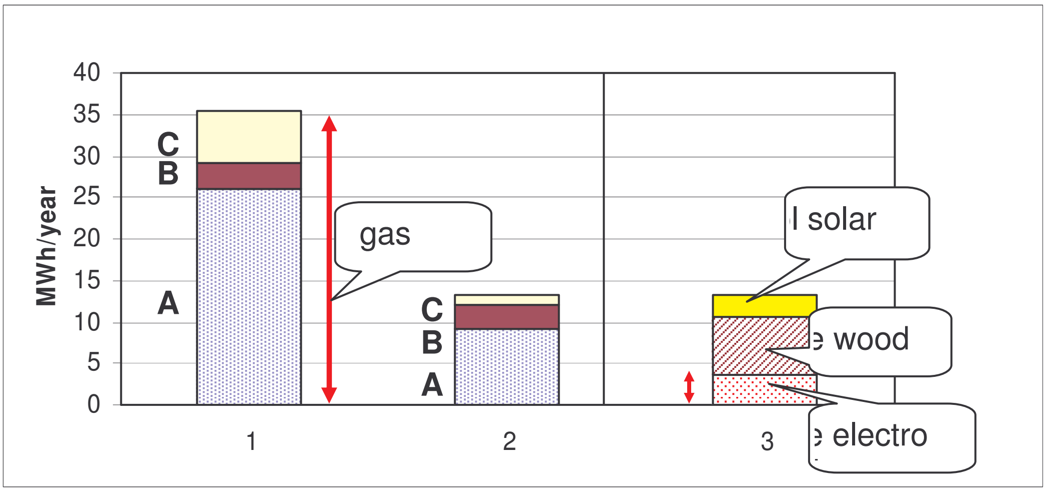


Fig.18 Preliminary energy balance for reference building (1) and house W (2,3), (A heat use for space heating, B heat use for hot water, C system losses, reference building represents a typical solution fulfilling the requirements, with natural ventilation and gas boiler)

