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RESEARCH ARTICLE

Building Information Modelling in the decision process of retrofitting the envelope of public buildings – a case study

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Abstract

The result of the assessment of energy auditing of 100 public buildings made it possible to develop a new method which can function as a decision tool for retrofitting similar facilities. This article deals with the reduction of transmission heat losses because of the high investments of the building constructions. Building Information Modelling system plays a central role in the developed method. It is important to invest cost-effectively which can be measured by the payback of the investment. The order of the retrofitting was calculated with the help of Life Cycle Cost Analysis.

Keywords

Building Information Modelling · energy saving · specific heat loss coefficient · operating and maintenance costs · discounted payback time

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1 Introduction

The larger part of the Hungarian building stock is to be retrofitted. According to the Hungarian Central Statistical Office's (HCSO) data 2007, 956,021 facilities were owned by local governments [1]. Statistics show that 50.5 percent of the 13,928 educational buildings should be renewed partially and 7.9 percent of them totally to satisfy current criteria [2].

Educational buildings, hospitals, nursery schools, crèches, public authority buildings etc. do not generate profit to local governments that means that these buildings cause continuous future expenses (follow-up costs). Operational and maintenance costs usually increase every year in a town because of new buildings and growing energy prices [3]. Meier stated that every local government is interested in keeping the percentage (ϕ) of future expenses in a low level to decrease the overwhelming effect of the future expenses. As it was stated by the Energy Conservation in Buildings and Community Systems Programme (ECBCS) of the International Energy Agency (IEA) the energy consumption can be decreased by retrofitting of HVAC, lighting, by the insulation of building envelope and also how the building is used [4]. An integrated retrofit concept including the thermal envelope and the services installations leads to better cost-efficiency [5]. Local governments cannot retrofit all operated buildings at once. They need a strategy, a schedule of the retrofitting to be able to make an annual budget. Studies have shown that the decision-makers often lack the knowledge of the efficiency of potential energy saving measures [5].

This research presents the method of the survey and the analysis of the specific heat loss coefficient in case of 100 public facilities in Kecskemét that are to be renewed by the local government because of their high running costs. Specific heat loss coefficient contents, without the transmission heat losses, the utilized direct and indirect solar gains for the heating season. This includes only building-related parameters and depends on the relation of the surface to volume ratio of a building. The basis of the developed system is Building Information Modelling (BIM). The BIM system is able to import and export all information using common file formats in the building industry [6].

We planned the retrofitting of building envelopes with the help of a 3D model; we simulated the building envelope with seven surface elements and one line shaped element at the calculation of energy performance and economical analysis. The proposed range of retrofitting was counted out with the help of the discounted payback time.

The survey proved that buildings owned by the local government of Kecskemét were poorly insulated. According to our calculations on the average 51% energy saving can be achieved by the insulation of the building envelope. That means the same amount of percentage in the decrease of CO_2 emission and energy cost.

This study shows an efficient and rapid method of surveying the energetical retrofitting of buildings that can be documented very well. The BIM database can be used not only by architects, but also by other designers, owners and users of the facilities too. The built-up database can be used efficiently at the facility management during the whole life cycle of the buildings.

2 Methods

2.1 Building Information Modelling

According to Vanlande et al. [6] Building Information Modelling (BIM) will take a leading role in the integration, interoperability and collaboration in the near future of the building industry. BIM can be regarded as the next generation of Computer Aided Design (CAD) and Information Technologies (IT) for buildings. BIM is a complex system which serves the process of generating, storing, managing, exchanging and sharing building information throughout the life cycle of a building [6]. A BIM system is a tool which is able to handle several types of information, e.g. planning, analysis, presentation, collection of data on-demand. However, the main advantage of BIM is the 3D modelling system with data management. Indeed, buildings are created from geometrical items, which give the basis of building's construction. Parametric data management has a great advantage namely the generation of the building information can be automated. This feature makes it possible to keep all the data up-to-date during the life cycle of a facility.

Using of BIM accelerates and simplifies data exchange among the phases of a project. It is due to the following features of BIM: the changes in the 3D model immediately show up in all concerned documents and BIM is able to export and import the most common file format: e.g. IFC (Industry Foundation Classes), DWG – DXF (Autocad Drawing), PDF (Portable Document Format), XML (Extensible Markup Language), DWF (Design Web Format), KMZ, KML (Google Earth and Google Maps use KMZ and KML code), U3D (Universal 3D).

For the initiation of IAI (International Alliance for Interoperability) an ISO-certified file format, namely IFC (Industry Foundation Classes) was developed. According to the ArchiCAD IFC 2x3 Guide (2009) [7] IFC is a neutral file format which is capable to exchange information between different CAD systems and other systems in the building and facility management sectors. An IFC file contains both 3D objects and so called properties, which are additional parameters assigned to an IFC entity.

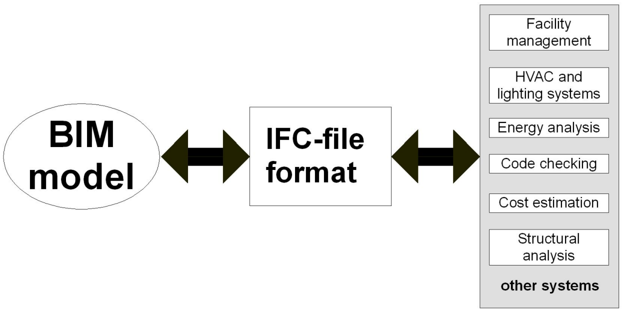


Fig. 1. Links between IFC and BIM and the other systems

2.2 Life Cycle Cost Analysis

Life Cycle Cost Analysis (LCCA) is an economic evaluation technique that determines the total cost of owning and operating in a given period of time [8]. LCCA leads to a good solution at a certain facility if changes can be predicted fairly right during its analysed period. LCCA method can be used at every stage of a project and it is an excellent tool at cost analysis of retrofitting existing buildings. The aim of LCCA is that the decision makers now can take into account investment expenses (initial expenses), annual operating and maintenance costs (future expenses). There are three factors which must be taken into account when you make LCCA: costs, time and discount rate.

