SOLANOVA – “Factor 10”-retrofit of large residential buildings

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Abstract

On January 1, 2003 the combined research and demonstration project “SOLANOVA – Solar-supported, integrated eco-efficient renovation of large residential buildings and heat-supply-systems” started. SOLANOVA is supported by the Fifth Framework Programme of the European Commission.

Ongoing renovations of the huge stock of large residential buildings in the new Eastern European member states (Hungary: 726 000 flats) only result in minimal non-sustainable energy improvements. SOLANOVA proposes to make this process more sustainable by transferring the existing know-how about new passive houses to the renovation of large buildings. In the Hungarian town Dunaújváros a 7-story panel building of the 1970s is to be transformed into a „Factor 10“-building by reducing the space heat demand of the flats to almost 10%. Being the first EC project of this type in Eastern Europe dealing with a „major renovation“ of a large existing building, SOLANOVA serves as best practice example for the proper implementation of the European Union’s Energy Performance of Buildings Directive. 16 cm wall insulation, windows with integrated shading for acceptable summer comfort, mechanical ventilation with high-efficient heat recovery and fans as well as a big solar thermal collector area have never been integrated and applied in this context. Moreover, all flats are owner occupied and all retrofit measures have to be implemented in occupied state.

Dwellers’ satisfaction, indoor climate and energy consumption are permanently investigated by a scientific monitoring. The first retrofit measures are to be implemented in autumn 2004. All project steps explicitly consider ecological, social and economic components over the building’s life-cycle.

Introduction

On January 1, 2003 the combined research and demonstration project „SOLANOVA – Solar-supported, integrated eco-efficient renovation of large residential buildings and heat-supply-systems“ started. SOLANOVA is supported by the Fifth Framework Programme of the European Commission.

The main target is to show how existing passive house know-how can be applied to large panel buildings in order to avoid lost-opportunities during the forthcoming renovation process, which on a European scale is just at its beginning.

SOLANOVA: Panel Building meets Passive House

PROJECT OUTLINE

Ongoing renovations of the huge stock of large residential buildings in the new Eastern European member states only result in minimal non-sustainable energy improvements. SOLANOVA proposes to make this process more sustainable by transferring the existing know-how about new passive houses to the renovation of large buildings. In the Hungarian town Dunaújváros a 7-story panel building of the 1970s is to be transformed into a „Factor 10"-building by reducing the space heat demand of the flats to almost 10%. Being the first EC project of this type in Eastern Europe dealing with a „major renovation" of a large existing building, SOLANOVA serves as best practice example for the proper implementation of the European Union's Energy Performance of Buildings directive. 16 cm wall insulation, windows with integrated shading for acceptable summer comfort, mechanical ventilation with high-efficient heat recovery and fans as well as a big solar thermal collector area have never been integrated and applied in this context. Moreover, all flats are owner occupied and all retrofit measures have to be implemented in occupied state.

The whole process has been evaluated with the life-cycle approach with respect to its environmental adequacy. The reconstruction design as far as possible has been eco-efficiently optimised by confronting environmental benefits with the costs. For the large panel construction areas in Eastern Europe an exemplary design for an ultra-energy efficient reconstruction of these panel constructions will be developed. The renovation effects will be checked with the help of monitoring the energy consumption, indoor temperatures and humidities as well as the dwellers' satisfaction. A similar building standing nearby acts as referee. By means of a social scientific survey the socio-economical effects have been and will be evaluated. Main partners in the project are the University of Kassel (Project idea, Coordinator, eco-efficient optimisation and socio-economic research), the Budapest University of Technology and Economics – BUTE - (Architecture and Building Physics, Supply System), the Austrian window producer Internorm, the District Heating Company of Dunaújváros, the Energy Centre Hungary and the Passive House Institute Dr. Feist – PHI.

PANEL BUILDINGS IN HUNGARY

The first Hungarian building with industrial technology was built in Budapest in 1954. Later on, the wide-range application started in Dunaújváros, located ca. 70 km in the South of Budapest, where a new industrial town emerged from a small fishing-village. Until the middle of the 1960s the application of monolith medium-sized panel blocks and moulded structures dominated the construction industry, but from the end of the 1960s uniform technology was introduced all over the country and 11 "house-factories" were founded in different main towns. Ten factories produced building types based on the Russian, and one based on the Danish Larsen-Nielsen licence. These buildings were built with prefabricated sandwich panel elements. The productivity of the panel construction industry dominated the era of the seventies and the eighties, it reached its highest production level between 1975 and 1985, then started to decline and the last building of uniform panel construction was erected in 1992. In Hungary altogether 726 000 flats were built with industrial technology, thereof 508 000 with prefabricated sandwich panels. This means that presently 13,8 % (ca. 1.4 Million) of Hungarian citizens live in this kind of buildings. This sort of technology and construction volume was typical in all socialist Eastern European countries, for example in the former East-Germany more than two million flats were erected (Hermelink, Csoknyai 2004).

***Figure 1**. Southern view of the SOLANOVA building.*

PASSIVE HOUSES – FROM GERMANY TO HUNGARY

The term "Passive House" refers to a construction standard that can be met using a variety of technologies, designs and materials. It is basically a refinement of the low energy house standard. Passive Houses are buildings which assure a comfortable indoor climate in summer and in winter without needing a conventional heat distribution system. To permit this, it is essential that the building's heating load does not exceed 10 W/m^2.

The first Passive House was built in Darmstadt/Germany in 1991. A real take-off for this type of ultra-low-energy buildings began by the end of the 1990s, when the idea started to spread in Germany, Austria and Switzerland. Already in 2001 more than 1000 dwelling units had been erected using Passive House technologies. While the very first dwelling units only could be found within single-family-, semi-detached- or row-houses, in the meantime the technology has been transferred to multi-family buildings and even office buildings (Schnieders 2003).

The small heating load is roughly equivalent with an annual space heat requirement of 15 kWh/m^{2}a. Passive Houses thus need about 80% less space heat than new buildings designed to the various national building codes valid by the end of the 1990s and even more than 90% less than the building stock, which means "Factor 10". As building new flats has a very low share in the housing sector, e.g. less than 1% in Germany, the building stock by far offers the biggest saving potential. To demonstrate this enormous saving potential, the SOLANOVA project was designed.