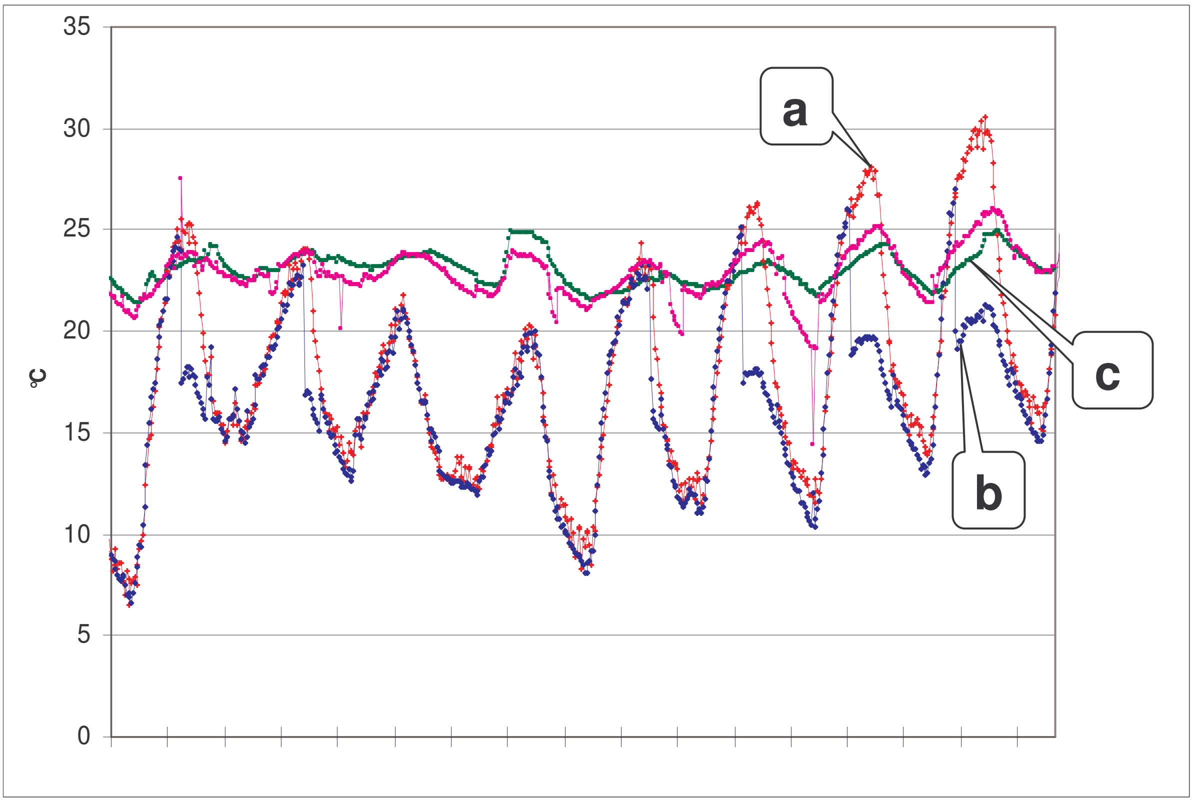


Fig.19 From long time measurement of the earth heat exchanger in house W: If the external air temperature is higher than 25 °C (curve a) the fresh air comes through the earth heat exchanger to the ventilation unit (b). The indoor air temperature in living space doesn't exceed the 25 °C in this case, even by intensive use of the building (c, admissible is 27 °C).

Fig. 20 presents the low-energy single family house (house F) built in 2004 with calculated specific heat use about 30 kWh/(m^2a) (~ 25 % of admissible value). The massive building envelope (lightweight concrete element masonry with external thermal insulating layer 22 cm mineral wool) and concrete floor structure was used here. The large glazed area on SW façade is partially shaded by metallic structure (separate, to avoid thermal bridges) and by movable wooden elements. The garage and storage are consequently excluded from heated volume. The solar thermal system (8 m^2) creates an important architectural element. The additional investment costs for higher amount of thermal insulating material, mechanical ventilation with heat recovery, integrated heat accumulator with direct hot water preparation were estimated approx. by 7 % of usual costs. The pay-back calculated in the simplest way using the present energy costs (2004) is lower than 13 years. The energy pay-back (annualized embodied energy / operating energy) is expected by 3 years.

Note: The use of the best available windows (thermal transmittance approx. 0,8 W/(m^2K)) without other improvements could lead to further significant energy need reduction by 22 kWh/(m^2a), which is very close to passive-house standard).

Fig. 20 House F (design J.Tywoniak et al.) with expected specific heat use for space heating by 30 kWh/(m^2a). The windows area: SW 30 %, SE 12 %, NE 6 % of particular façade.

Tab.3 gives an overview about proportion in thermal transmittance. The energy effect of thermal couplings (thermal bridges) is not trivial. Based on calculations of multidimensional heat transfer, their effect doesn't exceed 5% of total transmission heat losses due to carefully optimized design.

Tab.3 House F – Analysis of transmission heat losses based on multidimensional heat transfer calculation

		[W/K]	[%]
Transmission heat loss (total)		131,3	100
Building components (opaque)		53,9	41
Doors, windows		56,4	43
via the ground		14,1	11
Thermal bridges, thermal couplings		6,9	**5**
(100%)	Walls/roofs couplings (negative value due to external dimension calculations)	-0,52	-7,6
	Walls/windows	3,05	**44,4**
	Walls/ground	3,12	**45,4**
	Fastening of shading system	0,10	1,5
	Fastening of metallic structure in two points only	0,02	0,2
	Fastening of handrails for two windows at SE façade only (due to later change of window size)	1,10	**16,0**

6.2 Building as a learning instrument

The Slunakov Ecological Education Center (SEV) [14] *(Fig.21)* has been designed to educate the public about the environment and its processes and to support public environmental awareness. This consequently designed energy-saving building using elements of alternative energy sources (solar + biomass) will also provide the public with an example of the possibilities available when designing ecological housing and promote sustainable development.

The idea of architects to create the earth-sheltered northern side of the building fluently adjoining the green roof was reflected in the building-energy concept. The space available in the curved earth mound and the need for a large flow of air in the summer months led to the use of the earth heat exchanger system with 3 sets, a total of 16 pipes 250 mm in diameter, length approx. 32 – 35 m, at 3 altitudinal levels. The designed solution can be classified as a good compromise between the highest energy efficiency, pressure losses and the investment costs.

The total absorption surface of low-flow solar collectors placed on the open green space near the entrance area is 85 m^2. A solar accumulation tank (13 m^3) will provide heat for hot water preparation for 4-5 days of no sunshine.

The primary energy need for heating, hot water and service electricity (funs, pumps etc.) is only about 3 % of common solution of the building with the same size and purpose (gas heating, mechanical cooling,..).

Fig.21 SEV building visualization (PROJEKTIL Architekti, energy-concept Tywoniak). Building is under construction now.