2.2.1 Costs

There are two main groups of costs: initial expenses and future expenses. Initial expenses are usually equal to the investment of a project. Future expenses are usually equal to the incurring costs after the occupation of a facility.

It is useful to distinguish between energy and other running cost because it is possible to assign different discount rates for different cost items [9]. Schade showed the model from the American Society for Testing and Materials:

$$LCC : C + R - S + A + M + E \tag{1}$$

where:

- LCC – Life cycle cost
- C – Investment cost
- R – Replacement costs
- S – The resale value at the end of study period (residual value)
- A – Annually recurring operating, maintenance and repair costs (except energy costs)
- M – Non-annually recurring operating, maintenance and repair cost (except energy costs)
- E – Energy costs

There are two standards in Germany which summarise the costs in the building industry. The Standard 276-1 (DIN, 2006) [10] contains the building costs of building construction. The aim of the DIN 276-1 standard is to give the opportunity to stand up a complete structure of building costs and to make it possible to project all costs of an investment planned. Each cost element is encoded and compartmentalized to three levels. The first level has a reference to the total investment costs (budget):

- 100 building plot
- 200 preparation and public utilities
- 300 building – construction
- 400 building – installation
- 500 outdoor construction and installation
- 600 outfit and artworks
- 700 additional expenses

The other German Standard 18960 (DIN, 2008) [11] defined the following future expenses during the life of a building:

- 100 Capital costs: interest loss and amortization
- 200 Object management costs: personal costs in connection with the operation of the building and other material expenditures
- 300 Operating costs
- 400 Maintenance costs

As it was shown in our previous study we developed a break down structure (BDS) of operating costs combined with the American and German standards (Szőnyi, 2008) [12]. This BDS makes it possible to handle the costs of energy consumption separately.

1 cost of integrated energy consumption
  - heating
  - hot water supply
  - ventilation
  - cooling
  - lighting

2 water and sewage

3 cleaning of the building
  - cleaning staff
  - cleaning agents
  - waste disposal fee

4 services
  - computer-network
  - installation equipments
  - information flow (intranet, internet, cable TV, etc.)

5 reception, control and telecontrol systems, operating
  - installation systems
  - telephone
  - alarm system
  - porter, service.

6 operating of traffic and green surfaces

7 others (for example the replacement of the expendable material)

According to the 7/2006. (V.24.) Ministry regulation [13], which is ruling the energy performance in Hungary, the integrated energy consumption does not include the consumption of:

- the technological heating,
- the technological ventilation,
- the technological hot water,
- swimming pool technology,
- balneology systems,
- outdoor lighting.

2.2.2 Time

Time is equal to the study period and its length is usually between 20 and 40 years, depending for example on the certainty of the owners program and the life time of the studied construction or facility. The time of the design phase and the realisation period depends on the circumstances of the investment, the type of the facility and lots of other factors and may take longer time than one year; so the investment costs are considered to be given at the end of the investment. Therefore the investment costs will be entered into the LCCA at their full values.

2.2.3 Discount rate

The discount rate testifies the time value of the investor's money. With the help of this interest rate the value of the investment in the future can be calculated from the investment cost of the present. There are two types of discount rate: the real discount rate and the nominal discount rate [8]. The real discount rate excludes the rate on inflation and the nominal discount rate includes the rate of inflation. Practically, the usage of the real discount rate simplifies the LCCA calculation and gives the same result as usage of the nominal discount rate within the present value equation. Using the real discount rate in present value calculations, costs must be expressed in constant currency, e.g. in Forint in Hungary.

Several articles consider Life Cycle Cost Analysis (LCCA) more and more important in constructing. There are alternatives in constructing buildings that can be compared to different methods of LCCA, but each method has advantages and disadvantages too [9]. It is important to know the target of the analyses in order to choose the suitable method. Schade itemised the following methods: Simple payback (PB), Discount payback method (DPB), Net present value (NPV), Equivalent annual cost (EAC), Internal rate of return (IRR), Net saving (NS).

3 Case study

3.1 Collection of data

Practically there were not any data about the facilities in the most cases except their addresses in the time of binding the contract. The facilities were placed in Kecskemét and in the vicinity of the town. The local government owned 100 facilities, classified by function as follows:

- 16 medical facilities and social services
- 37 crèche and nursery schools
- 32 elementary schools and secondary schools
- 8 cultural facilities
- 7 authority buildings

At first we surveyed each building. The survey was carried out by three different teams that divided themselves into more groups: they surveyed the building envelope, electrical and HVAC systems. Each team had compiled a blank before the surveying.

This study deals with construction retrofitting; hence we do not discuss here the measurement of electric and HVAC systems. We used the following tools to survey the building envelope: tape measure, laser distance measurer, thermo graphic and digital cameras. We identified the building constructions with the help of its age, mustering and measuring, existing plans or instrumental tests.

The following difficulties occurred during data collection:

1 only a few drawings were available

2 the available drawings usually did not content technical descriptions and section drawings

3 in many cases more buildings belonged to one facility with dissimilar constructions

4 there were partial renovation on some buildings, e.g. some windows and front doors were changed on some sections of the facades

5 it was not allowed to identify the building constructions by invasive methods

3.2 Method of data processing

In the next stage we designed each building in 3D mainly with drawing building envelope. We made supplementary measuring if the available data were uncompleted.

We used the ArchiCAD software to model the buildings and this way we produced the base of the BIM. Fig. 2 shows a 3D model below as an example.

