386. Energy efficient renovation of dwellings: lessons learned

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Abstract
In the Demohouse project, five building projects were renovated with an energy ambition of saving at least 30% compared to a regular renovation. On paper, the CO_2 emissions for building related energy consumption were reduced by 20-70%, compared to a business as usual renovation. This shows the potential of CO_2 savings for the building stock in Europe.

The main barrier to energy efficient renovations is of a financial nature. Solutions can be found in the availability of low-cost components (such as the heat recovery unit developed in the Demohouse project), finding local subsidy funds, applying new financing models e.g. EPC (Energy Performance Contracting) or implementing prefab rooftop apartments.

At the risk of stating the obvious, a good cooperation before, during and after the renovation process between tenants, builders, consultants, housing associations etc. proved very valuable.

Quality control during the renovation process can correct mistakes at an early stage and monitoring after the renovation can identify to what extend targets were met. The energy signature method can help to compare expected and achieved energy consumptions and analyse possible differences, as is demonstrated for the Austrian project.

Keywords: energy efficient renovation, lessons learned, energy signature

1. Introduction
With the current state of building experience and expertise, it is no longer a challenge to design and build healthy, comfortable and energy efficient new dwellings, as the successful implementation of the Passive House concept in the German speaking and Scandinavian countries has demonstrated.

However, an analysis of the energy consumption of the built environment in Europe shows that the main challenge to obtain substantial energy reductions in this sector lies in improving the energy efficiency of the existing stock rather than in building energy efficient new dwellings. This challenge is especially pungent when taking into account the building stock of Eastern European countries, where energy efficiency was never a great issue and where investments in energy efficiency are hard to find.

This is an area where the Demohouse project which is supported by the EU-6th Framework programme, is focusing on. In this project, partners from Austria, Denmark, Greece, Hungary, the Netherlands and Spain are cooperating to develop, implement and demonstrate solutions to reduce the heating demand by at least 30% compared to current or 'business as usual' renovations. The advantage of the European dimension of the project is that participating countries learn through sharing their experience and solutions.

2 The renovation projects
The Demohouse project started in 2004 with 18 partners, and 8 building projects, of which 7 renovations and 1 new build. In the first phases of the project, 2 renovation projects were withdrawn and one more followed in January 2007. Finally Hungarian project was withdrawn in November 2007. Since the latter participated in most of the analyses and provides useful lessons learned, it is nevertheless included in this paper. Pictures of the 5 projects and the main characteristics are briefly described in the following sections.

2.1 The Spanish project
The Spanish building is located in the old historical centre of Bilbao. A four storey building with brick walls and tiled roof, it was built in 1910 and partly renovated in 1960. Pictures of the building before and after renovation are shown in Fig. 1.

Fig 1. The Spanish Demonstration building, before (left) and after renovation (right).

2.1 The Austrian project

The Austrian building consists of two adjacent blocks of flats in Graz. They were built in 1975-76 as social housing and that is still their function today. The flats are heated through district heating. Pictures of the building before and after renovation are shown in Fig. 2.

Fig 2. The Austrian Demonstration building, before (left) and after renovation (right).

2.3 The Danish project

The Danish project consists of 3 out of 12 blocks of apartments in the Gyldenrisparken area in Copenhagen. They were constructed between 1965 and 1969 from prefab concrete elements. The buildings are connected to a district heating system. Pictures of the building before renovation and during renovation are shown in Fig. 3.

Fig 3. The Danish demonstration building, before renovation (left). On the right a single test apartment with external insulation.

2.4 The Greek project

The Greek project is located on the outskirts of Athens, consisting of 4 buildings, each containing 2 dwellings. Being the only new built project, construction started in 2005 and was scheduled to end by mid 2008. The buildings are of concrete frame structure, with brick walls. Pictures of the building during and after construction are show in Fig. 4.

Fig 4. The Greek Demonstration building, during construction and after completion. The picture above shows that weather conditions can be severe and good thermal insulation will pay off.

2.4 The Hungarian project

Finally, the Hungarian project is a former military complex in Budapest. Three out of a total of eleven 3-storey building blocks of bricks/concrete construction were to be renovated. Unfortunately, the project had to be withdrawn by the end of 2007 before renovation started. Pictures of the building before renovation and artist impression of the post renovation state, including rooftop apartments are shown in Fig. 5.