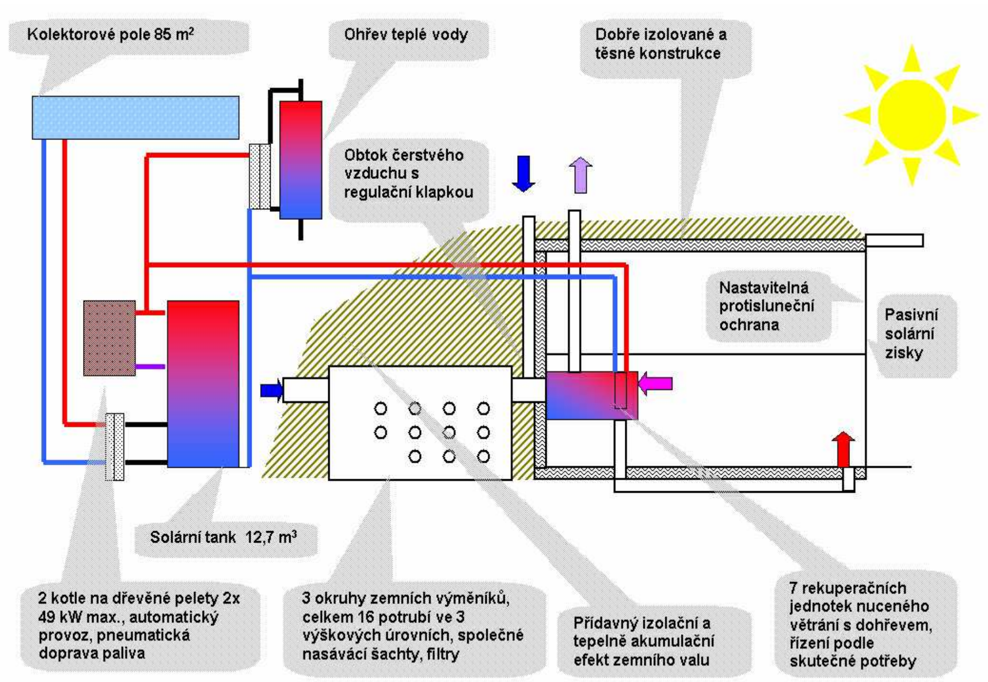


Fig.22 Building-energy concept of SEV building

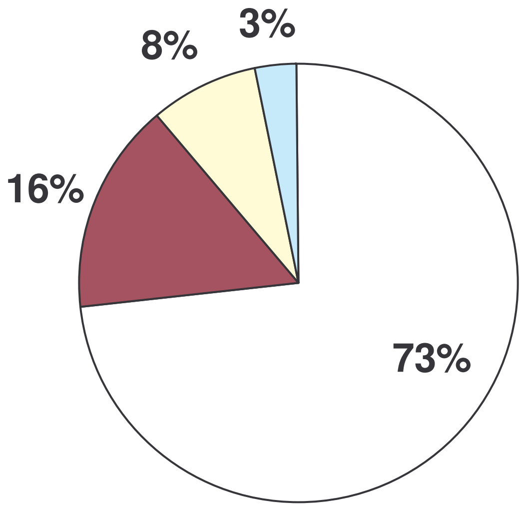


Fig.23 Total energy balance of SEV building. The most important part is the energy saving due to optimized building structures and heat recovery in ventilation units. The energy demand is covered by renewable sources: wooden pellets (16%), solar energy (8%) and earth heat (3%). 100% corresponds to typical solution fulfilling the requirements). Electricity for appliances is not included.

6.3 Building integrated photovoltaic installation for research and education

During 2005 a large-scale experimental PV installation was erected at the Faculty of Civil Engineering Czech Technical University (FCE CTU) campus building in Prague [ ]. Total output power of 40,9 kWp (peak value). The system consists of two parts - a mechanically ventilated PV facade and an open-rack roof PV installation (*Fig.24*). A total of 386 monocrystallic PV panels were used (176 on the facade, 210 on the roof). The system is divided into seven independent groups of panels with different geographic orientation each of which is equipped with a DC/AC converter. The energy produced is delivered to the building grid.

Fig.24 Ventilated PV facade at FCE CTU and a part of roof installation.

The research focuses especially on building-physics, energy and structural phenomena, e.g. the effects of PV-facade ventilation on conversion efficiency enhancement, air gap geometry design, ventilation system design and optimization of waste heat removal and possibilities of waste heat utilization. A numerical model is being developed to predict performance characteristics of ventilated building integrated PV systems. The facade installation is equipped with extensive devices to measure key physical quantities, like PV panels' backside surface temperature, air temperature and air velocity in the ventilated gap and global radiation on the panels' surface.