The advantages of the 3D drawing during the calculation of energy consumptions and analysis period were the following:

1 collection of data was rapid and the results were exact at a very complex buildings too

2 it was easier to follow up the changes in the constructions which had happened during the life of the buildings (e.g. exchange of some windows or extension of buildings)

3 it was easy to process the data again if they were changed

4 it was not difficult to count out the volume of complex buildings

5 it was easier to explore the structurally wrong details, e.g. energy loss through constructions *(thermal bridges)* or uneconomic configuration of the rooms

6 each group in the team could make the 3D drawing parallel

3.3 Calculation of energy performance of the existing buildings

Data achieved from the 3D models were processed in a special EXCEL table developed to this project. Each building had its own table. At first we calculated the original heat loss and energy gain in each case. Our calculations of the primer energy consumption of HVAC and electric systems were based on the consumption of a so called “standard consumer”; so it was possible to compare the results.

The calculation was done with the real size of constructions. We parted each building envelope to seven surface elements and one line shaped element:

- external walls
- windows
- outer doors
- roofs (at built in attic)
- slabs under attic
- flat roofs
- slabs above cellar
- plinths (line shaped)

We determined the thermal conductance (U-value) of the constructions either with the help of calculations or measurements and calculations or technical tables about existing constructions [14]. The quantitative data were listed by the ArchiCAD. The Table 1 shows an example based on some listed data: heated floor area and volume, surfaces of walls, windows, doors, roofs, slabs, plinth etc., length of plinths etc.

In some cases we used thermographs to calculate average U-values at walls and windows.

We have taken into consideration the direct solar energy gains in the calculation of specific heat loss coefficient (kWh/m^2,a). It was possible to control the length of sunshine on the facades by ArchiCAD when the solar energy gains have been calculated. We calculated the length of the heating season and the connected heating degree days at each case. The calculated difference between external and internal temperature usually was not higher

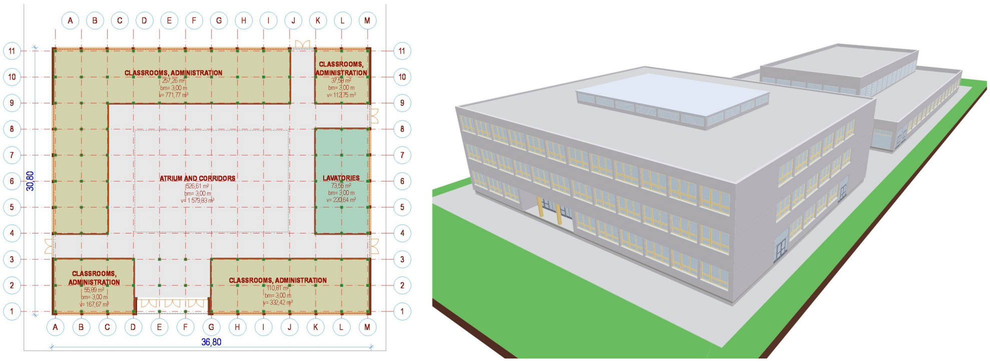


Fig. 2. Mátyás Király High School: part of the ground floor and 3D model (school building and the gym)

Tab. 1. List of the heated floor area and volume of the Mátyás Király high school

List of heated floor area and volume			
Layer	Rooms	Heated floor area (net) [m^2]	Heated volume [m^3]
Rooms			
	atrium and corridors	526.61	1579.83
	central heating room	36.40	109.20
	classrooms, administration	1493.80	4481.41
	corridor	747.33	2241.99
	dining hall	161.98	485.94
	dressing rooms and lavatories	250.90	752.70
	gym	659.32	4615.24
	kitchen	337.42	1012.26
	lavatories	220.64	661.93
	space area of the atrium	0.00	1625.66
		4434.41 m^2	**17566.15 m^3**

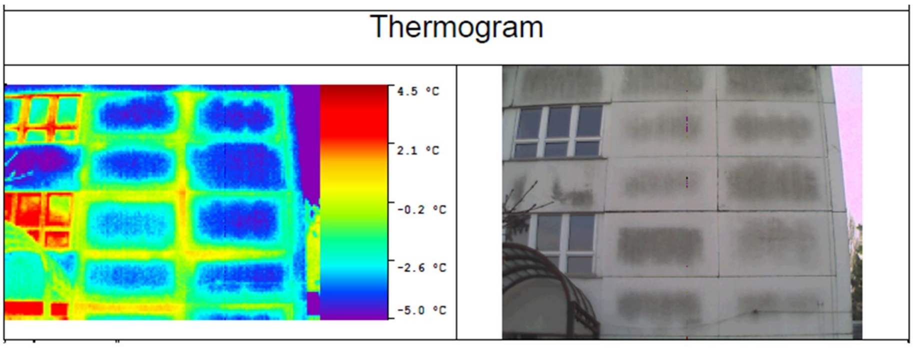


Fig. 3. Thermograph of the Mátyás Király High School built with prefabricated technology (with the help of TESTO thermo camera and software)

than 8 Kelvin in poise state; so the length of the heating season was 4400 hours in the existing buildings based on 7/2006. (V.24.) Ministry regulation [13].

Finally we counted out the integrated energy performance and qualified the building. Table 2 shows the actual qualification of buildings based on the Hungarian regulation (176/2008. (VI. 30.) Government regulation) [15] .

The qualification of the facilities shows a poor picture: there were 2 D, 21 E, 36 F, 36 G and 5 H qualified facilities.

The modernisation of the HVAC systems were planned or fulfilled in most cases of our filed survey. It can be stated based on our results that remarkable energy savings could be achieved by the insulation of building envelope in the future. The counted energy consumptions of the public buildings are very high, thus we planned the insulation of the building shells. The aim of the local government was to achieve at least the level C at each facility.