The design process

The biggest challenge of the SOLANOVA project is to transfer the Know-how from new Passive Houses to the case of obsolete panel buildings which moreover are situated in Hungary, where no such severe standards exist like in Germany, Austria or Switzerland. Thus there is no practical Passive House experience at all which the local partners being responsible for the implementation could rely on. To illustrate the dimension of the task, several technical and non-

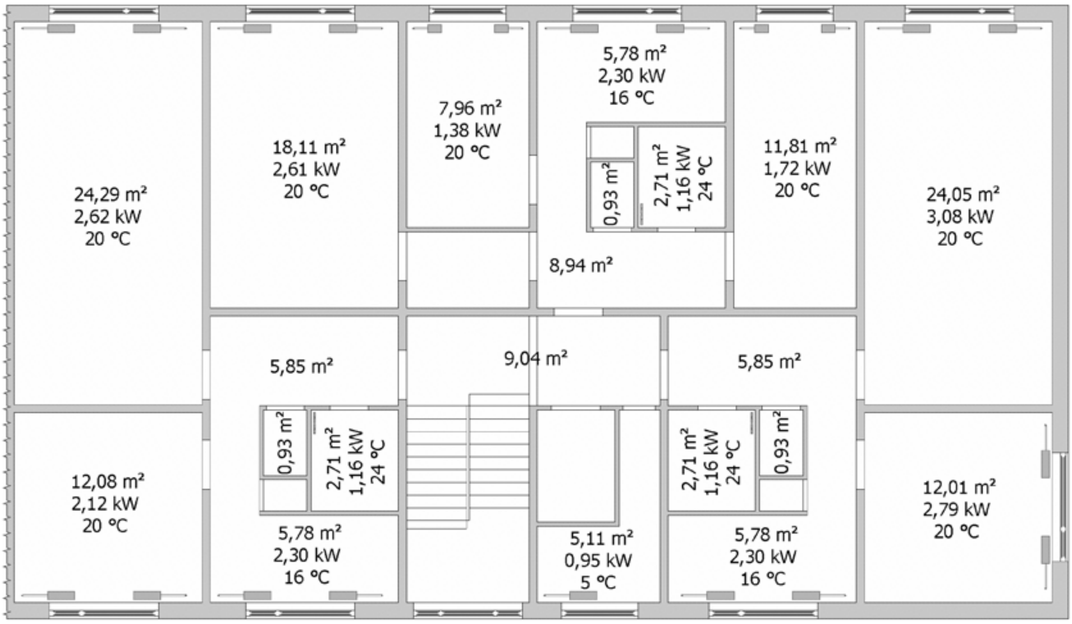

***Figure 2**. Designed heating power and flats' layout, one half of the SOLANOVA building.*

technical aspects of the current and future aspects of the project will be highlighted below.

ENERGY CONSUMPTION

Current State

The originally designed heating power for the whole building is 373 kW or 136 W/m² respectively. Applying current Hungarian building regulations for a calculation of the heating power results in 291 kW or 106 W/m² respectively. The monitoring of the current heat consumption showed an average consumption only for space heat of ca. 220 kWh/m²a. Figure 2 gives an overview about the designed heating power and the flats' layout.

Designed state

Dynamic simulations for a perfectly renovated state placed the heat demand close to 20 kWh/m²a. Cautious and probably more realistic assumptions regarding the quality of a first time implementation (prospective air-tightness and quality of reduction of thermal bridges) yielded a result well below 25 kWh/m²a for the flats. The same level of reduction is valid for the heating power. The flats on floor 2-6 will have a maximum hating power of ca. 10 W/m², whereas the flats in floor 1 and 7 may need ca. double heating power, which is especially due to the partly non heated shops in the ground floor and the attic on the roof which will be well insulated but still remains a considerable heat bridge. The ground floor is designed for a heat demand of 60 kWh/m²a.

ARCHITECTURE AND BUILDING PHYSICS

Current State

Walls

In the original state the external walls of the building consist of three layers - two concrete layers with a polystyrene insulation layer in between. At the edges of these elements there are serious thermal bridges. The theoretical U-value of the undisturbed centre region of the elements is U = 0.435 W/(m²K).

Due to the effects of the prefabrication technology, when the polystyrene is exposed to water, to the weight of the concrete layer, vibration and thermal treatment, the real conductivity is 50% higher than the theoretical value. This was shown by measurements carried out by the Laboratory of Building Physics, Technical University of Budapest in the 1980s. In addition there are several more factors which further increase the difference between theoretical and real U-values of the whole wall: the steel joints of the concrete layers, the perimeter of the panels where no insulation can be found, damages of the perimeter and above all the joints between neighbouring panels. The thermal bridge calculations made by BUTE and PHI have proven that the thermal bridge losses are 80% - 280% of the one-dimensional transmission losses of the panels. The exact value depends mainly on the construction period and building geometry. Therefore the real average U-value of the panels varies between 1,3 and 2,6 W/(m²K). Thus the main effect of an additional external thermal insulation of the façades yields the most significant energy savings not on the panels, but at the joints. Figure 3 and Figure 4 illustrate the significance of these thermal bridges.

