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COMPARISON OF THE COST AND ENERGY EFFICIENCY OF ENERGY SAVING MEASURES IN CASE OF A HUNGARIAN SINGLE FAMILY HOUSE

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ABSTRACT

This paper describes the evaluation of different improvement possibilities of a single family house on the Hungarian climate. Cost of Conserved Energy and Cost of Comfortable Hours of the active and passive energy saving measures are compared by means of a building energy modelling (BEM), using IDA ICE, and investment cost estimations. The methodology applied includes the following steps: 1. selection of a typical, single family house, designed in accordance with the Hungarian regulations; 2. BEM 3. changing and adjusting parameters of the building one by one in accordance with the defined improvement measures; 4. evaluation of the results in order to determine the exact percentage of investment cost increase, indoor comfort improvement and energy savings in case of each parameter; 5. determination of the most effective measures. The main goal of this research paper is to assess the effect of the relevant building improvement measures and to determine the most effective ones that may help architects during the design process in order to design single family houses in a more energy and cost efficient, environmentally-friendly way.

INTRODUCTION

The EU's Energy Performance of Buildings Directive (EPBD), introduced in 2002 and recast in 2010, is the main legislative instrument for improving the energy performance of the building stock in the European Union. By 2020, all new buildings constructed in Europe, not to mention an increased number of existing buildings, must be nearly-zero energy buildings. The exact definition of this notion is not clear yet. However, it is extremely important to investigate the main aspects on time, which allows us to reduce the energy consumption of buildings. The residential floor area is 75% of the total floor space of buildings in Europe and 64% of these is associated with single family houses (Economidou, 2011). 34% of the total primary energy consumption of Hungary is used by residential buildings for heating and DHW production (Fulop, 2011). Therefore, it is most important to consider the characteristics of the main energy consumers in case of single family houses. Beyond the aspects of energy consumption, it is getting more important to consider cost related issues, as well. In Hungary, the operation and maintenance cost of buildings is approximately four times more than the initial investment cost of the construction according to local energy certification statistics. After a detailed examination of these high expenses, it can be stated that 65% of them is due to the utility bills in connection with heating (Belafi et. al, 2012). Besides heating costs, cooling is getting more and more widespread in Hungary, as well, because of high summer heat loads and unproper design of buildings. However, cooling is usually not installed yet in case of an average heavy-weight single family new construction house because the investment cost of a cooling device is high and the usual maximum indoor summer temperature is 28-30 ˚C (assuming that building users cool the considerable thermal mass of their building during the night).

Therefore, the impact of different measures has been investigated, with which the heating energy consumption and the periods of high summer indoor temperatures can be reduced. The investigation has been carried out by means of IDA Indoor Climate and Energy (IDA ICE 4.5) software.

METHODOLOGY

As a first step of the research, parameters of the baseline, a typical, Hungarian single-family house were defined. After definition, a detailed building energy model was built and simulated with IDA ICE. Results of the simulation such as calculated energy consumption and comfort data were carefully analysed. The improvement possibilities were defined in a parameter matrix with the adjustable parameters of the building that cause energy savings or enhanced summer indoor comfort in a cost efficient way. These parameters as building solutions were carefully selected considering technical feasibility and investment cost aspects. Afterwards, the parameters were adjusted in the baseline model one by one, always changing only one parameter of the baseline building at the same time. Simultaneously, investment cost estimates were carried out in case of every adjusted parameter. Results were analysed by means of two indicators: Cost of Conserved Energy (CCE) (Meier, 1984) and Cost of Comfortable Hours (CCH). Based on the analysis, the most efficient parameters were selected in terms of energy and comfort.

Indicators Used for Evaluation

Improvement possibilities were evaluated by means of two indicators: Cost of Conserved Energy (CCE) (Meier, 1984) and a new variable, Cost of Comfortable Hours (CCH).

CCE is a statistical investment value indicator showing how much it costs to save one kWh energy annually for a given lifespan (as a lifespan, 30 years was used as the European Commission determined that Member States shall use a calculation of this period for residential buildings (EU regulation, 2012)). CCE is defined as:

$$CCE = (c_i-c_0)/(t*A(E_0-E_i)) \quad (1)$$

where c_i is the net investment cost of the "i" case of the parameter matrix (EUR), c_0 is the net investment cost of the baseline building (EUR), t is the lifespan of the building (years), A is the net floor area of the baseline building (m^2), E_i is end energy use of the "i" case of the parameter matrix (kWh,a) and E_0 is the end energy use of the baseline building (kWh,a). The lower the CCE value of an investment is, the lower is the payback period.