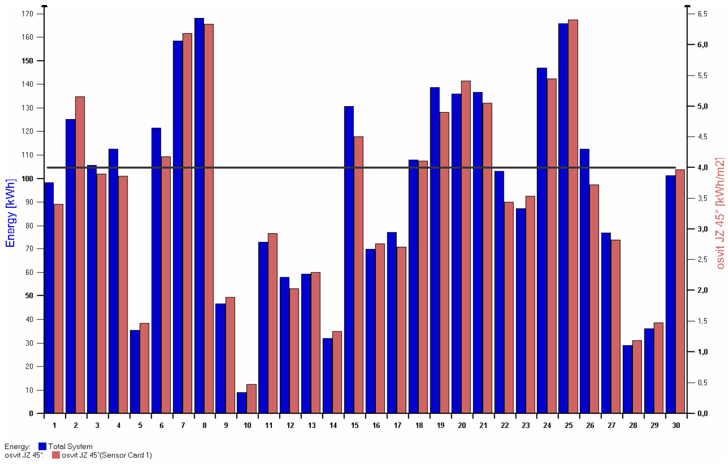


Fig.25 Electricity production (dark blue) of a total PV- system in April 2006 (daily mean value 95,3 kWh, maximum 168 kWh) and irradiation on SW, 45° sloped surface (kWh/m^2)

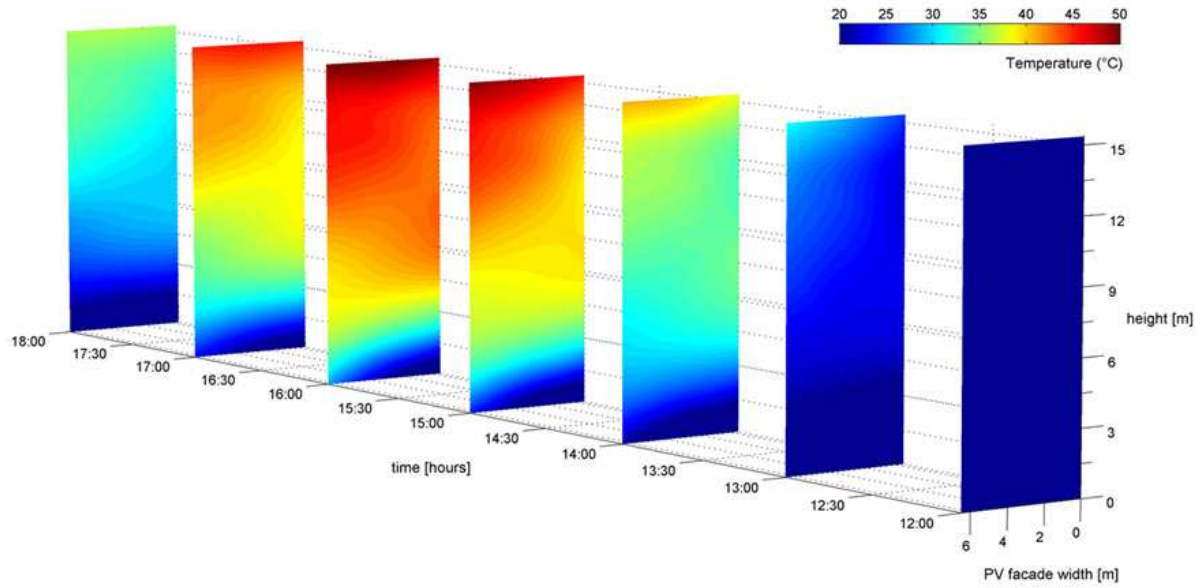


Fig.26 Measured temperatures at back side of PV-façade (SW orientation, 12:00 a.m.-18 p.m. 8.4.2006)