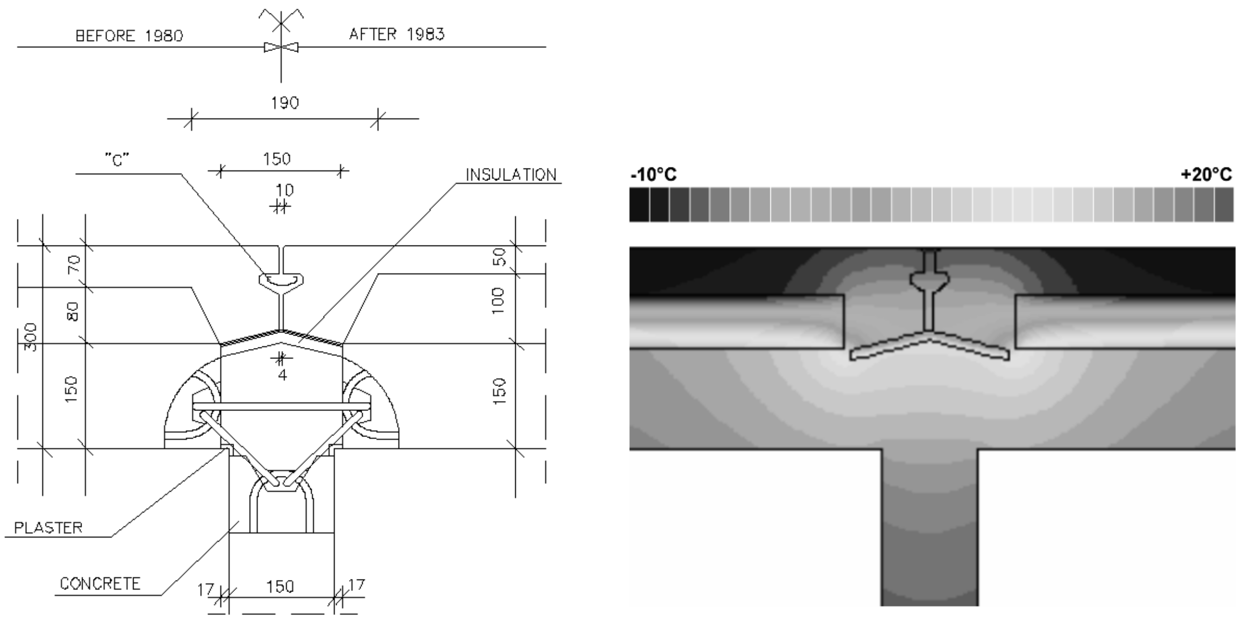

Figure 3. *Joint between outside and inside wall and corresponding isothermal lines.*

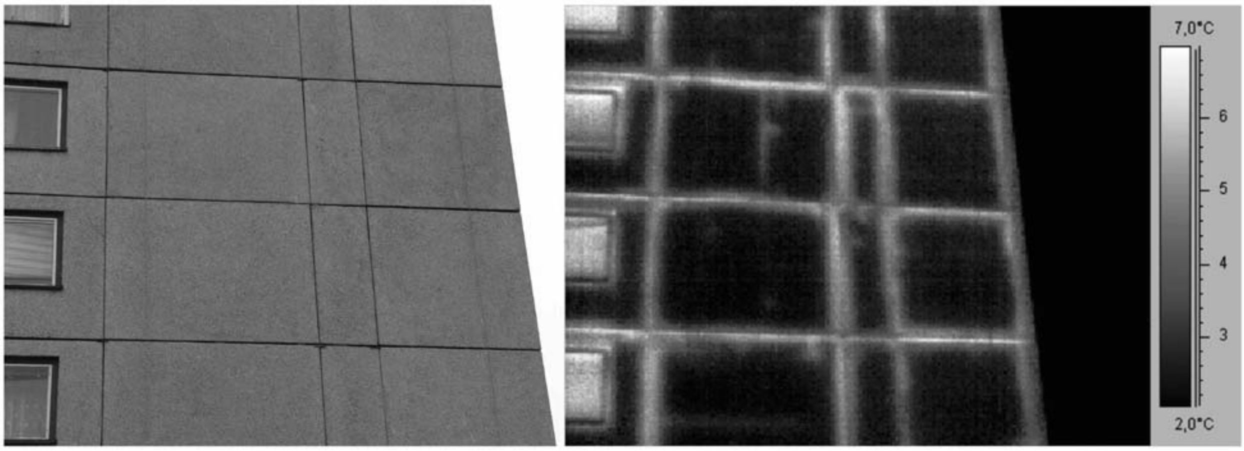

***Figure 4**. Real photo and thermography of panels and joints.*

Windows
The original windows consist of a wooden frame with standard float glass (4 mm without low e-coating, 45 mm air gap). The U-value of the frame was calculated to be 1,5 W/m^{2}K, the U-value of the glazing to be 2,8 W/m^{2}K. The resulting U-value of the window is 2,3 W/m^{2}K. Including the thermal bridges around the frame, the resulting U-value of the original window in the panel wall was calculated to be 3,2 W/m^{2}K.

Roof
The existing roof consists of the concrete slab (130 mm) covered with a 50 mm lightweight concrete layer and an 80 mm insulation layer. In order to realise the slope for water drainage, a wedge shaped layer (lightweight concrete) is added. The total theoretical U-value of the existing roof layers is calculated according to DIN EN 6946 annex C to be 0,46 W/m^{2}K, which in reality is much higher due to the several moisture problems and inappropriate construction. Due to the poor quality of man work during the original construction, moisture problems have occurred several times. Therefore the tenants were sceptical about leaving the roof flat and they proposed to build up a pitched roof. This proposition was finally rejected, because of financial reasons.

Designed State

Wall
Usually the insulation width in Passive Houses is ca. 30 cm. SOLANOVA's main target is to demonstrate cost-efficient solutions which match the Passive House standard as far as possible. As the project is intended to serve as starting point and model for following modernisation efforts, there are severe budget restrictions. Therefore the team finally chose 16 cm polystyrene insulation as an adequate level. Due to the very low relation between the building's surface and volume this still is sufficient to almost reach the Passive House level. Figure 5 indicates the fundamental reduction of the above

presented thermal bridge by installing an effective outside insulation.

Windows

Several requirements must be fulfilled by the windows. They must provide for an effective shading in summer, they must enable free ventilation at night and their U-value should be near to the Passive House level of 0,8 W/m²K. It turned out, that due to cost-efficiency, compromises had to be made. At first the "non-PVC" idea had to be buried. Surprisingly, overheating in summer turned out to be the worst characteristic of the current building. This had been revealed by the preliminary summer and winter monitoring and a detailed user survey. As energy wasting electric air-conditioning should be avoided under any circumstances by using passive techniques, an effective shading became the highest priority for the southern and western windows. Due to the buildings height of ca. 22 m the necessary resistance against high wind speeds as well as the willingness to minimise heat bridges excluded external shading systems. All these requirements can be fulfilled by a window which has been developed by the SOLANOVA partner Internorm. It is a 2+1 glazing with integrated shading in the space between the window panes (SBW). The final solution will be the "Dimension 4"-type, a PVC frame with 2+1 glazing. Thanks to the static function of the double-glazed part, the usage of reinforcing steel in the frame – which increases the heat loss through the frame - is minimised. This leads to a still very low U_w-value of the total window of ca. 1,1 W/m²K. Without using the shading the g-value of the window is 0,55. By using the shading with an optimal setting of the lamella angle the g-value can be reduced to 0,10. This is much less than any available kind of sun-protection-glazing. According to a simulation of the Passive House Institute, the application of this shading leads to considerably higher summer comfort than e.g. the application of the common internal shading. An internal shading system in combination with double glazing (U-Value 1,1 W/m²K, g=0,65) would result in 12,8% overheating, which means about 47 days of the year with indoor air temperatures over the comfort level of 25°C. Most of July and the whole August there would be a serious overheating problem. Using the 2+1 system reduces the overheating to 3,9%, which is equivalent to 14 days in summer. A section through the 2+1 glazed window and a scheme of the integrated shading can be seen in Figure 6.