CCH is an indicator that shows how much investment cost was required to obtain one comfortable hour annually. Comfortable hour is defined as the time when the indoor temperature is below 27˚C in average zone. This indicator is defined as:

$$CCH = (c_i-c_0)/(t*8760*0{,}01*(NC_0-NC_i)) \quad (2)$$

where NC_i is the percentage of hours when operative temperature is above 27°C in average zone in the "i" case of the parameter matrix and NC_0 is the same percentage as in the baseline building. In case the CCH is low, the investment affects the summer comfort positively.

DETERMINATION OF THE BASELINE BUILDING

NegaJoule2020 research study carried out by Energiaklub Climate Policy Institute Applied Communications (Fulop, 2011), statistical data (KSH), European standard and a Hungarian Ministerial decree (TNM, 2006) have been used to determine the parameters of an average, Hungarian single family house.

The total number of dwellings was 4 383 000 in Hungary in 2011 (source: Hungarian Central Statistical Office (KSH, 2011) data). 66% of Hungarian residential buildings are single family houses which is 2% higher than EU average (Fulop, 2011). According to issued building permit statistics from 2001 to 2011, the average floor area of a single family house in Hungary is 130 m^2 (KSH, 2011). The NegaJoule2020 study assumes that in case of new built single family houses the two-storey buildings are more common (Fulop, 2011). The average indoor clearance of the Hungarian dwellings is 272 cm (Fulop, 2011).

EU harmonised standard (MSZ EN 832:2000) identifies three air tightness categories characterised with air change rate at 50 Pascals pressure difference: low (>10 1/h), medium (4-10 1/h) and high (<4 1/h). High quality: 1,5-2 1/h in Hungary.

In connection with the typical HVAC system, it can be stated that 51% of the Hungarian dwellings use natural gas for heating in most of the cases by means of a gas boiler, which has an average of 24 kW performance (Fulop, 2011). In case of a new constructed single family house, the condenser gas boilers are the most common ones as it is suggested in the Hungarian EPBD implementation, covering articles 3-6 (TNM, 2006).

Generally, no active cooling is used (Fulop, 2011). However, nocturnal ventilation is commonly used in bedrooms as a passive cooling measure.

According to the authors' expertise, it can be stated that the secondary heat emitters are usually radiators 100 W/m^2, mechanical ventilation is only seldom used and nocturnal ventilation is applied through bedroom windows.

Insulation levels were determined in accordance with the Hungarian TNM (TNM, 2006) decree. The U-value of the increased insulation in case 1A (see Table 2) was determined in accordance with the Passive House Planning Package (PHPP).

BEM PARAMETERS OF BASELINE BUILDING

Taking into account data from the research on the parameters of average Hungarian single family house, the baseline building used for this current research had the following characteristics.

The architectural drawings of a Hungarian pilot project (Ertsey, A. 2012) served as a basis for present research building. The pilot project was introduced in 2012 at a Hungarian conference (Eco-logical, 2012) and the main goal of it was to design a typical single family house for the Hungarian climate which will be able to meet the goals of the EU 2020 objectives. The baseline building is a two-storey, detached single family house with a living room, a kitchen, a bedroom and a bathroom on the ground floor and with two bedrooms, a bathroom and an HVAC room on the second floor.

After considering the average dwelling data collected and parameters of the Hungarian House, the baseline building was defined and modelled in IDA ICE software. (See Figure 1 and 2)

Nocturnal ventilation was modelled with opening bedroom windows, controlled by an opening control macro which activates the window between 10pm and 6am in case the outdoor temperature is above 16˚C.

The results of the baseline BEM simulation and the cost estimation are shown in Table 1.

Figure 1 Floorplan, of baseline building, ground floor, zoning in IDA ICE

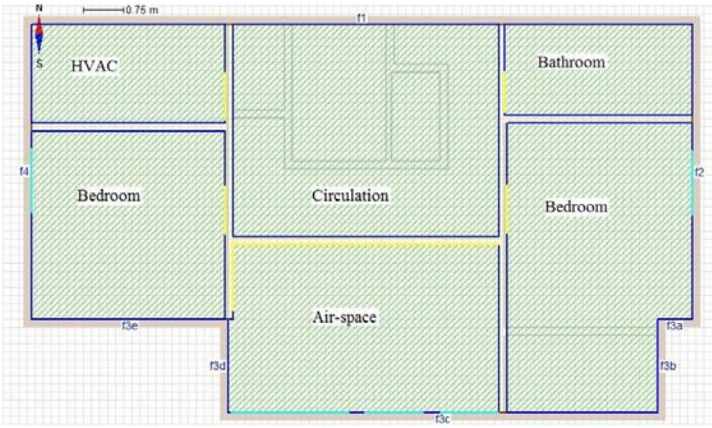

Figure 2 Floorplan of baseline building, first floor, zoning in IDA ICE

Table 1
Results of the baseline building

BASELINE BUILDING
End energy: 91,9 kWh/m^2,a (100%)
Investment cost: 113038 EUR (100%)
% of hours T_{op}>27 ˚C: 19% (100%)
Cost of Conserved Energy: 0
Cost of Comfort Hour: 0

