QUANTIFICATION OF RETROFIT MEASURES ON A MULTI-FAMILY RESIDENTIAL BUILDING FOR DIFFERENT EUROPEAN CLIMATES WITH DETAILED AND SIMPLIFIED CALCULATION TOOLS

Gerhard Zweifel

Lucerne University of Applied Sciences and Arts
School of Engineering and Architecture
6048 Horw, Switzerland

ABSTRACT

In an international simulation study, the measures to be taken with an example retrofit building at different locations were quantified in order to reach the energy demand goal of 30 to 50 kWh/m^2 a of primary energy for heating, ventilation and domestic hot water production. A systematic difference in the results from the simplified and the detailed calculation tools for the building "as is" at its original location could be identified mainly by the different treatment of losses to unheated spaces. For the climates of Lucerne (Switzerland), Stockholm (Sweden) and Guimarães (Portugal), the necessary measures, such as U-values, glazing properties and solar collector area were identified.

INTRODUCTION

General

The work reported in this paper was done in the frame of the project IEA ECBCS Annex 50 "Prefabricated Systems for Low Energy Renovation of Residential Buildings" (Zimmermann, 2006). The objectives of this Annex have been the development and demonstration of an innovative whole building renovation concept for typical apartment buildings. The concept is based on largely standardised façade and roof systems that are suitable for prefabrication. The highly insulated new building envelope includes the integration of a ventilation system.

Participating countries were: Austria, Czech Republic, France, Netherlands, Portugal, Sweden and Switzerland.

Calculation Exercise

The goal of the calculation exercise, which is described in full detail in (Zweifel, 2010), was to show the order of magnitude of the measures to be taken at different locations in the countries represented in the task on typical retrofit cases, in order to reach the energy demand goal defined in the project definition, i.e. the amount of 30 to 50 kWh/(m^2•a) of primary energy for heating, ventilation domestic hot water production and possibly cooling (if needed). With one or more example retrofit buildings, the measures to be taken to reach this goal should be specified and quantified. Measures include

- improved building insulation, including window replacements and additional insulation of opaque surfaces,
- the application of a ventilation system with heat recovery,
- the use of renewable energy sources, especially solar energy for domestic hot water production,
- improved energy production (by replacement of the heat generation), possibly including electricity production.

The definition and quantification of the measures should be expressed in terms of

- U-values to be achieved and – derived from this – thickness of additional insulation to be applied,
- specification of window properties to be applied,
- heat recovery efficiency requirements,
- contribution of active solar energy production to the domestic hot water production, and derived from this, area of collectors needed for this,
- specification of efficiency for heat and possibly electricity production.

From this list, it can easily be seen, that a coincident optimisation of all these measures would be a multi dimensional optimisation procedure. This would have exceeded the possibilities of the project. Therefore, some of these measures could be assumed as fixed and used as boundary conditions for the ones to be determined.

METHOD

Object Choice

The Swiss potential demonstration building "Elfenau", located in Lucerne (see figure 1), was chosen as the example building. The building is one half of a multi-family house with three regular floors with 2 flats each, an unheated basement with garages, cellar rooms and a central heating, and an attic floor with two small single room flats and unheated attic space. The construction is rendered double brick masonry with concrete floor slabs and a concrete basement. The sloped roof is tile covered. Windows are double glazed with a wood frame. The radiator heating system is served by an oil fired boiler, which also provides domestic hot water. Ventilation is purely natural through open windows.

The building, erected 1958, was considered by all project group members representative for a considerable part of their building stock.

Calculation Procedure

The calculations were performed in different steps as summarised in table 1.

The goal of step 1 was, to compare the results from the different tools used by the different countries, in order to get an indication of the accuracy of the results obtained. The use of different level tools led to the expectation, that there would be differences in the results, which would have to be explained.

The calculations were performed based on the following information made available to the contributors:

- Specification document,
- a set of plans of the building, including situation, floor plans of all floors, façade views and cross sections,
- a set of photographs of the building,
- climatic data for step 1 (Lucerne) in monthly and hourly resolution
- a set of primary energy factors for the evaluation of delivered energy carriers.

