LOW-ENERGY BUILDING HEATING SYSTEM MODELLING

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ABSTRACT

The paper is discussing problems of modelling of those elements in low-energy building design process. There is preview of the mathematical approaches and tools, which could be used to evaluate and predict energy-environmental aspects of the low-energy building systems design process. Discussion is supported by evaluation of case study of energy system in low energy building using ESP-r. The evaluation is focused on energy consumption in the conditions of the Czech Republic.

INTRODUCTION

Low-energy building heating design concept in climate conditions of Central Europe is based on minimising of heating energy consumption as one of the critical criterions in building design aiming to decrease total energy consumption and environmental pollution. Problematic of low energy buildings is not only in perfect thermal insulation of the building envelope, but also in design and control of heating systems, which are distributors of energy in the building and main producers of the operational pollution (Kabele,K.,2002). Heating system must cover transmission and ventilation heat loss. Comparing with traditional buildings, where the main part of heat loss was in transmission, the low-energy buildings are typical with reverse ratio of transmission and ventilation heat loss. There are several building elements, which are used to minimize energy consumption (Kabele K., Kadlecová M., Matoušovic T., Centnerová L.,1999). Besides well insulated building envelope there are elements like heat recovery, controlled air exchange rate, earth pre-heater, accumulation, solar energy utilisation (PV and water systems), wind energy utilisation and systems like warm-air heating. Development of requirements on thermal properties of new buildings in them Czech Republic is now at this stage, that each new building, built from public finances or private finances with annual energy consumption over 700 GJ, could be considered as low-energy building with

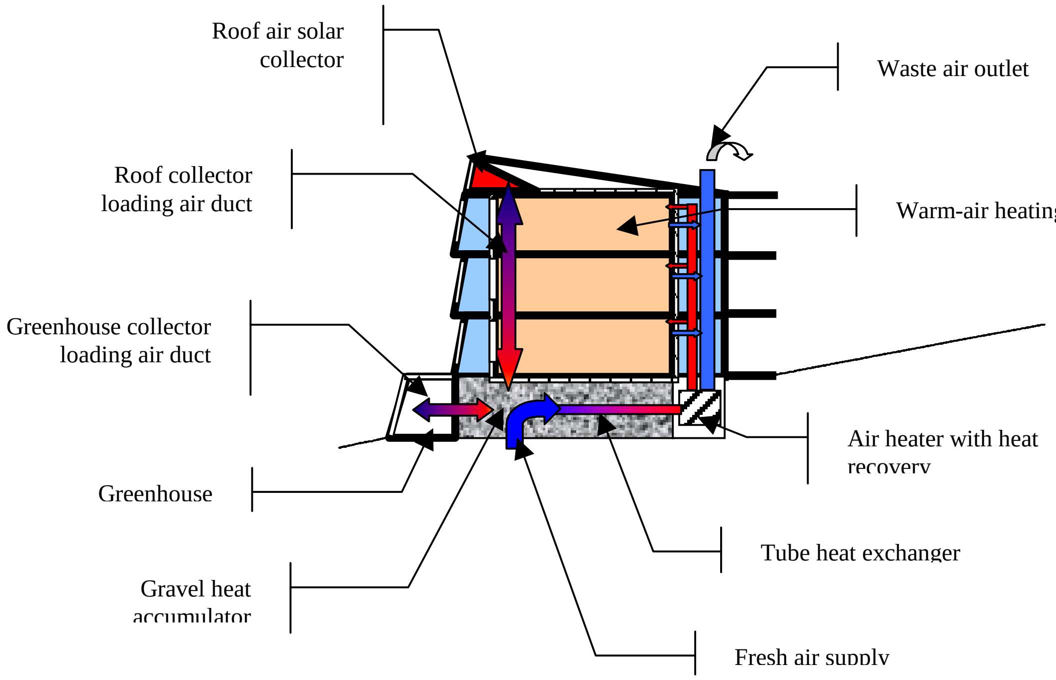
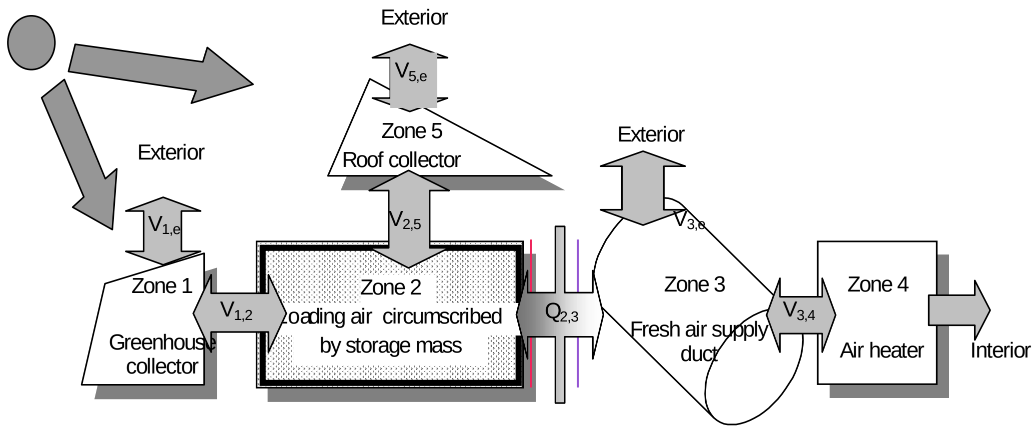