Tab. 2. Energy classification of buildings

A+	<55	Low-energy
A	56–75	Energy efficient
B	76–95	Better than acceptable
C	96–100	Acceptable
D	101–120	Almost acceptable
E	121–150	Better than average
F	151–190	Average
G	191–250	Almost average
H	251–340	Poor
I	341<	Bad

3.4 Planning of the retrofitting

Both the technical possibility and the investment costs of insulation limit the rate of the insulation, that is to say the investment cost of insulation and energy saving should be in balance. This relation can be formulated with the help of the payback period of the investment. The payback time of building's insulation usually exceeds 4 years, which time interval could be accepted reasonably in business life. However, even 10-20 years payback time is rewarding during the average 30 years life time of building insulations, because of the real energy savings, the preferable building physics, and the higher real value of buildings, not to speak of the protection of our environment [16]. Our calculations show that the payback time of the analysed buildings is about 18 years on the average, so it would be rewarding to insulate them. The local government wanted to achieve the requirements regularized by the 7/2006 Ministry regulation [13]:

- requirements which refer to the thermal conductance of the constructions of building envelope ($U_{\mathrm{r}oof}$, $U_{\mathrm{w}all}$, etc [W/m^{2}K])
- requirements which refer to the specific heat loss coefficient (q [W/m^{3}K])
- requirements which refer to the integrated energy performance (E_P [kWh/m^{2}a])

The specific heat loss coefficient includes only building related parameters and depends on the relation of the surface-volume rating of a building. According to the 7/2006 Ministry regulation the specific heat loss coefficient can be counted as follows:

$$A/V \leq 0.3 \qquad q_m = 0.2 \mathrm{W/m^3K} \tag{2}$$

$$0.3 \leq A/V \leq 1.3 \quad q_m = 0.086 + 0.38(\Sigma A/V) \mathrm{W/m^3K} \tag{3}$$

$$A/V \geq 1.3 \quad q_m = 0.58 \mathrm{W/m^3K} \tag{4}$$

where:

- ΣA – Sum area of building's envelope [m^2]
- V - Heated volume (heated air volume) [m^3]
- q_m– Specific heat loss coefficient [W/m^{3}K]

We separated the energy planning and LCCA at each building. We extended the Excel table used at the calculation of energy performance. We complemented every structure of construction layers with an insulation layer, which thickness could be modulated. We edited a new column next to the existing windows, where the average U-values of the new windows and outer doors were written. We planned the thickness of insulations according to the requirements of the 7/2006 regulation [13], and we took into account the effect of the thermal bridges as well. Finally, we compared the specific heat loss coefficient of the planned building to the value of the requirement. If the specific heat loss coefficient of the planned building did not exceed the value of the requirement, it was counted by the formulas (2), (3) or (4), then we qualified the building shell as suitable. We calculated the primer energy consumption of HVAC and electric systems with assumption of "standard consumers", and we took into consideration the built-in HVAC and electric systems.

The actual standards and regulations, and the latest technical literatures as well were taken into account in the planning of the additive insulation of the building constructions. Ladener and Siepe (2004) [16] summarized the type of the original constructions of building envelopes. Ladener, H. and Feldhaus, M. (2004) wrote about the modern insulation materials and the right installation of insulations, about the parameters of insulations e.g. air transmittance, and they evaluated the insulations from an environmental point of view in the same book.

We have taken into account the engaged and suited building technologies that have been ingrained in Hungary yet. The above mentioned conditions and the given possibilities strongly limited the assortment of building constructions. We chose the following solutions:

- External walls: Thermal insulation composite system with 10 cm thick rock wool insulation. We planned the similar construction to the insulation of the slabs of arcades.
- Windows: We planned the exchange of the economically not renewable windows to new, modern timber or plastic windows. Quality of the planned windows: average U-value: 1.60 W/m^{2}K (at least), double glazed units with low-emissivity glass (e.g. medium-SHGC, low-e).
- Outer doors: We planned the replacement of the deteriorated doors, because their renovation would not be economical. We planned steel doors at heavy traffic and timber doors at low traffic. The parameters of the steel doors: average U-value: 2.10 W/m^{2}K (at least), double glazed units with low-emissivity glass. The parameters of the timber doors: average U-value: 1.80 W/m^{2}K (at least), double glazed units with low-emissivity glass.
- Pitched roofs (in case of in-built attic): an insulation could be built in the roof without the demolition or disassembly of it

Tab. 3. Energy qualification of the Mátyás Király High School

Calculation of the integrated energy performance			
	E_P =	209.61	kWh/m2a
Allowed maximum of the total energy consumption of the building, if the surface to volume ratio was 0,37 m^2/m^3:			
0.3 < A/V < 1.3	E_P = 40.8+164(A/V) =	102.06	kWh/m^2a
	Energy qualification of the facility (%):	205.4%	G

only if it is built under the construction of the roof. We chose 10 cm thick rock wool insulation covered with plasterboard.

- Slabs under attic: 15 cm thick rock wool insulation, laid on the floor, covered by board layer.
- Flat roof: It is recommended to connect the insulation of flat roofs with the renovation of the roof. It is worth to involve a specialist in that case. If the roof is intact, it is enough to lay an additive insulation layer on the top of the roof. We did not take into account those costs, which belonged to the renovation of the constructions; hence we took into consideration only the additional insulation even if it was built in into the construction. After mature deliberation we chose 10 cm thick extruded polystyrene foam (XPS). XPS insulation board was allowed to build into every roof construction.
- Slabs above cellar: We preferred the installation of insulation boards below the slab, because it was not possible to build in any insulation board above the slab without demolition. Hence we planned 5.00 cm thick wood-wool composite board with rock wool core fixed under the slab.
- Plinths: We chose 6.00 cm thick XPS insulation board, covered by acrylate based exposed aggregate rendering (stone finish).

The architecturally protected and historical buildings were exceptions, where the insulation of the facades was not allowed. We could not fulfil the requirements of the thermal conductance in the cases of facades, but it was usually possible to compensate the heat losses of facades with better insulation at other constructions. Authentic appearance of historic buildigns can be combined with today's requirements. Szabó and Zepkó show an example of the refurbishment of historic windows [18].

3.5 Calculation of life cycle costs (LCC)

3.5.1 Investment costs of building constructions

The detailed database comes from the 3D model and our technical knowledge made it possible to stand up a quantity take-off calculation. We calculated the unit price of the eight building elements mentioned in Section 3.3. We used m^2 unit at the surface elements and m unit at the plinth element.

We did not take into account the costs, belonging to the repair or maintenance of the constructions.