The building use data were derived from the Swiss standard for heating energy performance of buildings (SIA, 2009). The global values for occupancy, lighting and equipment were translated into schedules, considering seasonal variations like day length for lighting etc., in order to provide enough detailed information for the detailed tools. This way it was made sure, that there was at least no difference between the detailed and simplified tools from this side.

In step 2, the influence of the different locations was to be shown. The calculations were made based on the same specification as step 1. Instead of the provided climate and use information, the contributor's own information was used.

In step 3, the retrofit measures were applied, specified and quantified. The base of this calculation was, in respect of building geometry, a retrofit strategy in form of a set of new plans, provided by the Swiss retrofit team. This strategy considers the situation that retrofit measures often not only consist of an energy related improvement, but include building enhancements in form of additional space, added elements needed for compliance with current standards and regulations (not only energy, but security, handicapped accessibility etc.). The strategy includes an added lift tower and attached balconies, an extension of usable area in the attic and basement floors and the inclusion of former balconies in the heated area. Figure 2 shows the main floor plans of the retrofit strategy. The old uninsulated sloped roof is thought to be completely removed. In some parts, where the heated area in the attic floor is extended, this is supposed to be done by complete prefabricated boxes with flat roofs (indicated by dash-dotted lines in figure 2 right).

Figure 1: Main façades of the Elfenau building (photos: Robert Fischer, HSLU)

Table 1
Calculation steps

CALCULATION STEP	DESCRIPTION	LOCATION	CLIMATE	BUILDING USE
1	Building as is	Lucerne, Switzerland	Lucerne	According to specifications
2	Building as is	Chosen by contributing country	According to location	According to common practise in contributing country
3	Retrofit case	As for step 2	As for step 2	As for step 2

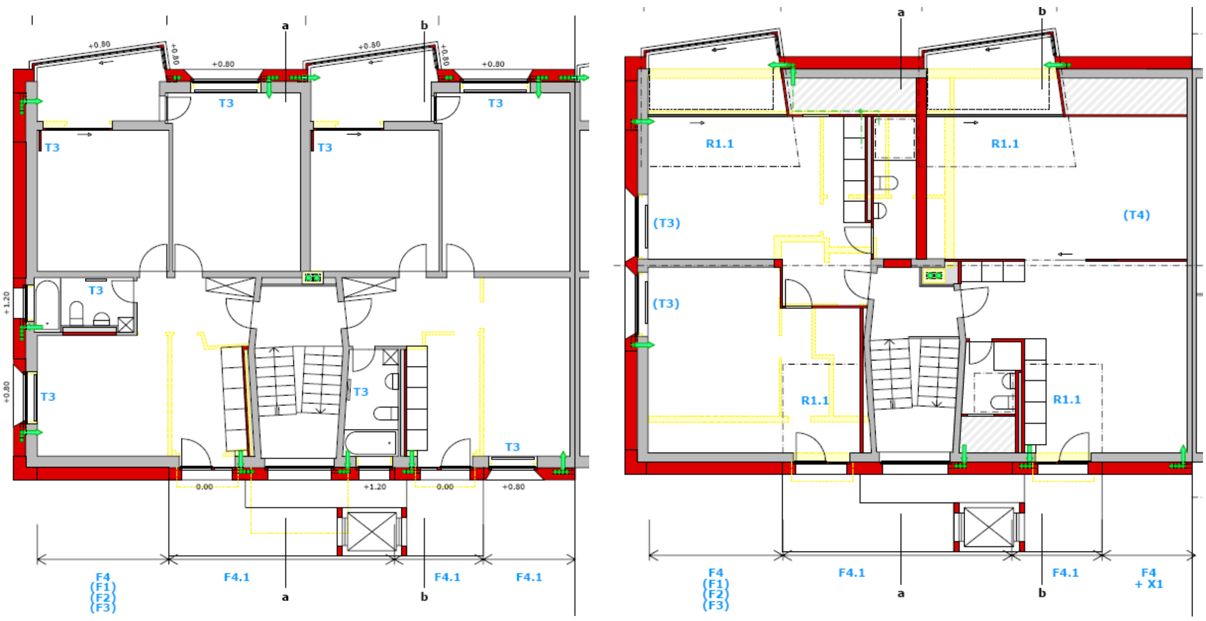

Figure 2: Floor plans for regular floor (left) and attic (right; source: Robert Fischer, HSLU)