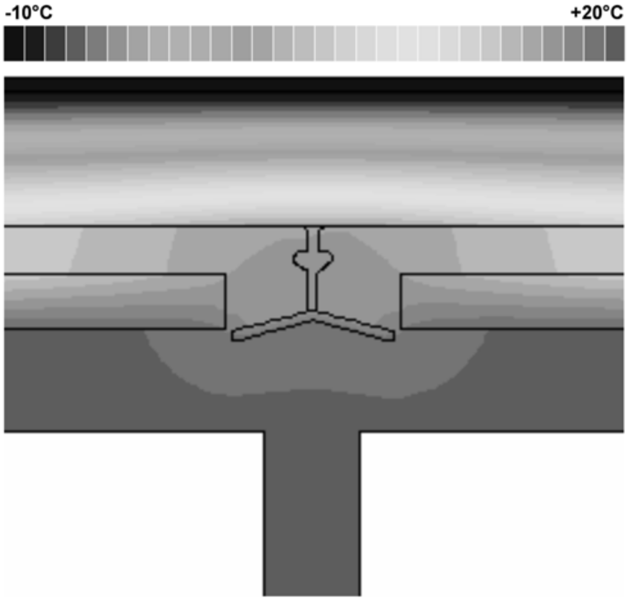

Figure 5. *Joint between insulated outside wall and inside wall and corresponding isothermal lines.*

Roof

The roof will be insulated with 30 cm to 40 cm extruded polystyrene foam. In addition, the idea is pondered to have a green roof. As the building does not have any balconies, this measure would provide for a recreation area for the dwellers. The final solution is not yet available, it will depend on the feasibility within the restricted budget.

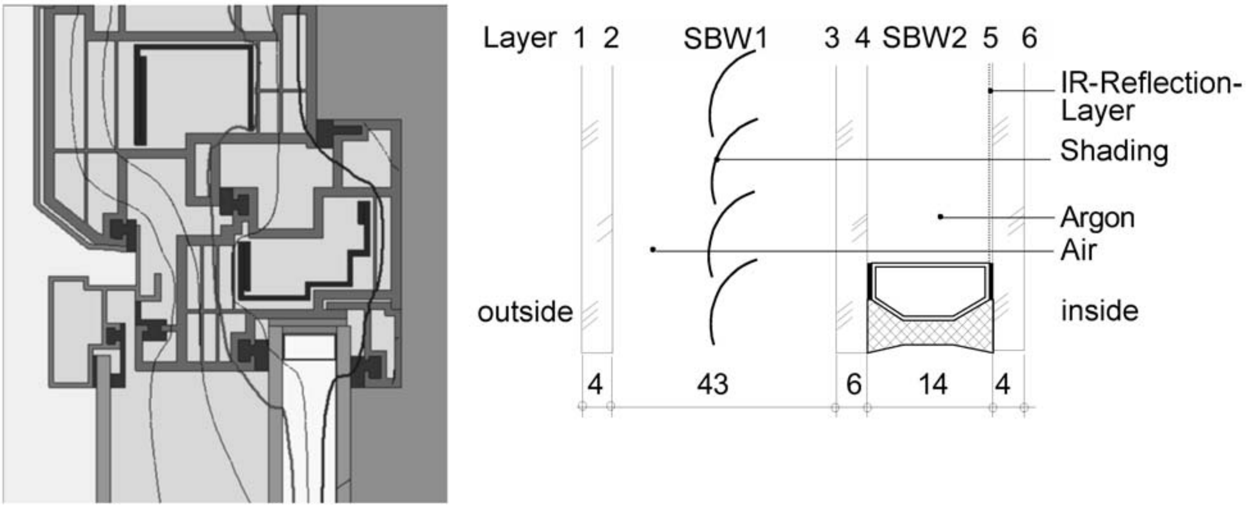

Figure 6. *Window with integrated shading.*

SUPPLY SYSTEM

Current State

Space heating and hot water system, Ventilation
Presently the heating system is an uncontrollable single-pipe system, with a heating power of 325 kW. Seven radiators are connected to one upward pipe and another seven to the same pipe downwards. Thus, altogether 14 radiators are in series, which is an extremely wrong solution both from hydraulic and thermal point of view. Consequently even manual control is not possible. The age of the system is equal to the age of the building, so the exchange of only some elements of the system, for example only the radiators, would not assure correct operation and low maintenance for the next 30 years. At the moment there is an exhaust air system with grids in the kitchen, the WC and bathroom which is powered by several highly inefficient fans on the flat roof. As the air-tightness of the whole building shell is extremely poor, the high unavoidable air exchange leads to noteworthy low humidity values, which are beyond any recommended range for a healthy climate. Figure 7 gives an example for two average winter days; the data were recorded by highly precise portable data loggers.

Designed State

Heating system
The current system has to be replaced in order to provide a satisfactory heating for the dwellers. A main focus regarding the heating system for the refurbished state has been on decreasing the uncontrolled heat losses from heating pipes. The future heat demand for the flats is designed to be less than 35 kW. The single pipe system will be converted into a double-pipe system to give dwellers control over their heating system. The old pipes are quite big and omit a lot of heat. To decrease this uncontrolled heating from the pipes, many vertical strands will be removed. The kitchen and probably also the bathroom will no longer have a radiator. New pipes with a smaller diameter will decrease the uncontrolled heating even more. Another measure to decrease the uncontrolled heating is to lower the forward and return temperature of the heating system. The forward/return will decrease from 90/70°C to 60/45°C. The final step to decrease the uncontrolled heating is insulating the pipes for space heating and domestic hot water.

Several variations have been developed during the course of the design stage. From technical point of view a solution with one heat exchanger per flat providing heat for hot water and space heating has been favoured. Although this solution only needs one circulation pipe for both space heating and domestic hot water and is fed from the same heat storage tank, this solution had to be rejected because of its high cost. Only two solutions remained:

- heating system with radiators and minimised number of rising pipes
- air heating system with air recirculation

More details will be given in the next chapter about ventilation.