3.5.2 Operating and maintenance costs

We have focused on the retrofitting of the building envelopes in our case study. If everything but the insulation of the building shell stays unchanged, only the energy consumption component of the operating costs changes; hence it was not necessary to involve the other existing operating costs to the LCCA. The changing of the maintenance costs caused negligible differences.

According to Pfundstein at al. [18] the anticipated durability of a building component depends on numerous factors. However there are some methods to estimate the average durability of building components, e.g. the ISO 15686 standard, "Building and constructed assets – Service life planning". Pfundstein at al. [18] gave a selection of durability for insulating materials in building components. We could state with the help of the given data that the average durability of the planned constructions were more than 30 years, thus we did not calculate with the replacement costs of the planned constructions.

3.5.3 Calculation of energy savings

If the whole building envelope is insulated, we can say, that the energy saving of a building is equivalent to the sum of the energy savings of the building elements. We counted the transmission heat loss of a building element as follows. The difference between the original and the decreased heat loss of a building is the energy saving.

$$Q_T = U \cdot A \cdot H[\text{kWh/a}] \tag{5}$$

$$Q_T = \Psi \cdot l \cdot H[\text{kWh/a}] \tag{6}$$

where:

- Q_T – Transmission heat loss [kWh/a]
- U – Overall heat transfer coefficient [W/m^2K]
- A – Area [m^2]
- H – Thousandth part of the annual length of heating thermal degree hours [Kh·1000]
- Ψ – Linear heat loss coefficient [W/mK]
- l – Length of connecting edges or circuit [m]

3.5.4 Calculation of discounted payback time

Amongst the LCCA methods the discounted payback time method was the most suitable for us, because we wanted to take into account the time value of money and the continuous raise in energy prices. With the help of the following formula – deduced by Christiensen [19] – we were able to count the discounted payback time:

$$n_k = \frac{\ln\left(A(q_x - 1) + 1\right)}{\ln(q_x)} \tag{7}$$

where:

- n_k – Discounted payback time (year)
- A – Quotient of additive costs (here the investment costs) and energy saving costs
- q_x – Quotient of rise in prices (here rise in energy prices) [%] and interest of capital [%]

At first we had to calculate the real discount rate and the rise on energy prices. If we want the effect or inflation or deflation to exclude we count with constant currency (Forint in Hungary), real interest rate and real rise on energy prices. We could count the real discount rate with the help of the following formula:

$$d_{real} = \frac{1+i}{1+\Pi} - 1 \tag{8}$$

where:

- d_{real} – Real discount rate
- i – Interest rate [%]
- π – Average inflation (deflation) [%]

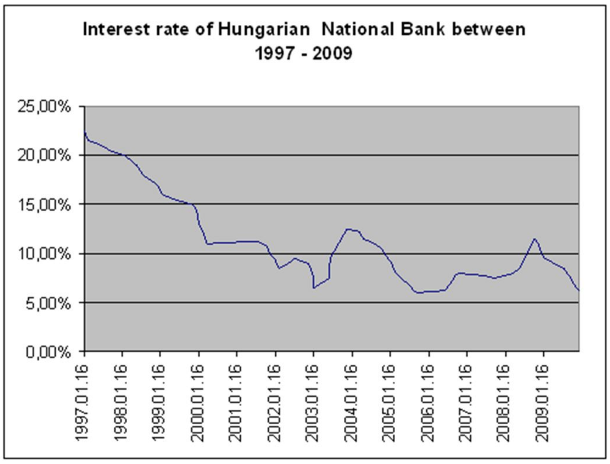


Fig. 4. Interest rate in Hungary between 1997 – 2009 (source: The Central Bank of Hungary (MNB)-a) [20]

According to the charts above Figs. 4,5 we estimated the annual nominal average interest rate and the annual average inflation. The method of the evaluation was the same. We fitted an exponential regressive curve on the data with the help of the method of the minimal squares. In this case the mathematic model is the following:

$$y = a \cdot e^{bx} \tag{9}$$

Where:

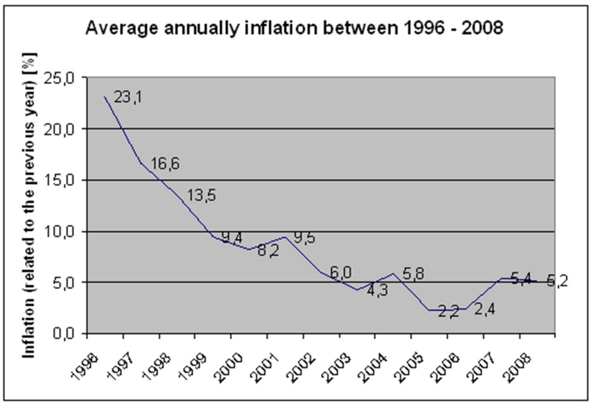


Fig. 5. Inflation in Hungary between 1996–2008 (source: The Central Bank of Hungary (MNB)-b) [21]

- a and b – Constants
- x – Months or years, for example: January 1999 = 1, February 1999 = 2,. . . ,

The constants were estimated to the average interest rate based on the last 10 years: a =11.408 and b =−0.004. The average interest rate based on the constants is for the years 2010-2020: 5.595% and for the years 2010-2030: 4.528%. The constants were estimated to the average inflation based on the last 13 years: a = 19.797 and b = -0.150. The average inflation based on the constants is for the years 2010-2020: 1.163% and for the years 2010-2030: 0.7117%.

According to the (8) formula the real discount rate was given for the years 2010-2020: 2.049 % and for the years 2010-2030: 2.230 %.

Every building was heated by natural gas, even if the heating water was based on district heating source. The Table 4 below shows the rise in energy prices.

Quadratic and cubic curves can be fitted well on the given data of the gas prices. This can be observed in the picture below Fig. 6:

The equation of the quadratic curve:

$$y = 492.214 - 79.286x + 16.214x^2 \tag{10}$$

The equation of the cubic curve:

$$y = 526.048 - 103.159x + 21.048x^2 - 0.293x^3 \tag{11}$$

where:

- y – Prognosis of energy prices to the years of 2010-2030
- x – Year 2000

We summarised the calculated data according to the curves in Tables 5,6.