Table 2
Calculation contributions

CALCULATION STEP	CONTRIBUTING COUNTRY	TOOL	REFERENCE	TOOL CATEGORY
1 and 2	Belgium	PEB - CALE2	(Wallonia, 2008)	Simplified
	Portugal	RCCTE	(Republic of Portugal, 2006)	Simplified
	Portugal	EnergyPlus	(US Department of Energy, 2010)	Detailed
	Czech republic	Bsim 2000	(Grau, K. et al, 2000)	Detailed
	Switzerland	IDA-ICE 4.0	(Equa Simulation AB, 1995)	Detailed
3	Portugal	RCCTE		Simplified
	Portugal	Energy+		Detailed
	Switzerland	IDA-ICE 4.0		Detailed

These areas are at disposition for possible solar collectors, whereas for preservation order reasons the rest of the replaced sloped roof is not. The retrofit includes the addition of a mechanical ventilation system with a seasonal heat recovery efficiency of 0.8 and a new heat generation.

In addition to the retrofit strategy, a further specification document was handed out, giving information on the quality of the retrofitted building and system parts, additional floor areas etc.

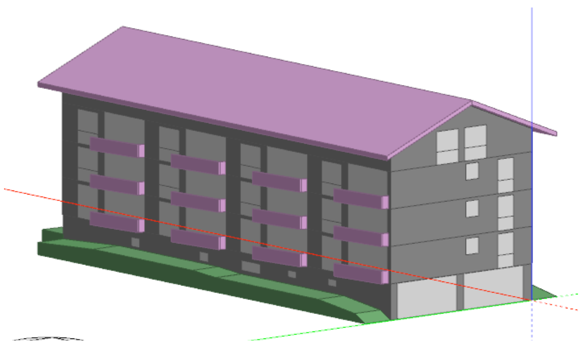

Figure 3 3D representation of the "as is" case 1/2 generated with Design Builder for Energy+

Overview of the Calculations Performed

For the different steps, different project partners contributed results, using different programs. Both simplified calculation tools (on a monthly or even seasonal basis) and detailed simulation programs were used. An overview of the contributions is given in table 2.

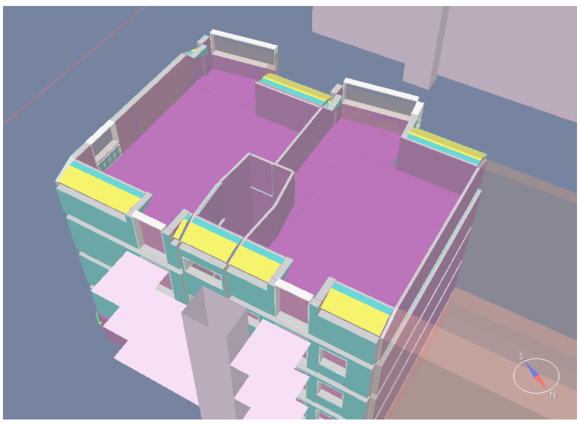

Figure 4 3D representation of the retrofit case 3 generated with IDA-ICE

Reports were received from all contributors, giving the required results and additional information on the calculations, like assumptions made and more detailed results. For the detailed simulation tools, 3D geometry representations were provided. Examples are shown in figures 3 and 4.

RESULTS

The results from the different contributors for steps 1 and 2 are shown in table 3. The values for the primary energy demand were derived from the contributed values for the useful energy demands for space heating.