Ventilation
The ventilation system is one of the most sensible parts of the SOLANOVA project. It is *the* passive house feature which increases comfort most in case it is designed considering all comfort requirements inherent to passive houses. Special emphasis has to be put on freeness of draught, maximum heat recovery rates to get high temperatures of infiltrated air and least possible noise emission. Above, possibilities which might exist in projects with tenants moving out during the construction works do not exist in Hungary where the flats are owner occupied. Naturally in our case the dwellers don't have the possibility to move out during the construction stage. This means that all considera-

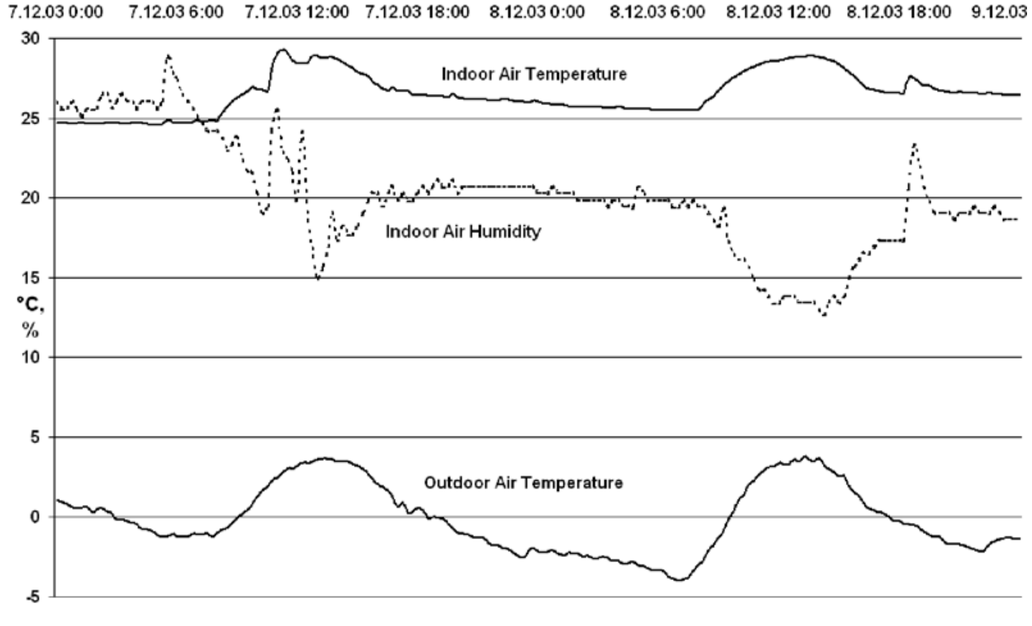

***Figure 7**. Winter indoor climate.*

tions, regardless which constructional measure is spoken of, have to have a strong focus on the least possible disturbance of the dwellers. The ventilation system causes the strongest interference with the dwellers flats.

Throughout the design stage there were several discussions about the best solution for the ventilation system. Generally the following criteria have been pondered during all discussions:

- investment costs, operational costs
- maintenance (access, availability of spare parts, risk of failure)
- disturbance caused by installation (noise, dirt)
- noise during operation
- space requirements
- risk of abuse
- requirements of fire protection
- comfort (thermal, odours)
- replication potential
- complexity
- easiness of handling
- availability on the market.

Several variations had been drafted and evaluated according to the above listed criteria. Finally two main concepts remained: a centrali and a decentral ventilation system. The parameter with the biggest uncertainty was the price. Neither of these two solutions has ever been realised in Hungary up until now. It was assumed, that probably the central version would be cheaper. Therefore the team decided to elaborate both alternatives and also to include both of them in the tender. After the tender the decentral version turned out to be as cheap as the central version. Because of the higher replication potential, since then this variation got the main focus.

In the central solution there would have been a central unit for each of the two staircases. A main advantage from noise point of view would have been the situation of the fans outside the flats. Drawbacks of this solution would have been high fire protection requirements because of connecting several flats to the same duct, uncertainty about the state of existing ducts and more collisions with existing furniture in the flats.

Main advantages of the decentral version are the independence from what retrofit measures are taken in adjacent flats and no fire protection requirements. In this version each flat gets a unit with integrated high-efficient DC fans and heat recovery with an efficiency of more than 80%. Considering that all flats are owner occupied the replication of this solution is much easier. In following projects each flat owner may decide about installing such a unit or not. In case of a central solution, at least *all* flats in one staircase *must* connect to the system. To get such a degree of agreement is quite difficult to achieve.

There are two solutions for the heat supply in case the decentral version is chosen. Either air heating or radiator heating. Only during negotiations after the tender it turned out, that there are cost efficient possibilities for an air heating system. Until then this possibility had been rejected by the ventilation experts in the team because the flats in the ground floor and in the top floor do have heating loads of significantly more than 10 W/m^2, which usually is the limit for comfortable air heating systems. A Czech producer was found, who was willing to develop a unit matching the SOLANOVA requirements. The unit is equipped with high efficient DC ventilators and applies air-recirculation which enables higher heat loads without resulting in an unacceptable low relative humidity in the flats. This would be the effect without recirculation, as the air temperature is limited to 50°C and thus higher heating power only can be achieved by higher airflows. In case these are pure flows of ambient air, this leads to very high real air exchange rates, which would directly reduce the humidity in the flat. Applying the air-heating solution, the heating system is reduced to an absolute minimum, as only six forward and return pipes have to be installed in the already existing installation shaft. To each of such a pair of heating pipes seven units will be connected. A disadvantage of cost-efficient air heating systems is the impossibility to provide for single room temperature control. Only single flat temperature control is possible, which might lead to unsatisfactory temperature differences between southern and northern rooms within the same flat. Considering that currently there is no possibility to control the temperature at all – except opening the windows – this might be only a theoretical disadvantage. It also can be assumed that the noise level of such a solution would be higher due to the high recirculation volume flows.

Solar system

To achieve a considerable amount of solar energy supply, initially a collector array between 40 and 120 m^2 was foreseen. Due to financial reasons, the application of water saving equipment and the final position as the building's southern canopy led to a final size of ca. 75 m^2.

ECO-EFFICIENT OPTIMISATION

One of the main aspects of the project is the focus not only on the technical aspects but to a similar extent to their economical and ecological effects. Figure 8 illustrates the structure of the eco-efficient optimisation.