Figure 1.Scheme of the low energy building energy system



specific energy consumption from 80 up to 140 kWh/m^{2}a [1]. That is approximately 1/3 comparing to existing buildings, where specific heat consumption is in range 210-300 kWh/m^{2}a.

Within the new buildings it is necessary to calculate with specific heating output 30 up 60 W/m^2 of heated floor area. This property has impact to the heating system, which should enable to operate in much lower outputs than in existing buildings (Kabele,K., Centnerová L.,Krtková,Z.,2001).

PROBLEM ANALYSIS

Presented study is example, how to use modelling and simulation of building energy performance during conceptual stage of building design process. At the beginning of this case study was architect's idea to use green house and part of the roof like a air solar collector and top store energy in underground gravel storage in the space below the building. The questions were – will this system work; what will be contribution of this system to total energy balance? At this design stage, there was only coarse idea about shape of the building, size of the zones and therefor it was not possible to go to deep into the details in input and, of course, not to expect exact results. Accurancy of the results is adequate to the accurancy of the inputs and therefor we tried to find optimal level of detail in the zones description.

The section of the building is on the figure 1, operational scheme of the analysed system is on the figure 2. The building is equipped with two sets of air solar collectors. One is created by south-faced glazed cavity in the roof space, second one is in front of the building, created by green-house space. Accumulator is created by free strewn gravel in thermal insulated space below the house. Accumulator loading is solved by uniform air exchange of entire volume of the gravel by "loading air", which is heated up in above mentioned air solar collectors. If the loading air temperature is higher than gravel accumulator temperature, load fans are switched on and circulation of the air between accumulator and collectors is running. This circulation is terminated by balanced temperature between the collector and accumulator.

Accumulator unload is solved by air-tight tube heat exchanger, represented by plastic pipes register. Through this heat-exchanger is supplied all fresh air, used for controlled ventilation and heating of the building. Fresh air, pre-heated in this accumulator, is further heated to the required temperature in traditional air-conditioning heater unit and than transported into the flats.

MODEL

To analyse thermal behaviour of system elements, we used ESP-r (ESRU,1996) modelling and simulation environment (Clarke, J.A.,1985). We divided entire system into five thermal zones according to the scheme (figure 2). Zones of the roof collector and greenhouse (zones 1 and 5) were modelled like standard thermal zones in the building, with given thermo-physical properties of surrounding constructions (Kabele,K. 1998). These two zones are loaded with fixed infiltration rate 0.3 ACH ($V_{1,0}$), which represents untightness of the zone envelope construction. At the decision phase of the model design we discussed also possibility of setting-up flow network, but at this level of design of the system components there were no more details about construction and we decided to use fixed infiltration rate.