The prognosis is more optimistic in the case of the cubic curve. We created the calculation for the pessimistic and the optimistic cases too Table 7.

Tab. 4. Rise in natural gas prices in Hungary between 2002–2009 (rise in energy prices: relation to the year before) (source: HCSO-c) [22]

Year	2002	2003	2004	2005	2006	2007	2008	2009
Natural gas, transmitted by pipeline, Ft/10 m^3	390	410	457	491	548	757	931	1070
Rise in energy price, %		4.88	10.28	6.92	10.40	27.61	18.69	13.13

Tab. 5. Prognosis of energy prices to the years of 2010-2030 based on the quadratic curve

Year	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Prognosis of natural gas prices, Ft/10 m^3	1.321	1.582	1.876	2.202	2.560	2.951	3.374	3.830	4.318	4.839	5.392
Rise in energy price, %	18.99	16.51	15.66	14.81	14.00	13.25	12.55	11.90	11.31	10.76	10.26
Year	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	
Prognosis of natural gas prices, Ft/10 m^3	5.978	6.595	7.246	7.929	8.644	9.391	10.172	10.984	11.829	12.706	
Rise in energy price, %	9.79	9.37	8.98	8.61	8.27	7.96	7.67	7.40	7.14	6.90	

Tab. 6. Prognosis of energy prices to the years of 2010-2030 based on the cubic curve

Year	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Prognosis of natural gas prices, Ft/10 m^3	1.306	1.548	1.813	2.098	2.403	2.726	3.064	3.416	3.780	4.155	4.538
Rise in energy price, %	18.09	15.62	14.60	13.61	12.69	11.83	11.04	10.31	9.64	9.02	8.45
Year	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	
Prognosis of natural gas prices, Ft/10 m^3	4.928	5.324	5.723	6.123	6.524	6.923	7.318	7.707	8.090	8.463	
Rise in energy price, %	7.92	7.43	6.97	6.54	6.14	5.76	5.40	5.06	4.73	4.41	

Tab. 7. Prognosis of energy prices in percent

Calculation of real rise in energy prices	based on the			
	quadratic curve		cubic curve	
Interval, years	2010-2020	2010-2030	2010-2020	2010-2030
Average inflation, %	1.1630	0.7117	1.1630	0.7117
Average nominal rise in energy prices, %	13.6344	11.0513	12.2616	9.2969
Average real rise in energy prices, %	5.7658	6.0406	5.1311	5.0156

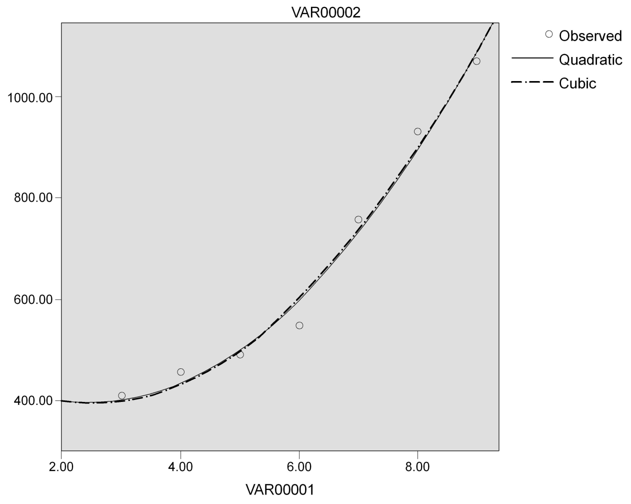


Fig. 6. Quadratic and cubic curves fitted to the data of gas prices

Our calculation was based on the longer interval because of the quite long payback times at the most cases.

We calculated the anticipated CO_2 emission decrease in the relation of the energy saving. We depicted every result in tables; each table contained the result of one facility. We demonstrate the results of the calculation with one example (Table 8).

We will show the discounted payback times referred to the studied buildings in increasing order.

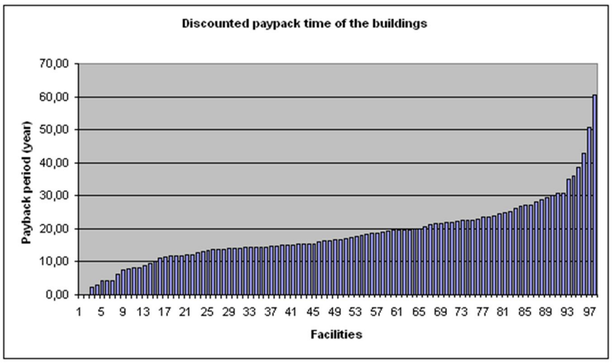


Fig. 7. Discounted payback times of the buildings in increasing order – pessimistic solution

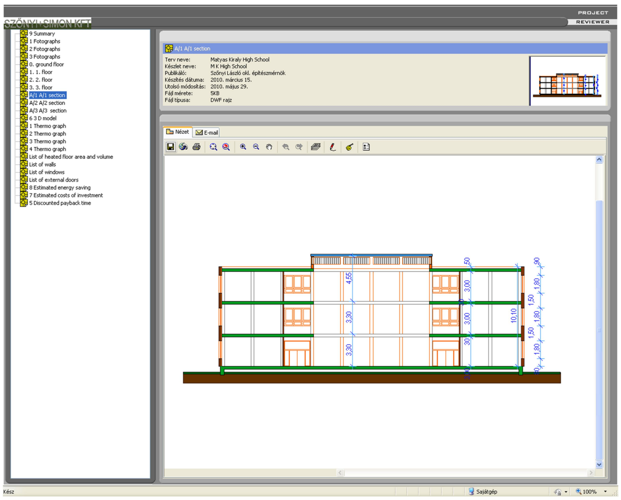
The average payback time of the analysed buildings was 18.35 years, if the rising of energy prices was estimated with the help of the cubic curve, and 16.94 years, if the rising of energy price was estimated with the help of the quadratic curve.