At the beginning the building's current state has been analysed. One of the main questions was brought to the formula: "Retrofit or dynamite", i.e. is it from eco-efficiency point of view worth the while to maintain these buildings or is the better option to tear them down and build new?

The analysis started with a rough comparison between the current state and the refurbished state by applying a Life-Cycle-Assessment approach. Here, we have to discern between input for permanent consumption and manufacturing. The average space heat consumption in the flats and ground floor is 220 kWh/m^{2}a, the average consumption for domestic hot water (DHW) equals 50 kWh/m2a, where circulation losses account for almost 40% of the DHW losses. The primary energy factor of the average Hungarian district heating supply has been calculated to be 1,41 kWh/kWh. Considering a period of 40 years, the primary energy input (PEI) would be ca. 40 000 MWh only to cover the heat demand, the corresponding $CO_{2,eq}$ emissions have been calcu-

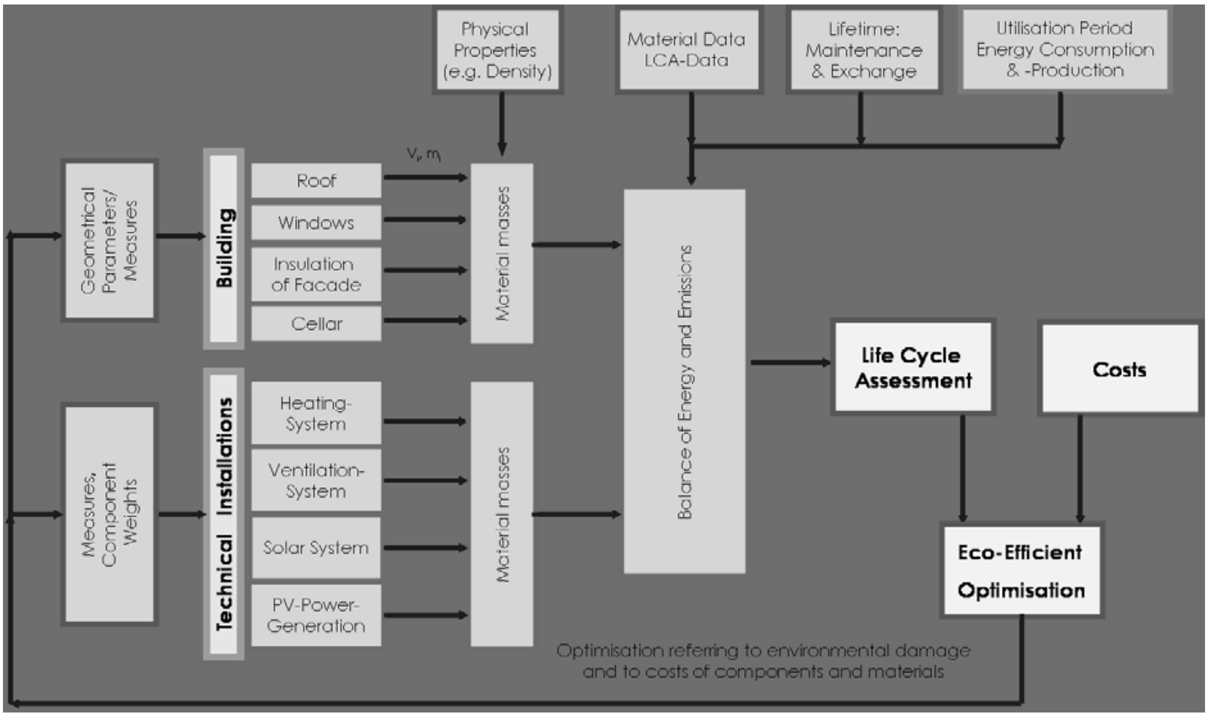

***Figure 8**. Scheme of Life-Cycle-Assessment (LCA) and eco-efficient optimisation.*

lated to be ca. 10 000 t. The current electricity and gas input (only for cooking) are quite low. The electricity consumption for the current exhaust fans and the future single ventilation units is almost the same, whereas electricity consumption for heat and DHW pumps will reduce sharply. As we have to compare scenarios about the future development, a considerable increase of electricity consumption for summer cooling can be assumed for a future, where in contrast to the SOLANOVA scenario no highly effective passive cooling measures would be applied. The total difference in electricity consumption between “nothing changes” and “SOLANOVA” scenario has been estimated to be ca. 4 kWh/m^{2}a. After renovation the space heat demand for the flats has been cautiously calculated to be ca. 25 kWh/m^{2}a, for the ground floor ca. 60 kWh/m^{2}a, which for the whole building is on average ca. 30 kWh/m^{2}a. By applying water saving equipment, solar thermal panels and insulation of DHW pipes, the remaining DHW consumption is estimated to be ca. 13 kWh/m^{2}a. The 40 years PEI input for heat calculates as ca. 6 300 MWh, with corresponding $CO_{2,eq}$ emissions of ca. 1 600 t. Including electricity the 40 years reduction of PEI is ca. 35 000 MWh, the reduction of . $CO_{2,eq}$ emissions ca. 8 600 t.

Compared with the PEI and CO_2 savings, the PEI and CO_2 “investment” to achieve these saving is quite low. The PEI for the retrofit has been calculated to be ca. 810 MWh, the $CO_{2,eq}$ input to be ca. 270 t.

Thus it turned out, that because of the high level of the targets from eco-efficiency point of view retrofit is the right decision – and not dynamite. After having had this main result some building elements like insulation, windows and solar thermal collectors including the supporting structure have been thoroughly analysed.

The wide use of solar energy by thermal collectors is one of the key features of SOLANOVA. Thus there had been a high impetus to analyse the optimal use of this technology. At first, the optimal placement of the collectors was found serving as canopy on the ground floor. On this place the collectors not only deliver heat but also serve as shading and weather protection for pedestrians. As some dwellers and the representatives of the Housing Association had been afraid of vandalism, in the plans the collectors were shifted temporarily to the top of the building. A thorough LCA restricted to the manufacturing of the solar system revealed the negative consequences of such a solution. Figure 9, shows the relative share of the solar system’s main parts in five impact categories - Masses, Primary Energy Input (PEI), Global Warming Potential (GWP), Acidification Potential (AP) and particles.