Fig 5. The Hungarian Demonstration building before renovation (left) and artist impression of post-renovation state, showing the rooftop apartments (right).

The main energy saving measures are listed in table 1 below.

Table 1: Main energy saving measures in the housing projects.

City, Country	Main energy saving measures
Bilbao, Spain	Insulation of building envelope Solar collectors + PV (Photo Voltaic) Building Management System
Graz, Austria	Insulation of building envelope Air tightness Biomass-CHP-plant
Copenhagen Denmark	Insulation of building envelope Air tightness Heat recovery unit in each apartment
Athens, Greece	Insulation of building envelope Ground heat exchangers for cooling Demand controlled ventilation (CO_2)
Budapest, Hungary	Insulation of building envelope Solar collectors + PV (Photo Voltaic) Rooftop apartment

As can be seen from table 1, all projects reduce the energy demand for space heating by applying thermal insulation of the building skin. The thickness of the insulation differs from country to country. In Austria and Denmark, typical insulation thickness is 10-20 cm for the façade and 25 cm for the roof. In Greece and Spain, the value is more modest with 6-10 cm, which is still rather ambitious compared to current renovation practice. Ventilation losses in most of the projects are reduced by achieving good air tightness and applying a heat recovery unit or by applying demand controlled ventilation, using CO_2 - sensors.

In addition, each country has a focus on specific elements. In Spain, it is the application of solar collectors and PV (Photo Voltaic) cells, in Austria a biomass fired CHP (Combined Heat and Power) plant, in Denmark a novel cost-effective heat recovery unit in each apartment, in Greece ground heat exchangers for energy efficient cooling were implemented and in Hungary light weight rooftop apartments were foreseen.

The renovations undertaken are compared to a 'business as usual' or 'regular' renovation. For all buildings, including the Greek building, this is a theoretical exercise, where the building is 'virtually' renovated according to current practice or (when applicable) the national or local building code.

The total renovation cost and the simple Pay Back Time (PBT), calculated as the ratio of investment and the savings in operational cost (both compared to a 'regular' renovation) are shown in Table 2. The operational cost includes energy cost and maintenance.

Table 2: Investments and pay back time of the projects.

	net floor area [m^2]	Renovat-ion cost [€/m^2]	simple PBT [yrs]
Spain	496	1463	26
Austria	9860	130	14
Austria, no CHP	9860	118	8
Denmark	2880	218	21
Greece	2787	153	46
Greece, no BMS	2787	75	7
Hungary	6300	117	30

Unfortunately, the biomass fired CHP plant in the Austrian renovation project appeared not to be economically feasible in the end due to 1) the increase of vegetable oil price by approx. 60% since the start of the project and 2) the relatively high maintenance cost related to the use of vegetable oil. Figures for the case with CHP and without CHP are presented in Tables 2 and 3.

In Greece, the cost of the Building Management System (BMS) was much higher than foreseen. Figures for the case with BMS and without BMS are shown in Tables 2 and 3.

Table 2 shows that the total cost of the renovation ranges from 75 to 220 €/m^2, except for the Spanish building. The structural reinforcement that was necessary (see below) made this renovation particularly costly.

The simple Pay Back Time (PBT) ranges from 7 to 30 years. The low figures, from the Austrian and Greek projects, are for the scenario without the biomass CHP and BMS respectively.

The heating demand for space heating and DHW (Domestic Hot Water) compared to a regular renovation is shown in Table 3. Also shown are the savings in CO_2 emissions related to space heating, DHW and cooling (the latter only in the case of Greece). CO_2 emissions due to domestic electricity consumption are not included.

Table 3: Heating demand for space heating and DHW and CO_2 -savings compared to a regular renovation.

	Space heating + DHW [kWh/m^{2}a]	CO_2-savings [%]
Spain	80	65%
Austria	102	52%
Austria, no CHP	102	22%
Denmark	40	50%
Greece	46	21%
Greece, no BMS	46	21%
Hungary	22	73%

Model calculations for the heating demand show figures in the range of 22 to 102 kWh/m^{2}a, where the low figure - for the Hungarian project - presents a challenge to be reached in practice. CO_2 -savings compared to a standard renovation range from 21% for the Greek project to 73% for the Hungarian project, again, a challenge to achieve in practice. The relatively low value of 22% in the case of the Austrian project without CHP is caused by the relatively high standards of current renovation practice in that country.