3.6 Documentation of the results

With the help of the BIM system we gathered the results and made a document about each building or facility in PDF and DWF file format. We gave the following information from each building:

- summary about the suggested measures of the energy retrofitting
- photos about the existing building(s)
- drawings in 3D
- drawings: plans from every dissimilar floors, elevations, sections; usually in 1:200 scale
- quantitative data about the construction elements
- thermographs (not in every case)
- planned energy savings
- planned investment costs
- planned payback time

It is possible to see DWF-format with the help of the ArchiCAD Project Reviewer or other free DWF viewer.



Terv neve: Matyas Kiraly High School
Készlet neve: M K High School
Publikáló: Szőnyi László okl. építészmérnök
Készítés dátuma: 2010. március 15.
Utolsó módosítás: 2010. május 29.
Fájl mérete: 5KB
Fájl típusa: DWF rajz

Fig. 8. Example (Mátyás Király High School) to the documentation of the results of building's retrofitting with the help of DWF-format (ArchiCAD Project Reviewer)

We summarised the whole process of the retrofitting of the facilities with the help of the Fig. 9 below.

4 Conclusion and perspectives

In this paper we have focused on retrofitting public facilities using BIM and LCCA. Using the BIM and LCCA systems we proposed to the local government such solutions to retrofit their buildings, which take into account both the initial and future expenses.

It is not enough to take into account only the initial costs by retrofitting a building, but it is important to estimate the future expenses too.

It is worth handling separately the cost of integrated energy consumption from the operating costs, so the special changes of the energy prices can be taken into account in the LCCA.

It takes more effort to prepare the BIM system at the retrofitting of a building, but it is worth because there are several advantages.

Tab. 8. Calculation of discounted payback time – pessimistic solution (Mátyás Király high school)

Calculation of discounted payback time:	Original	Planned
Gross heat of combustion (kWh/m^3)	9.47	9.47
Heat gain (kWh/a)	367 484.38	143 837.61
Exploitation coefficient of the furnace	1.24	1.24
Energy requirement (kWh/a)	455 680.63	178 358.63
Energy saving (%)	0	61
CO_2-emission (g CO_2/kWh)	249.00	249.00
CO_2-emission (kg CO_2/a)	113 464.48	44 411.30
Decrease of CO_2-emission (%)	0	61
Requirement of fuel (m^3/a)	48 107.05	18 829.65
Price of fuel (2009, gross) [HuF/m^3]	107.00	107.00
Fuel cost (gross) [eHuF/a]	5 147.45	2 014.77
Decreasing of fuel cost (%)	0	61
Investment cost: building construction (eHuF)	0	123 416
Investment to energy saving ratio, A = (year)	0	39
1 + average real rate of rise on energy price: q_2		1.050
1 + average annually real interest of capital: q_1		1.022
Quotient of rise in energy price and interest of capital: q_x =		1.027
Anticipated discounted payback time (year)		27.12

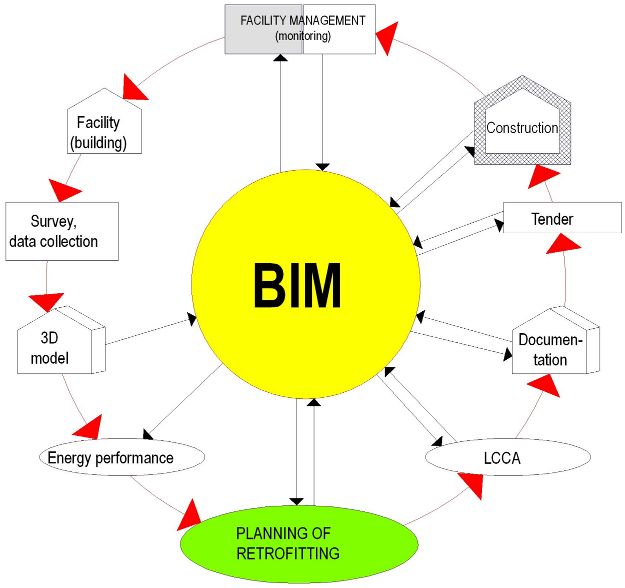


Fig. 9. Process of energy retrofitting

The 3D model comprising of surface elements allows the use of the same surface elements for estimating the quantity, the energy performance, the energy savings and the initial costs of the retrofitting as well.

Among the LCCA methods the discounted pay back time method is the most suitable, because the time value of money and the continuous rise in energy prices can be taken into account.

Our calculations proved that the retrofitting of the analysed 100 public facilities may be refunded after 17-18 years and the retrofitting will save on average 51% energy and CO_2-emission.

The calculations and plans of the retrofitting can be documented easily with the help of the BIM system.

The continuous maintenance of the BIM database allows us to build an information system which can function during the life cycle of a building.

It is important to adopt the HVAC systems for the new requirements after the insulation of the building construction. This is a good opportunity to build up a modern monitoring system which can be attached to the BIM database.We suggested the local government operating a building commissioning or an energy management system based on the developed BIM database.

This information system, connected with Internet platform, enables the local government to make reliable, time saving decisions and to keep the operating costs of the facilities in a lower level.

References

1 **Hungarian Central Statistical Office's (HCSO)**, *Number of the real estates owned by the local governments*, Date accessed: 21.03.2010, available at `http://portal.ksh.hu/pls/ksh/docs/hun/xtabla/onking/tablonk07_01_01_01.html`.

2 ______, *Classification of the educational buildings by technical condition*, Date accessed: 21.03.2010, available at `http://portal.ksh.hu/pls/ksh/docs/hun/xtabla/onking/tablonk07_01_01_01.html`.

3 **Meier C**, *Investitions- und Folgekosten bei Bauvorhaben*: *Bedeutung und Planungskonsequenzen*, expert-Verlag, Ehningen bei Böblingen, 1988. ISBN 3-8169-0299-5.