[1] kWh/m^2/a – kilowatt-hours per square meter per year (*a* is abbreviation from Latin *annum* = year)

Zone 2 – gravel heat accumulator was modelled by transformation of the mass and surface of the gravel into the concave rectangular paralellelepipedwith similar thermo-physical properties. Mass of the gravel was concentrated into the walls of the rectangular paralellelepipedwith and on the outside surface of the walls was set fixed temperature +14°C according to preliminary simulation calculation of the average long-term gravel stones core temperature. Transformation is based on equal physical parameters in terms of heated surface, thermal capacity and heat transfer coefficient. Validation by real physical measurements of such model is problematic (no of existing gravel accumulators is available for measurements)and therefor we compared the results with results of specialized model for underground heat exchangers used for air pre-heating or pre-cooling(Passiv Haus Institut,1999, Kabele, 2002).

Zone 2 is loaded only by loading air exchange with collectors ($V_{1,2}$, $V_{2,5}$) and heat transfer through the walls of tube heat exchanger for fresh air supply ($Q_{2,3}$).Zone 3 represents inside of pipe heat exchanger for fresh air supply into the building. Common wall of the zones 2 and 3 surface is equal to the surface of the tube heat exchanger bank of pipes, the wall material has equal properties like the pipe. Zone 3 is loaded only by infiltration equal to fresh air supply ($V_{3,0}$) and same volume of air delivered into the air heater, represented by zone 4. There is only air exchange between zones 3 and 4.

Air heater is modelled by zone 5, where is set ideal control of heater output to keep fixed air temperature on the system exit into the building air distribution network.

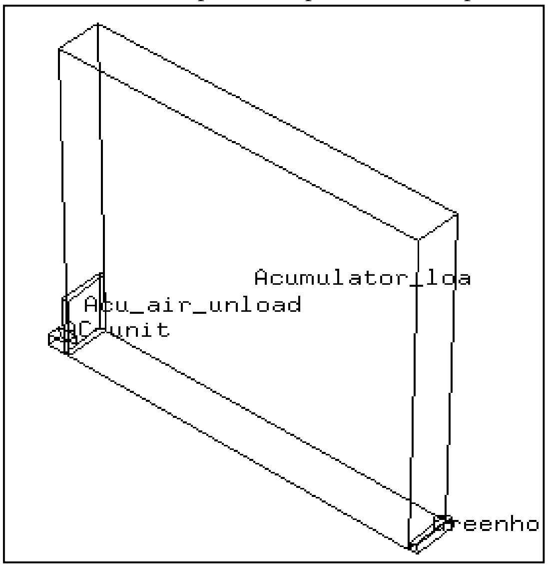


Figure 3 ESP-r model

Graphical representation of the model in the ESP-r is on the figure 3.

SIMULATION

For the simulation were specified problem ranges, which are difficult to solve by traditional design approach . It was above all two design questions:

- What is the sensitivity of the system to loading air volume set-up?
- What is the sensitivity of the system to the gravel mass in the heat accumulator?

Those parameters were analyzed in the relation to the annual heat consumption (Kabele,K.,Kadlecová,M.,Krtková,Z., 2000).

Respecting the complexity of the solved problem and in general small experience with realisation of such building energy system, we decided to use method of virtual experiments on the computer model with one-year simulation loop (Hensen, J.L.M.,1991).