The Austrian case demonstrates the difference between a target in terms of energy consumption (identical for the cases with and without CHP) and a target in terms of CO_2-emissions. Application of a biomass CHP also scores very highly in terms of CO_2-reduction per € invested.

3 Barriers for Energy Efficient Renovation

For most of the projects, the financial barrier appeared to be the most important one. In Spain the historical value of the building, in combination with its dilapidated condition made this renovation particularly expensive. Here, local subsidies from funds to revive the neighbourhood were found to help overcome this barrier.

In all countries, lack of low cost solutions for large scale implementation of energy saving measures was identified as a barrier. In particular, the availability of a cost effective heat recovery unit in the ventilation system was found desirable. In fact, lack of availability of such a system was one of the reasons for not implementing one in the Austrian project.

With the aid of EU-funding some important quality oriented R&D work was carried out to overcome this barrier. In the Danish project for instance, a cost effective heat recovery unit with high thermal efficiency, low noise and energy efficient fans was developed. The Austrian partners as well as the Spanish expressed great interest in the product, but the development came too late for application in their renovation projects.

Another example is the development of a prefab lightweight and CO_2-neutral rooftop apartment, also by the Danish partners. The sale of such apartments can partly cover the extra investment needed for an energy efficiency renovation of the remaining building. As a result of the cooperation within Demohouse, rooftop apartments were also planned in the Hungarian project, prior to its withdrawal.

In Austria, Hungary and Spain, introduction of an EPC (Energy Performance Contracting) model was considered to overcome the split-incentive problem, where the party investing in the renovation (the owner) is not the one to profit from the energy savings (the tenants). For various reasons, but mainly because of the time frame of the renovation process, the EPC concept was not implemented in the end in any of the renovation projects.

Unfamiliarity of stakeholders with energy savings was also encountered in a number of countries. A good cooperation between builders, consultants and housing association proved very valuable in the Danish project. In Austria, unfamiliarity of tenants with an energy saving concept is thought to be solved by gradual introduction of the concept with tenants of good social background.

In Hungary, subsidised gas prices decrease the feasibility of application of Rational Use of Energy (RUE) measures and Renewable Energy Sources (RES). Here, the subsidy system obviously is in need of revision, but this lies outside the scope of the project.

4 The renovation process, what went well and what didn't

In general, raising awareness with the stakeholders (housing association, tenants, and local authorities) went very well. In Spain, contacts with local government bodies like EVE (Basque Energy Board) and IHOBE (Public Society for Environmental Management) resulted in cooperation on developing energy policies and guidelines/legislation. In Denmark, tenants appeared to be very pleased with the application of the low cost heat recovery unit, particularly because it was very silent. In Greece, the success of RUE measures worked against the builders as future owners asked for additional measures causing some delays.

Different setbacks were experienced between projects. In the Spanish project it was the bad condition of the building, aggravated by the lack of information about the building in general and the building foundations in particular. The extensive and expensive structural reinforcements that were necessary, resulted in a substantial increase in renovation cost (see Table 2. Fig. 6 shows the added steel structure supporting the old parts of the building.

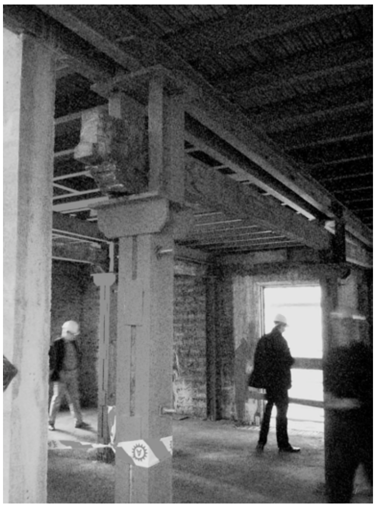

Fig 6. Structural reinforcements were necessary in the Spanish project.

In the Austrian project, it was the increase of the price of vegetable oil by 60% since the start of the project in 2004, making the application of a biomass powered CHP (Combined Heat and Power) plant economically unfeasible.

In Denmark, renovation measures have to be approved by a majority of the tenants. The process of reaching consensus caused delays in the renovation process. As a result, rooftop apartments could not be applied in the Demohouse part of Gyldenrisparken, as its application could no longer fit its time frame. The roof top apartment will however be applied in the remainder of the Gyldenrisparken renovation but outside the scope of the Demohouse project.