The results of the baseline building serve as basis for comparison in case of the parameter range investigated. (See Annex I.) The end energy use of the heating and the HVAC auxiliary energy is 91,9 kWh/m^2,a. The investment cost is 113 038 EUR, calculated with the exchange rate of 1 EUR = 293 HUF. This amount contains the material and labour costs of the construction works and does not include VAT. The percentage of hours throughout the year when the operative temperature of average zone is above 27 ˚C : 19% of all annual hours which in this case equals to 1664 hours/year.

DEFINITION OF THE ADJUSTED PARAMETERS, INDICATORS

The improvement possibilities of the baseline building were defined in order to achieve energy savings or enhanced summer indoor comfort in a cost effective way. These parameters were selected based on literature review in connection with energy efficiency measures (Pacheco et al., 2012), (Sharma et al., 2010), (Florides et al., 2002), (Comakl et al., 2003), (Chan et al., 2009) and the authors' previous expertise. After the parameter selection, a parameter range was determined and a parameter matrix was prepared (Table 2). In each row of the table, the number and name of the parameter can be found in the first two cells. In the third cell, the quality of the baseline building is shown regarding the parameter in question and in the last column(s), the parameter range investigated can be seen.

After the definition of the parameters to be adjusted on the baseline building, energy consumption, indoor comfort and additional investment cost were determined in every case of the parameter matrix.

Table 2
Parameter matrix

		PARAMETERS	BASELINE BUILDING	PARAMETER RANGE				
Hating Energy	1	Thermal insulation (U values W/m^2,K)	HU Regulation: External wall: 0.45 Pitched roof: 0.25 Floor slab: 0.50 Window, plastic frame: 1.60	1A				
				PHPP: External wall: 0.15 Pitched roof: 0.15 Floor slab: 0.15 Window, plastic frame: 0.8				
	2	Ventilation	Natural	2A				
				Mechanical (ACH=0.5, 85% heat exchange efficiency)				
	3	Heating setpoint	22 ˚C	3A	3B	3C		
				22 ˚C /20 ˚C*	20 ˚C	20 ˚C /18 ˚C*		
	4	Window frame insulation level	U_f=1.4 W/m^2,K 5 chamber	4A				
				U_f=1.0 W/m^2,K 7 chamber				
	5	Glazing type	Double, low-e U_w=1.7 W/m^2,K	5A				
				Triple, low-e U_w=0.6 W/m^2,K				
	6	Filtration (ACH, n_{50})	1.5	6A	6B			
				5	0.6			
Summer Indoor Comfort	7	Cooling setpoint	None	7A	7B	7C	7D	7E
				25 ˚C	25 ˚C /27 ˚C*	27 ˚C	27 ˚C, No nocturnal ventilation.	27 ˚C /29 ˚C*
	8	Secondary cool emitters (27˚C)	None	8A	8B			
				Fan-coil (100 W/m^2)	Radiant ceiling (50 W/m^2)			
	9	Shading (g)	Internal drape (0.52)	9A	9B			
				Glazing, solar protection (0.37)	Roller shutter (0,10)			
	10	Nocturnal ventilation	In bedrooms	10A				
				Cross ventilation				
	11	Roof structure	Lightweight, with air gap	11A				
				Heavy weight, with air gap				
	12	Window to floor area ratio	HU Average: 0.28	12A	12B			
				HU regulation: 0.12	High: 0.41			
	13	Roof reflectance	0.5 (cool coloured, bright red concrete tile)	13A	13B			
				0.08 (dark red concrete tile)	0.75 (white roof coating)			
Site Layout	14	Shading cast by trees on the site boundary	Exposed	14A				
				Shaded				
	15	Site layout type	Detached	15A	15B			
				Semi-detached	Attached			
	16	Orientation of living spaces	S	16A	16B	16C		
				W	E	N		

* When the building is unoccupied (weekdays from 9am to 3pm) and during the nights (from 10pm to 7am).