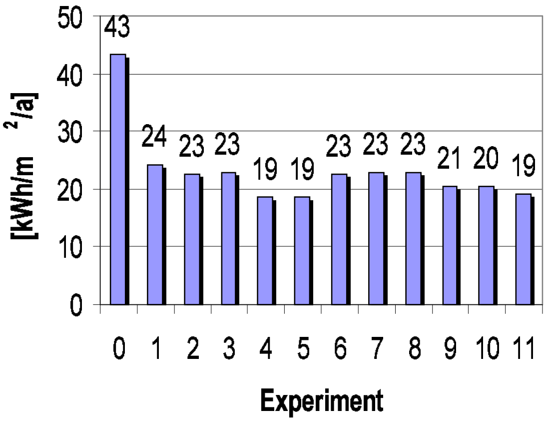
Climate data

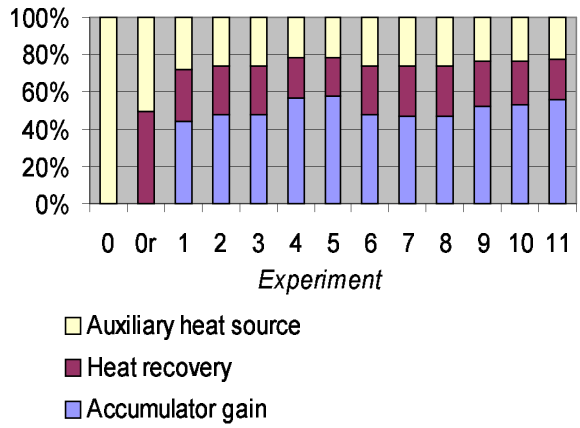
To define climate conditions we used database of test reference year (TRY) for Praha, which is possible to use for most of the Czech Republic regions. Ambient dry-bulb temperature in this TRY is in the range <-17.7°C to 27,3°C>.

System parameters preview

Greenhouse infiltration ($V_{1,0}$) – constant air exchange between the greenhouse and outside environment, representing greenhouse envelope un-tightness. Set at the value 0.3 ACH.

Greenhouse loading air ($V_{1,2}$) - forced air exchange between greenhouse and gravel heat accumulator, which transports collected solar energy into the accumulator. This air exchange is activated, when the temperature in the accumulator is lower than temperature in the greenhouse. The air exchange rate is in particular experiments variable in the range from 100 to 6000 $m^3.h^{-1}$.





Roof collector infiltration ($V_{5,0}$) – constant air exchange between the roof solar air collector and outside environment, representing collector envelope un-tightness. Set at the value 0.3 ACH.

Roof collector loading air ($V_{5,2}$) - forced air exchange between collector and gravel heat accumulator, which transports collected solar energy into the accumulator. This air exchange is activated, when the temperature in the accumulator is lower than temperature in the collector. The air exchange rate is in particular experiments variable in the range from 1000 to 3000 $m^3.h^{-1}$.

Fresh air supply – ventilation rate of the fresh air, which is delivered into the building. The ventilation rate was set according to the entire volume of the building on the level 0.5 ACH.

Accumulation mass of the heat accumulator – mass of the gravel in the accumulator. This parameter was calculated from the accumulator volume with fixed ground plan and variable height from 0.5 m to 1.8 m. From this volume was calculated mass of the gravel fraction 45 mm, which was in the range 50250 kg to 180900 kg (Kabele,K., Kabrhel M., 2001).

Table 3
Annual energy consumption

Experiment	*kWh/a*	*Savings*
0	11838	0%
1	6601	44%
2	6200	48%
3	6234	47%
4	5084	57%
5	5065	57%
6	6200	48%
7	6268	47%
8	6266	47%
9	5606	53%
10	5590	53%
11	5239	56%
Average	**5850.3**	**50.2%**

Virtual experiments preview (table 1)

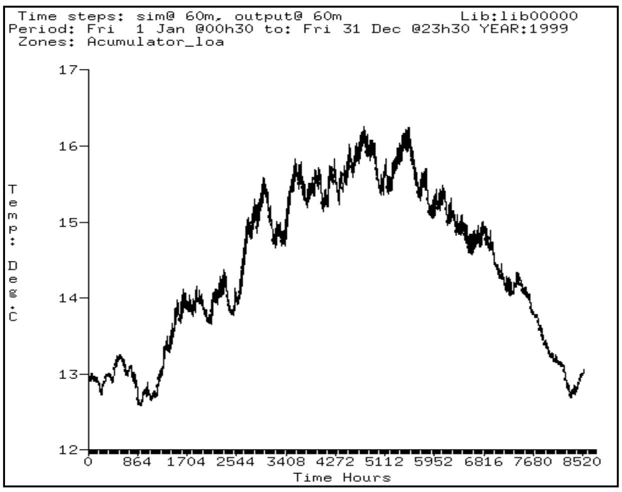
Experiment 0 - reference, when was not included any solar energy utilisation. All fresh air was transported directly into the air heater, where was heated up to required supply temperature. Energy used for this is equal to infiltration energy consumption in traditional house.