In Greece, the cost of the BMS (Building Management System) was much higher than foreseen. In Hungary, lack of support from the local authorities, both financially and cooperatively, eventually caused the project to be withdrawn.

5 Quality control

An important aspect, often overlooked both in renovation and new build, is quality control during the building process and monitoring after completion. Too often, contractors build what they are paid for and don't look back to see how it works.

In the Austrian project, IR (Infrared) photography revealed missing parts of insulation of the building envelope, as shown in Fig. 7, which were used to persuade the contractor to repair the construction fault. In the Danish project, repeated blower door tests in the course of the renovation proved very useful to correct failures in achieving the air-tightness required.

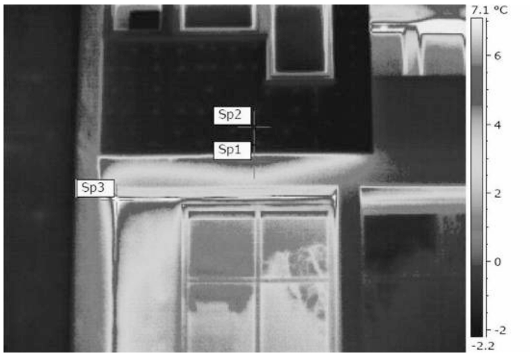

Fig 7. High temperatures on the outside of the entrance ceiling revealing missing thermal insulation, detected with IR-photography in the Austrian project

The price of these quality control techniques is generally a fraction of the total building cost. IR-photography for instance will cost in the order of €1000, giving the opportunity to correct cold bridges, air leakages, missing insulation etc.

6 Monitoring

Monitoring the building after completion can provide information on to what extent the targets with respect to energy savings, indoor environment etc. have been met.

Monitoring of all Demohouse projects is being carried out according to the so-called Common Evaluation protocol, agreed on by all partners, which includes measurements of energy consumption for space heating and DHW for one year and single measurements of e.g. thermal comfort and indoor air quality. The protocol also includes a methodology (the 'energy signature') to compare expected and achieved energy consumption.

6.1 The 'energy signature'

When comparing monitoring data with model calculations, there is always the problem that parameters such as weather conditions in the model and in practice differ, in particular the ambient temperature, solar radiation and wind. In addition, parameters such as indoor temperature and internal heat gains in practice may deviate from the values assumed in the model. A relatively simple way to solve (some of) these issues is the use of the so called 'energy signature' [1]. In this method, the energy consumption over a certain period, typically a week or a month is plotted versus the average ambient temperature in that period.

Since the main heat losses of a building are proportional to the difference between indoor and outdoor temperature, periods with lower ambient temperature will show higher heating demands for space heating. When the data points are plotted in a graph, the slope of the line through the data points is a measure of the heat losses of the building, as shown in Figure 8.

The advantage of this method is that the slope is independent of the indoor temperature – as long as indoor temperature is constant - and also independent of the internal heat gains – again, if these are constant. In addition, different sets of ambient temperatures (in a model or monitored) will result in different data points in the graph, but the slope will not be affected. This solves the problem of the ambient temperatures in the model being different from those measured.

The main limitation of the energy signature method is the disturbing effect of the solar radiation. Buildings with a large façade especially one facing south will receive a relatively large amount of solar heat, which results in a lower amount of heat supplied by the heating system than would be expected on the basis of the ambient temperature alone. The corresponding data point in the graph will therefore be lower than expected. In general, the disturbing effect is most pronounced in the spring and autumn, i.e. at intermediate ambient temperatures.

6.2 Monitoring data from the Austrian project

At the time of submission of the paper, only a limited amount of monitoring results were available. The Austrian renovation project, being the most advanced in terms of completion, has most data to offer.

In the Austrian project, energy savings using the Energy-10^{TM} modelling tool were calculated to be approx. 65% compared to pre-renovation state. At first these savings were not achieved. In the first winter of monitoring (2005-2006), with about half of the apartments renovated, the energy consumption of the building was reduced by a mere 5%. At the same time, it was observed that occupants open windows more often than before renovation. However, this appeared to be a necessity because the building in post-renovation state is very airtight (1.3 Air Changes per Hour at 50 pa overpressure) so an adequate ventilation rate relies on the tenants opening windows.

Still, the control of the heating system had to be adjusted to the different thermal behaviour of the building. Also, the tenants, unaccustomed to a well insulated building, had to get used to a different operation of the heating system.