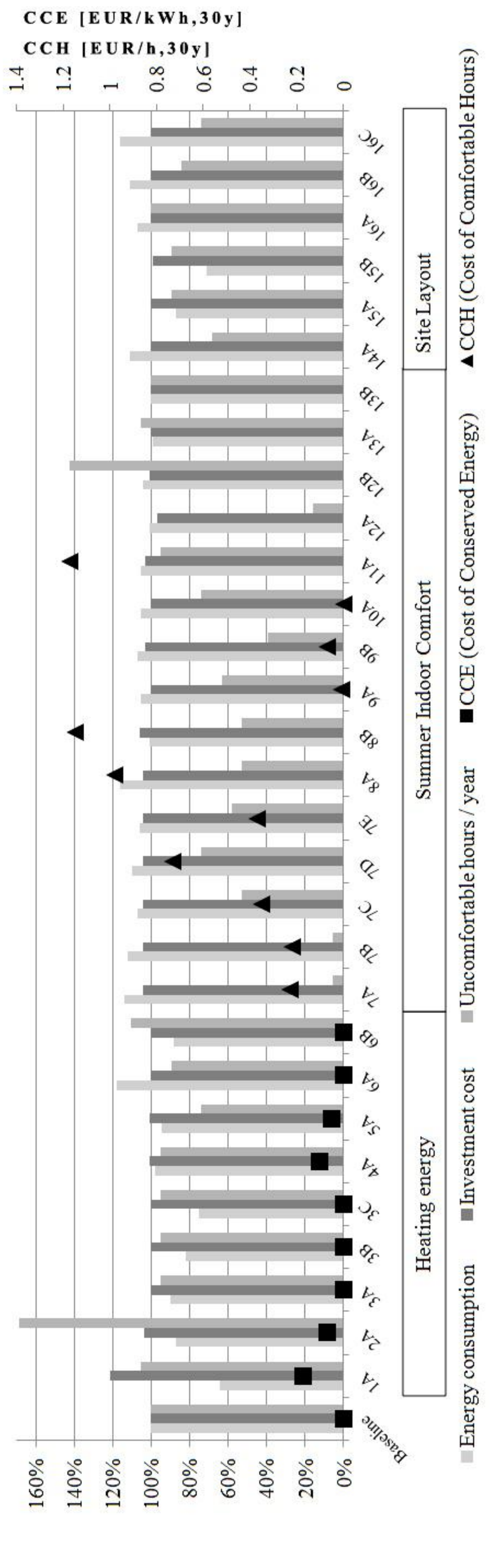

Figure 3 Results

DISCUSSION AND RESULT ANALYSIS

The final energy of each modelled case is the sum of heating, HVAC auxiliary energy and cooling (if applicable) energy calculated by the building energy simulation software.

The investment cost estimates of each case were carried out in line with the Hungarian Cost Assessment Guide (Building Information Centre, 2011) with cost estimation software called TERC (TERC, 2010).

The percentage of hours when the user comfort is unacceptable (cat. IV) or acceptable (cat. III) according to EU harmonised standard MSZ EN 15251 (on the indoor environmental input parameters) (MSZ EN 15251:2007) during the summer was defined by IDA ICE.

Results are shown on figure 3.

Measures Affecting the Heating Energy Consumption

Increasing thermal insulation levels (1A), mechanical ventilation with heat recovery (2A), improved window frames (4A) and glazing with higher performance (5A) are effective measures to reduce heating energy consumption.

According to the CCE values, the most effective measure is the application of glazing with higher thermal performance (triple Pilkington Optitherm S3 glazing, U_g=0.6 W/m^{2}K) (5A). By means of efficient mechanical ventilation 13% of the heating energy can be saved with a CCE of 0.07 EUR/kWh (2A). With improved window frames only 2% of heating energy can be saved (4A). However, this solution is relatively cheap (+955 EUR investment cost) thus the CCE is low. The application of increased thermal insulation caused 36% decrease in the final energy use (1A). However, this measure has a high CCE, namely 0.17 EUR/kWh because the additional investment costs are high. (+21%)

Investigation on the effect of heating setpoint adjustment (3A-C) has shown that this passive heating energy saving measure could result in 25% saving without additional costs. In case of case 3A and 3C, the heating setpoint is set back to 20 ˚C and 18 ˚C when the building is considered to be unoccupied (weekdays from 9am to 3pm) and during the nights (from 10pm to 7am)

By means of increasing air tightness of the building shell (6B), a considerable amount of heating energy can be saved. (12%) However, the estimation of additional investment costs of the special building structures and construction ensuring proper air tightness is hard. The air tightness of a building greatly depends on the quality of the building construction that shows considerable variety in Hungary.