The assumptions for the calculation of the primary energy use are: useful energy demand for domestic hot water: Q_w = 75 MJ/(m^2 a); distribution efficiency for domestic hot water: $\eta_{d,W}$ = 0.7; heat generation efficiency (heating and domestic hot water): η_g = 0.8; primary energy factor: f_{PE} = 1.24 (oil). With this, the following calculation formula results, and the values can directly be compared.

$$E_p = (Q_h + Q_W / \eta_{d,W}) / \eta_g \cdot f_{PE} = (Q_h + \frac{75}{36 \cdot 0.7}) / 0.8 \cdot 1.24 \qquad (1)$$

From table 3 it can be seen that there is a variety in the resulting energy demand of +/- 20% in primary energy against the average value. In useful heating energy demand, the variety is even close to +/- 25%. This result is not a surprise, considering the different tool categories involved.

A systematic difference can be recognised between the results for the useful energy demand for space heat-ing achieved with the simplified tools (values around 142 +/- 5 kWh/m^2) and the detailed simulation programs (values around 100 +/- 6 kWh/m^2).

Therefore there must be reasons to be identified for these differences. The following areas of possible reasons were identified:

- Staircase:
  In simplified calculations, the unheated staircase is usually counted as a heated space, because it is within the insulation perimeter. In the detailed simulations it is treated as an unheated space, its temperature being calculated as a result of the heat flows, which is closer to reality.
- Unheated attic and unheated basement: In simplified calculations, the walls towards these rooms are calculated as against outdoor climate with a correction factor according to European standards („b-factor"). This is a simplification, and the given b-factors are overestimating the losses through these walls to be on the safe side. In the detailed simulations, these rooms are, again, more accurately treated as unheated spaces.

An additional calculation with one of the detailed simulation tools (IDA-ICE, bottom line in table 3) was performed, with the simplifications according to the simplified tools listed above in place. The value of 136 kWh/(m^2•a) for the useful heating energy demand is about equal to the lower result of the simplified tools. Some further differences of minor importance may originate from other differences, e.g. in control.

From the step 2 calculations, it could be seen that the energy demand of the building reacts as expected to the different climates for the locations considered.

The result of step 3 show the necessary building modifications to be applied at the different locations in order to reach the goal of a primary energy consumption for heating, ventilation and domestic hot water consumption of 30 to 50 kWh/(m^2•a). An annual heat recovery efficiency of 0.8 had to be considered. As the results strongly depend on the goal to be reached, they are shown separately in tables 4 and 5 for the lower and upper boundaries of the target.

Table 3
Calculation results from steps 1 and 2

		STEP 1: AS IS, LUCERNE CLIMATE		**STEP 2: AS IS, LOCAL CLIMATE**		
		Useful energy demand for space heating	Primary energy		Useful energy demand for space heating	Primary energy
CONTRIBUTOR	**PROGRAM**	kWh/m^2	kWh/m^2	Location	kWh/m^2	kWh/m^2
Belgium	PEB-CALE2	137	259	Liège	125	239
Portugal	RCCTE	147	274	Guimarães	60	139
Portugal	Energy+	98	198	Guimarães	18	74
Czech Rep.	Bsim 2000	105	209	Brno	139	261
Switzerland	IDA-ICE 4.0	94	192	Lucerne		
Switzerland	IDA-ICE 4.0 with Simplifications	136	257	Lucerne		

Table 4 Calculation results from step 3 to reach the goal of 30 kWh/(m²•a)

		LUCERNE	STOCKHOLM	GUIMARÃES
Exterior walls – new parts - retrofitted existing walls	W/(m²·K)	0.15 0.2	0.15 <0.1*	0.23 0.23
Basement interior walls to non-heated zone	W/(m²·K)	0.55	0.55	0.73
Balcony floor	W/(m²·K)	0.15	0.15	0.67
Interior roof in contact with attic non-heated zone	W/(m²·K)	0.55	0.55	0.34
Window frame	W/(m²·K)	1.60	1.60	1.50
Glazing, U-value g-value	W/(m²·K) -	0.8 0.5	0.8 0.5	1.1 0.45
Collector area	m²	22.7	22.7	19.80