After the complete building was renovated and the heating system adjusted, the energy savings appeared to be around 55% compared to the pre-renovation state, somewhat lower than the calculated value.

In Fig. 8 the weekly energy consumption (expressed in W/m^2) is plotted versus the average ambient temperature, thus producing the 'energy signature'. Since the Austrian housing project has relatively small windows, as can be seen in Fig. 2 (approx 17% of the façade), few problems are expected from the disturbing effect of solar radiation mentioned previously.

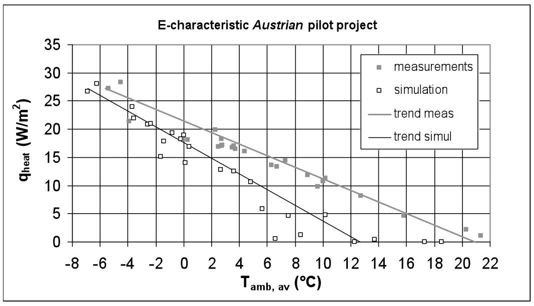

Fig 8. Energy signature comparing the measured (grey symbols and line) and simulated (black symbols and line) energy consumption in the Austrian project

A number of things are apparent from Fig 8. First, the slope of the grey trend line differs from the black by about 25%, a value which is rather good for a first result. In fact, the slope of the black simulations trend line is higher than that of the measurements, implying higher heat losses per degree of temperature difference between indoor and outdoor. The most plausible cause is an overestimation of the ventilation rate in the model. It is questionable whether the tenants open their windows enough in wintertime to achieve sufficient ventilation rates because open windows will cause cold draughts. Measurement of the ventilation rate which could shed light on this issue is not foreseen in the Austrian project.

A second observation from Fig 8 is that the grey measured data points are higher than the simulation data points. Possible causes are: 1) an overestimation in the model of the internal heat gains from electrical appliances, people etc. Overestimating the internal heat gains means that the heating system needs to deliver less heat in order to keep the building heated. However, the internal heat gains in the model were set to 4 W/m^2, following the Austrian ÖNORM EN 832, which is a rather conservative value. Alternatively, 2) the indoor temperature in practice may be higher than the value assumed in the model (20°C). As a high rate of tenants are immigrants from southern or tropical climates, it is very well possible that they set the heating to a higher temperature than 20°C. Fig. 8 shows that a parallel shift of the simulation data points to the right by approx. 4°C would roughly make both sets of data points coincide. That means that an indoor temperature of 24°C in stead of 20°C could account for the difference between measurement and simulation. Measurement of the indoor temperature in a number of apartments is foreseen in the remainder of the project, but these data were not available at the time of submission of the paper. In addition, a survey will be carried out among the tenants, but likewise these results are not yet available.

7. Conclusions

On paper, the housing projects undertaken in the frame of the Demohouse project succeed in reducing CO_2 emissions for building related energy consumption by 20-70%, compared to a 'business as usual' renovation. This shows the potential of CO_2 savings for the building stock in Europe.

Looking back on the renovation process, a number of lessons were learned. The first is that the reason for not applying energy saving measure in renovations is often unfamiliarity of stakeholders (housing associations, project developers and tenants etc.) with the approach and its consequences, and fear of extra costs. A good cooperation between tenants, builders, consultants and housing associations therefore is very valuable.

Related to this, the main barrier to energy efficient renovations is of a financial nature. Solutions can be found in the availability of low-cost components (such as the heat recovery unit developed in the Demohouse project), finding local subsidy funds, applying new financing models e.g. EPC or implementing prefab rooftop apartments. Also, a good cooperation with and support by local authorities (preferable including financial support) is imperative.

Quality control during and monitoring after renovation are also important lessons. It is recommended to check that the expected energy savings are indeed achieved and analyse the reasons for any discrepancy. The energy signature method can help to compare expected and achieved energy consumptions.

Finally, it is important to disseminate the research carried out, the knowledge gained and lessons learned in order to achieve more widespread application of energy efficient renovations. For this reason, a Decision Support Tool (DST) was developed [2]. This instrument is intended to facilitate decision makers on energy efficient and otherwise sustainable renovations. The DST focuses on the initiative phase of renovations since it is at this stage that the decisions regarding the ambition level of a renovation are made. The DST also includes information on quality control during the renovation process and information on monitoring procedures including the use of the energy signature. The DST is hosted at www. demohouse.net

9. Acknowledgements

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10. References

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