Measures Affecting Summer Indoor Comfort Levels

In case of parameter 7, a cooling system was modelled in the baseline model (7A-E). The effect of cooling setpoints on the energy consumption (cooling included) and summer comfort was investigated. It was found that it is reasonable to keep 27 ˚C during the day and bedroom windows should be opened during the night to provide nocturnal ventilation. This way the additional energy consumption increased only +7% and CCH is 0.35 EUR/h,a.

Radiant cooling works effectively and results in high comfort levels during the summer. (8B) However, this solution means high additional investment cost. (CCH=1.15 EUR/h,a)

Application of glazing with solar protection (g=0.37) is an effective tool (9A). One comfortable hour in the summer annually costs only 0,01 EUR. Despite the fact that the CCH value is 0,07 EUR in case of roller shutters (9B), the indoor climatic conditions are improved to such an extent (only 649 hours are too warm – 39% of baseline) that the use of this tool is highly recommended as well.

Nocturnal ventilation was provided in the baseline building but only in bedrooms. In case the inhabitants ensure the cross ventilation in the building (10A), the number of uncomfortable hours can be decreased by 26% annually (compared to the baseline). The cross ventilation has been defined in the IDA ICE model by means of complex, night ventilation opening control macros applied not only to bedroom windows but to both upstairs and downstairs windows on the opposite sides of the building.

The effectiveness of nocturnal ventilation can be increased with heavier building structures. Therefore, the effect of reinforced concrete roof structure was investigated (11A). Results show that this measure is not cost-effective, namely one comfortable hour in summer costs 1,17 Euros.

On the Hungarian climate, low window to floor area ratio (12A-B) can be recommended because the summer heat loads are more significant than winter heat losses. With a window to floor area ratio of 0.8 (prescribed by regulations (OTÉK, 1997)) the number of uncomfortable summer hours can be decreased by 84% compared to the baseline building.

The colour change of the roof covering tiles (13A-B) did not result in comfort improvement during the summer period. Therefore, this parameter is considered to be of lower importance on the Hungarian climate partly because the Hungarian pitched roofs generally have an air gap and are cross-ventilated.

Parameters in Connection with Site Layout Type

If the owners pay attention to proper green surfaces with potential shading effect around their future home (5-6 m high trees on the site boundary), it can influence the heating energy consumption (+11%) and the non-comfortable hours in the summer (-6%), as well (14A).

In case the site conditions are not ideal for a single family house, it can be stated that an attached building could work better (15B). In this case, 29% of heating energy can be saved and the number of summer uncomfortable hours is decreased by 11%.

Special attention should be paid on the orientation of living spaces (16A-C) during the planning process because it influences the heating energy consumption (+16% heating energy) and indoor user comfort, as well. (Max. 1231 uncomfortable hours.)

CONCLUSION

The most significant factors for heating consumption reduction are:

- the attentive heating setpoint adjustment when the building is unoccupied or at night because it can result in 25% heating energy saving (CCE=0 EUR/kWh);
- installation of glazing with higher thermal performance (CCE=0,05 EUR/kWh).

Regarding summer comfort improvement measures, it was found that :

- in case active cooling is applied, it is reasonable to keep 27 ˚C during the day and bedroom windows should be opened during the night to provide nocturnal ventilation. This way the additional energy consumption is higher by +7% and CCH is 0.35 EUR/h,a;
- the application of glazing with solar protection (g=0.37) is an effective tool. One comfortable hour in the summer annually costs only 0,01 EUR;
- the nocturnal cross ventilation of the building (instead of opening only bedroom windows) resulted in 26% decrease in the number of uncomfortable hours annually without additional investment costs. (CCH=0 EUR/h);
- with a window to floor area ratio of 0.8 the number of uncomfortable summer hours could be decreased by 84%.

Within parameters in connection with site selection, the most significant ones were:

- the attentive growth of plants with shading effect on site (-6% non-comfortable hours);
- the ideal orientation of living spaces (+16% heating energy, max. 1231 uncomfortable hours).

NOMENCLATURE

c_i = net investment cost of the "i" case of the parameter matrix
c_0 = net investment cost of the baseline building
t = lifespan of the building
A = net floor area of the baseline building
E_i = end energy use of the "i" case of the parameter matrix
E_0 = end energy use of the baseline building
NC_i = percentage of hours when operative temperature is above 27°°C in average zone in the "i" case of the parameter matrix
NC_0 = percentage of hours when operative temperature is above 27°°C in average zone in the baseline building
T_{op} = operative temperature

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