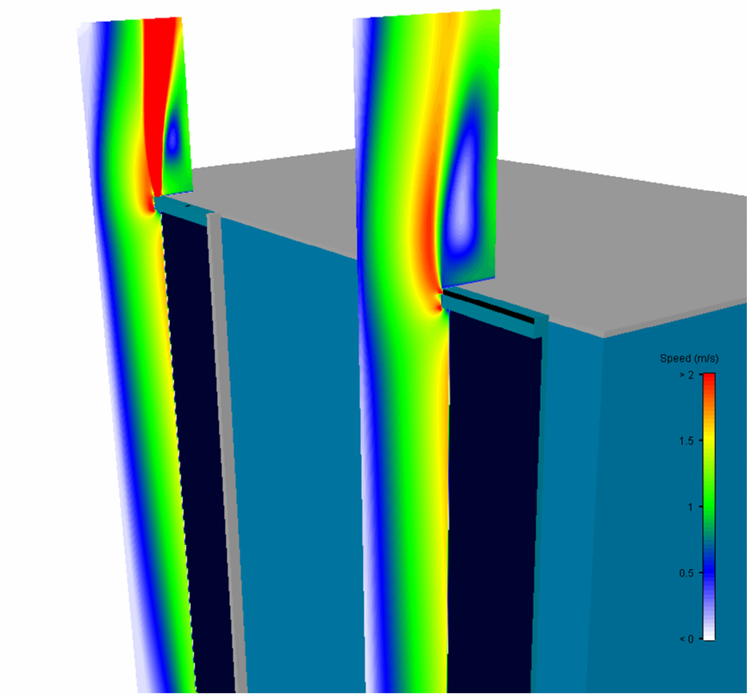


Fig. 27 Example of CFD simulations studying the effects in ventilated space of double skin façade with integrated PV-systems (air velocity distribution in vertical cross sections, left hand side: air movement in cavity supported by fans, right hand side natural convection)

7. Conclusion

New situation in energy policy on one hand, enormous energy saving potential of existing buildings together with promising results in low-energy and passive buildings on the other hand should be reflected in both, further research aims and in university education.

Deeper understanding of the relation between energy demand, energy savings due to overall better solution of buildings and use of renewable energy systems is necessary. The building physics, especially the theories of thermal performance of buildings, can be very helpful. The building-energy concepts presented here could play the leading role. Of course, together with overall performance assessment (sustainability agenda).

Recently, several very sophisticated software tools were developed to enable to simulate future situations in buildings and their parts. This is especially important for progressive solutions where traditionally made estimations based on empiric knowledge are not more valid. An excellent knowledge of theoretical fundamentals is needed to work with such instruments consequently and to obtain plausible results.

In the near future, the building design teams have to be changed: The *integrated design approach* [16] should be introduced in a large scale, regardless who is the project leader. The building-energy concepts can be used in different design stages, starting advantageously very early. The energy based optimization could be discussed in parallel with structural solutions. Therefore, a necessary "financial space" can be found which enable to use some advanced energy system. A substantial part of every design decisions should be the life-cycle consideration.

The negative expectations related to energy supply and the positive examples of solutions are the main characteristics of the current development of building-energy concepts. This concentration of interest could lead to the faster adoption of broader evaluative approaches to sustainable buildings, in which energy questions remain the driving force of this process. All of this can lead to an actual "inventory" of approaches and criteria to date.

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Education and qualification

1998 Doc. (Assoc.Prof.) thesis: On moisture balance of constructions, Faculty of Civil Engineering, Czech Technical University in Prague (CTU FCE)

1983-1989 CSc. (PhD.) study at CTU FCE, thesis: Contribution to solutions of moisture problems in buildings

1976-1981 Ing. (MSc.) CTU FCE

Professional positions

1998 – ff Assoc.Prof CTU FCE, Dept.of Building Structures

1986 – 1998 Assistant Professor CTU FCE, Dept. of Building Structures

1990 – 1996 Design and consulting in RedeS s.r.o., Prague

1991 – 1992 Consulting in Wolfseher und Partner A.G. Zurig

Teaching activities

Lectures - since l992

Building physics 2 (Thermal performance of buildings)

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Thermal protection of building in environmental context (PhD courses)

Practical training and seminars

Building physics 2, Energy and environment, Design projects, Diploma projects (18 in total), 2 successful PhD-students

Activities in international and national associations

2005 – ff vice-chairman of Czech Sustainable Building Society iiSBE CZ

2003 – ff member of Academic Senate of CTU FCE

2004 – ff chairman of group 14 Thermal protection of buildings, Society for Environmental Technique STP

1997 – ff chair of CZ standardization com. Thermal protection of building

1997 – ff member of CEN TC89/WG 4 and Czech delegate in CEN TC89

Visiting positions

1994 – 2000 several short stays at DTU Lyngby and TU Vienna

1990 – 1992 Research stay at ETH Zurig (22 month)

1989 TU Vienna (3month)

Research projects

1997 – 2000 AKTION 15P18, 19P21 together with TU Vienna

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1997 GAČR 103/94/0932 (Composite structures, Thermal analysis)
2003 –ff GAČR 103/03/H089 Sustainable building and sustainable development of urban space
2000 – 2004 MSM 210000005 Ekological aspects in construction industry
2005 – ff MSM 6840770005 Sustainable construction
2005 – ff member of research team CIDEAS

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