4 **De Boer J**, *Retrofitting of Educational Buildings - REDUCE, Energy Concept Adviser for Technical Retrofit Measures, Energy Audit Procedures*, International Energy Agency (IEA) Energy Conservation in Building & Community Systems Programme (ECBCS): Annex 36, 2003, http://www.annex36.com/eca/uk/06util/util.html.

5 **Erhorn H, Mroz T, Mørck O, Schmidt F, Schoff L, Thomsen K E**, *The Energy Consept Adviser - A tool to improve energy efficiency in educational buildings*, Energy and Buildings **40** (2008), no. 4, 419–428, DOI 10.1016/j.enbuild.2007.03.008.

6 **Vanlande R, Nicolle C, Cruz C**, *IFC and building lifecycle management, Automation in Construction*, Automation in Construction **18** (2008), no. 1, 70–78, DOI 10.1016/j.autcon.2008.05.001.

7 *Garphisoft manual of collaboration techniques, in Hungarian: Graphisoft Együttműködési megoldások kézikönyve*, ARCHICAD 13, Graphisoft, 2009. More information: http://www.graphisoft.com.

8 **Mearig T, Coffee N, Morgan M**, *Life Cycle Cost Analysis Handbook*, State of Alaska - Department of Education & Early Development, Education Support Services/Facilities, Juneau, Alaska, 1999, http://www.eed.state.ak.us/facilities/publications/LCCAHandbook1999.pdf,Dateaccessed:24.03.2010.

9 **Schade J**, *Life cycle cost calculation models for buildings*, Nordic Conference on Construction Economics and Organisation (Luleå, Sweden, 14.06.2007), 2007, pp. 321–329. Peer-reviewed conference article, Published, http://www.ltu.se/staff/j/jutsch?l=en, Date accessed: 24.03.2010.

10 *DIN 276-1 Building costs - Part 1: Building construciton, in German: Kosten im Bauwesen - Teil 1: Hochbau, Deutsche Norm*, November 2006. In: Fröhlich P J, Hochbaukosten - Flächen - Rauminhalte, DIN 276 - DIN 277 - DIN 18960, Vieweg+Teubner, GWV Fachverlage GmbH, Wiesbaden, 2008, p. 21-46, ISBN 978-3-8348-0591-1.

11 *DIN 18960 User costs of buildings, in German: Nutzungskosten im Hochbau, Deutsche Norm*, Februar 2008. In: Fröhlich P J, Hochbaukosten - Flächen - Rauminhalte, DIN 276 - DIN 277 - DIN 18960, Vieweg+Teubner, GWV Fachverlage GmbH, Wiesbaden, 2008, p. 195-200, ISBN 978-3-8348-0591-1.

12 **Szőnyi L**, *Calculation of operating costs of new buildings*, Technology and Management in Construction 8 (Umag, Croatia, 17.09.2008), 2008, pp. 51. ISBN 953-96245-8-4.

13 *7/2006. (V.24.) Ministry regulation about the energy performance in Hungary, in Hungarian: 7/2006. (V. 24.) TNM rendelet az épületek energetikai jellemzőinek meghatározásáról*, 2006, available at https://kereses.magyarorszag.hu/jogszabalykereso.

14 **Baumann M, Csoknyai T, Kalmár F, Magyar Z, Majoros A, Osztroluczky M, Szalay Zs, Zöld A**, *The new energy regulation of buildings, in Hungarian: Az új épületenergetikai szabályozás*, Bausoft Pécsvárad Kft, Pécsvárad, 2006. ISBN 9632291786.

15 *176/2008. (VI. 30.) Government regulation about qualification of buildings energy performance, in Hungarian: 176/2008. (VI. 30.) Korm. rendelet az épületek energetikai jellemzőinek tanúsításáról*, 2008, available at https://kereses.magyarorszag.hu/jogszabalykereso.

16 **Feldhaus M, Gabriel I, Janssen M, Klima M, Ladener H, Siepe B, Haefele G, Lichtbau F, Reinberg G, Schubert W, Viridén K, Horváth S E**, *Vom Altbau zum Niedrigenergiehaus – Energetische Gebäudesnierung in der Praxis*, Ökobuch Verlag, Staufen bei Freiburg, 2004. in Hungarian: Kisenergiájú házak 1. – Felújítás az energiatakarékosság jegyében, CSER Kidadó, Budapest, 2009, ISBN 978-963-278-057-3.

17 **Szabó L, Zepkó F**, *Archaism and up-to-dateness value-added refurbishment of windows on a historic building Károlyi Palace, Budapest*, Periodica Polytechnica Civil Engineering **50** (2006), no. 1, 27–34.

18 **Pfundstein M, Gellert R, Spitzner M H, Spengard Ch, Albrecht W, Rudolphi A**, *Isulating Materials, Principles, Materials, Applications: An Edition DETAIL book*, Birkhäuser, Münich, 2008. Istitut für Internationale Architektur-Dokumentation GmbH & Co. KG, ISBN 3764386541, 9783764386542.

19 **Christiensen S**, *Kosten und Nutzen energiesparender Baukonstruktionen: Tabellen, Diagramme und Ausführungsbeispiele für Neu- und Altbauten*, Bauverlag, Wiesbaden, Berlin, 1981. ISBN 3-7625-1302-3.

20 **The Central Bank (MNB)**, *Interest rate in Hungary between 1997–2009*, Date accessed: 01.01.2010, available at http://www.mnb.hu/Engine.aspx?page=mnbhu_statisztikak\&ContentID=2516.

21 ———, *Inflation in Hungary between 1996–2008*, Date accessed: 01.01.2010, available at http://www.mnb.hu/engine.aspx?page=mnbhu_statisztikai_idosorok.

22 **Hungarian Central Statistical Office's (HCSO)**, *Average annual consuming prices of some products and services (1996–2009)*, Date accessed: 22.03.2010, available at http://portal.ksh.hu/portal/page?_pageid=37,594652\&_dad=portal\&_schema=PORTAL.