As on 25 m height the collector array has to withstand very high wind speeds, a very massive steel carrier construction grew necessary. Figure 9 shows that this construction dominates not only in terms of mass but also in terms of PEI and GWP. The steel carrier construction alone would have contributed more than 2/3 of PEI and GWP to the whole balance of the solar system. Finally the solar collector array was shifted back to the canopy where a much smaller supporting structure will be applied.

The total cost of the project has always been a major point of interest, as the budget had been calculated very restrictive in the planning stage of the project and especially as the main target is to create an example with highest possible replication potential. During the last decade, some lessons could be learnt from retrofit projects e.g. in Eastern Germany: Recently it has got obvious that a mere focus on minimising of investment cost to achieve very short amortisation periods is an inadequate kind of myopia. A reduction from

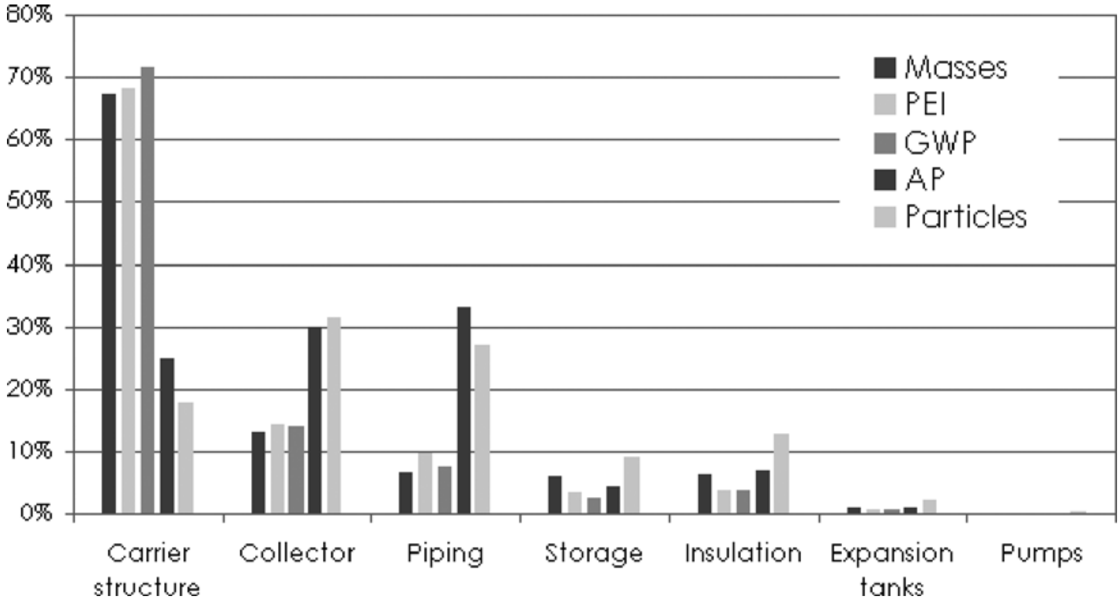

Figure 9. *Eco-balance for the construction of the solar thermal device.*

ca. 200 kWh/m²a to 120 kWh/m²a without doubt can be done very cheap, having very short amortisation periods – only by the end of this theoretical short period it has happened too often, that already a considerable share of flats was empty. A renovation focused on contributing to a sustainable lifestyle must reduce energy consumption near to Factor 10, at the same time provide for a comfortable and healthy indoor climate, ensure a high remaining lifetime of the building and keep the dwellers satisfied. This only can be done by applying an integrated renovation. Key figures like marginal cost (Euro/saved kWh) for different singular measures above all give interesting insights where cost reducing efforts should start and not necessarily where to start with the measures. Air-tight buildings simply require mechanical ventilation and thus this decision cannot be based on an amortisation period for a ventilation system alone. Moreover in some cases it is not an easy question which measures may claim which savings for themselves. Is the minimising of a heat bridge at the window-wall joint due to the new window or due to the insulation? How should the amortisation for a much smaller heating system - which necessary follows from the other measures – be calculated? Which measure is responsible for avoiding empty flats and thus avoiding income losses for the landlord?

In this paper we argue for an evaluation of the total renovation cost. In SOLANOVA there are several financing sources, partly with payment schedules extending up to three years after finishing of the retrofit. This leads to considerable internal financing costs. Moreover at the moment hardly any builder in Eastern Europe might be able to control, harmonise and organise several sub-contractors who should do some highly innovative retrofit for the first time. Consequently a general constructor probably might be needed who at least has some experience in the field of complex renovation and who requires his adequate profit share for doing this complex job. In addition, most of the sub-contractors apparently include a kind of "fear supplement" and probably also an "EC project supplement" in their prices as they lack any experience e.g. with super-air-tight mounting of windows, any kind of decentral ventilation in flats, large solar thermal panels in multi-story buildings, insulation thicknesses of more than 6 cm and have some weird ideas about the abundance of EC sources. From this point of view, it can be considered as quite a big step ahead, that the net budget of 240 Euro/m² treated floor area turned out to be sufficient. Given the total final energy savings of ca. 24 500 MWh/40 years, each kWh which is saved in SOLANOVA costs 2,6 ct. Assuming the targeted large scale implementation of this kind of retrofit, even 2 ct/saved kWh seem to be feasible. From sustainability point of view this is remarkable, as most renewable energy sources by far cannot compete with these marginal cost. Currently the marginal cost for large scale solar thermal energy is ca. 0,2 Euro/kWh (Kessler et al. 2005). In a nutshell this means that from a Least Cost Planning perspective even super-efficient renovation being on a level matching sustainability targets can be done much cheaper than any kind of large scale supply with renewable energies which currently is a much more popular option for sustainability.

SOCIO-ECONOMIC RESEARCH

Parallel to and assisting the bunch of technical analyses is the socio-economic research within the project.

Research during the last two decades revealed, that technical measures alone in most cases do not lead to the forecasted results. Reasons for these failures are among others:

- The habits of the users are not known and/or disregarded.
- The knowledge of the users regarding the "right" behaviour does not match the new installations or surroundings.
- Wishes of the users are often unknown and thus disregarded.
- The present state of the dwelling situation is unknown.

To avoid these traps already from the beginning of the SOLANOVA project, the users are integrated in the development of the various concepts for renovation by

- informing them and
- getting informed by them.
- At least 3 surveys are planned:
- before the renovation
- after the renovation before the first heating period
- after the renovation after the first heating period

This means a longitudinal study is going to be conducted, which in the end will provide for valid results about the users' "before-after" situation.