In all other experiments was fresh air transported into the air heater through the tube heat exchanger in the gravel accumulator.

Experiments 1 to 3 – variation of the greenhouse loading air rate

Experiments 4 to 8 – collector and greenhouse loading air variation and combination

Experiment 9 to 11 – variation of the gravel accumulation mass



SIMULATION RESULTS

Selected results of the simulation, which were used for the conclusion are presented in following tables and graphs. Table 2 summarises raw simulation results, on the figure 4 are results related to the ground plan area of the solved building.

The energy required for fresh air heating in the solved building will be covered by heat recovery from waste air and from auxiliary heat source (i.e.gas boiler). Energy consumption of particular heat sources is in the table 5, comparison of the

energy requirements coverage is on the figure 5.

CONCLUSION

Virtual experiments confirmed that use of preheating of fresh air supply in gravel accumulator, located below the building contributes positively into the energy balance.

Use of simple preheating of fresh air supply in gravel accumulator decreases annual energy consumption for ventilation air to approx. 50%.

Use of heat recovery unit decreases annual energy consumption for ventilation air to approx. 25%. Serial connection of the accumulator and heat recovery unit decreases the heat recovery unit efficiency due to the relative small temperature difference between supply and waste air.

Virtual experiments did not confirm significant influence of design parameters to the collecting and accumulating of solar energy in simulated configuration of collectors and accumulator size. The solar energy contribution is in this case very small and most of the accumulator energy gain is given by relative constant earth temperature below the building. In all of simulated virtual experiments was the accumulator mass temperature during the year in the range 12°C to 16°C (see figure 6) (Kabele K., 2002).

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Table 1
Virtual experiments preview

	Greenhouse infiltration	Greenhouse loading air	Collector infiltration	Collector loading air	Fresh air supply	Accumulating mass of the gravel
Experiment	[ACH]	[m³/hod]	[ACH]	[m³/hod]	[m³/hod]	[kg]
0-refer.	0.3	0	0.3	0	273	0
1	0.3	100	0.3	0	273	180900
2	0.3	2000	0.3	0	273	180900
3	0.3	6000	0.3	0	273	180900
4	0.3	2000	0.3	100	273	180900
5	0.3	6000	0.3	3000	273	180900
6	0.3	100	0.3	3000	273	180900
7	0.3	100	0.3	2000	273	180900
8	0.3	100	0.3	1000	273	180900
9	0.3	2000	0.3	2000	273	180900
10	0.3	2000	0.3	2000	273	50250
11	0.3	2000	0.3	2000	273	100500

Table 2
Virtual experiments evaluation

Experiment	Energy gain from the gravel accumulator	Heat recovery η=50%	Auxiliary heat source	Total energy savings	
	kWh/m²/a	kWh/m²/a	kWh/m²/a	kWh/m²/a	%
0	0	0	50	0	0%
0r[2]	0	25	25	25	50%
1	22	14	14	36	72%
2	24	13	13	37	74%
3	24	13	13	37	74%
4	28	11	11	39	79%
5	29	11	11	39	79%
6	24	13	13	37	74%
7	24	13	13	37	74%
8	24	13	13	37	74%
9	26	12	12	38	76%
10	26	12	12	38	76%
11	28	11	11	39	78%
Average (exp 1-11)	**25**	**12**	**12**	**38**	**75%**
Std. deviation (exp 1-11)	**2.21**	**1.1**	**1.1**	**1.1**	**2%**

[2] Experiment 0r is direct fresh air supply from outside with heat recovery unit.