The first survey was conducted in spring 2003, three months after the start of the SOLANOVA project (Hermelink 2003). To get a sound baseline not only the dwellers in the demo building were personally interviewed but as a reference also the dwellers of an identical building standing nearby. Numbers in brackets represent the values of the reference building. Among others variables like "persons per flat", age, income and educational level had been investigated. Some remarkable key figures could be derived from that.

- The average number of persons per flat is 2,8 (3.0). Compared to western European standards this is high. In Germany the corresponding value is only 2,2.
- The average living area per person is 19,2 m^2. This is less than half of the German average which recently got higher than 40 m^2 per person.
- Not only from socio-economic point of view this is remarkable but also for the high share of heat which is contributed by the dwellers. Assuming 80 W/person, in Germany the average heating power of the dwellers is 2,0 W/m^2 whereas in the demo building we can calculate with 4,2 W/m^2. Keeping in mind the *maximum* heating load of Passive Houses of 10 W/m^2 this has to be taken into consideration in simulations and dimensioning of the technical systems.

The general satisfaction with the flat was measured with the question "How satisfied are You with Your flat?" Answers were possible between 1 "very dissatisfied" and 5 "very satisfied". The general satisfaction is above average, with 3,49 (3,30).

To get an unprejudiced picture about what people like or not, four questions were asked:

- What do You like best about Your flat?
- What would You like to have another way at Your flat?
- What do You like best about Your building?
- What would You like to have another way at Your building?

In the following the answers are not separated between demo and reference building, because an interpretation of these questions must stay on a qualitative level.

Favourite characteristics of the flat are especially - the situation (20 mentions), segmentation/size of flat (18 mentions), brightness (16 mentions), size of certain rooms (9 mentions), separate WC (4 mentions), warmth (4 mentions), quietness (3 mentions). Regarding the refurbishment the following conclusions can be drawn: People like the brightness. All flats have windows which exceed the size required by building regulations. Nevertheless people are accustomed to the big windows. Finally it has been decided to leave the size of the window unchanged.

Things that could be different regarding the flat are - ordered by frequency of mentions - bigger kitchen (30 mentions), bigger kitchen and bathroom (21), windows (and doors) should be tight or replaced (8 mentions), eliminating with draught (4 mentions), better heating system (4 mentions), better noise protection (4 mentions), segmentation (4 mentions), balcony (3 mentions), bigger room (apart from bathroom and kitchen) (3 mentions). Regarding the refurbishment the conclusion can be drawn that on top of the list is the demand for a bigger kitchen. In the frame of the SOLANOVA it won't be possible to change the segmentation of the flats. Nevertheless it got very clear that any decrease of the usable size of the kitchen and the bathroom should be avoided under any circumstances. The result also helped the team to keep realistic. The energetic aspects can be found on the list but they do not enjoy the highest priority.

The favourite characteristics regarding the building are "nothing" (12 mentions), the situation (10 mentions), only 7 floors (6 mentions), availability of elevator (5 mentions), bright stairhouse (4 mentions) and the neighbours (4 mentions). Obviously some of the occupants are quite disenchanted in saying they like "nothing" about their building. Thus the refurbishment might help to cheer them up a little. Again the survey had some effect on the architecture. While the architects first draft also included the diminishment of the staircase windows this idea was neglected after getting the results of the survey.

Regarding the building the following aspects could be different: more colour (30 mentions), balcony (14 mentions), better windows (10 mentions), better roof (6), better insulation (5 mentions), better or safer entrance door (3 mentions). Obviously the majority of the occupants is fed up with the grey monotonous look of the buildings. A nice colour concept which differs considerably from the also monotonous non-colourful look of other demo projects should be made and implemented. Quite a lot of mentions regard the lack of balconies. Because of the targeted cost-efficiency of the project the new construction of balconies is apart from the financial possibilities. Some ideas about surrogates with some recreational value were made and finally it has been decided to establish a kind of recreation area on the roof by building a green roof. Furthermore the image of the flat roofs is not the best. Therefore the planning for the roof should provide for a really waterproof construction. As to the insulation and the safer entrance door these problems won't exist any more after the refurbishment.

Another aspects which turned out to be a real problem is the air quality. 92% in the demo building and 77% in the reference building shared the opinion that something is wrong with the air quality. Above all "dust" (44 mentions), "Malodorousness" (15 mentions) and "Dry air" (5 mentions) are the reasons for this striking result. The main source seems to be the paper factory in the neighbourhood. Naturally the

Table 1. General satisfaction with indoor air temperature.

	1 very dissatisfied	2	3	4	5 very satisfied
	%	%	%	%	%
Demo building winter	8,1	16,2	32,4	29,7	13,5
Demo building summer	35,1	27,0	27,0	8,1	2,7

problem decreases with closed windows. For convincing the inhabitants to keep their windows shut in winter and during daytime in summer this could be a precious argument. It also should be thought about the effects of this amount of dust on things like changing intervals for filter, filter quality, that should be used and so on. Bad odours result from the neighbourhood of the paper factory, steel factory and the railway station. Probably closed windows also might help a little to reduce this problem. The filters of the ventilation system also will partly remove the odours from the infiltrated air. This surely will enhance the occupants' evaluation of the project's success considerably.

Maybe the most valuable results from the survey was the insight about satisfaction with indoor temperatures.

In winter more people are on the "satisfied" side than on the "dissatisfied" side in the demo building. The average value is 3,24 (2,80).

In summer much more people are on the "dissatisfied" side – 62,1% – than on the "satisfied" side – 10,8%. The same is true for the reference building, where 53,5% "dissatisfied" and 14,3 % satisfied people were found. Compared to the winter result this can be called an alarming result. Temperature perception in summer is even much worse than in winter.

For the concept phases of the refurbishment this was a completely new aspect. Usually the focus is on winter, because of the energy aspect. In this case it became obvious, that planning for comfortable conditions in summer needed even more weight than providing for ultra-low-energy demand in winter.

Conclusions and outlook

In summer 2004 the tender for the SOLANOVA project was finished by a contract between a local general constructor and the builder. The finishing of the constructional measures is expected the latest for autumn 2005. It turned out that the target of the project – reaching almost the Passive House standard in renovation can be achieved with reasonable cost. The foreseen net cost per m^2 should be around 240 Euro/m^2. Until the end of the project in December 2006 valuable data about the building's real performance and the dwellers' satisfaction will be available.

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