*or a different set of measures

Table 5 Calculation results from step 3 to reach the goal of 50 kWh/(m²•a)

		LUCERNE	STOCKHOLM	GUIMARÃES
Exterior walls – new parts - retrofitted existing walls	W/(m²·K)	0.15 0.4	0.15 0.2	0.44 0.44
Basement interior walls to non-heated zone	W/(m²·K)	0.55	0.55	2.43
Balcony floor	W/(m²·K)	0.15	0.15	0.67
Interior roof in contact with attic non-heated zone	W/(m²·K)	0.55	0.55	0.50
Window frame	W/(m²·K)	1.60	1.60	2.35
Glazing, U-value g-value	W/(m²·K) -	0.8 0.5	0.8 0.5	2.1 0.45
Collector area	m²	22.7	22.7	15.84

For the Swiss climate – assuming that the elements added new to the building such as balcony enclosures, new elements in the attic floor and the roof are made according to Swiss 2010 standard target quality, i.e. having a U-Value of 0.15 W/(m²•K) – the value of 50 kWh/(m²•K) is not really a challenge. To reach the value of 30 kWh/(m²•a), measures were identified in dependence of the heat generation system (see figure 5).

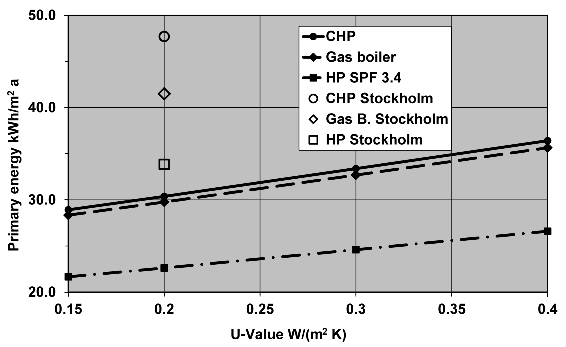

Figure 5 Results (primary energy for heating, ventilation and domestic hot water) for different heat generation types, for locations Lucerne and Stockholm (U = 0.2 W/m² K only)

While the CHP according to the specifications and a gas boiler lead to nearly equal results given in table 3, the use of a heat pump allows for U-values for the existing building elements of 0.4 W/(m²•K), the limit being defined by the comfort and damage prevention requirements rather than by the energy target.

With the same tool and input as for the Lucerne location, simulations were done also for the Nordic climate of Stockholm, taking a simplified approach. Some differences originating from local standards or regulations were not considered. The contribution from the solar collectors was not changed and assumed to be the same, which is probably not true. This would, however, not influence the results dramatically and could be compensated by an increased collector area. From figure 5 it can be seen, that with a U-value of 0.2 W/(m²•K), the primary energy value is within the boundaries of 30 to 50 kWh/(m²•a) for all types of generation. It must be concluded, however, that even with the heat pump a dramatic decrease of the U-values of the retrofitted existing walls below U = 0.1 W/(m²•K) would be needed to reach the target of 30 kWh/(m²•a). Other combinations of measures would be recommendable in that case (lower U-values also for new added elements and windows).

CONCLUSION

The results lead to insights in two areas:

- The systematic difference between the simplified and detailed calculation methods, leading to 42 % higher values for the useful energy demand for space heating given by the simplified tools, could be explained to a large extent by the different treatment of losses through or against unheated spaces like staircases, basements and unheated attic spaces. This also shows that there is a considerable reserve in the energy demand calculated by the simplified calculations for the buildings considered here due to this fact. Care must be taken when applying different classes of tools for the same target. The boundary conditions, including simplified assumptions for e.g. the treatment of unheated spaces, must be carefully set and clearly stated to ensure comparable results.

- The step 3 results show that the given span of the goal of 30 to 50 kWh/(m^2•a) is quite large. The upper boundary not really being a challenge, except for the northern climate, it is possible with a reasonable technical effort to achieve a target of 30 kWh/(m^2•a) for a wide range of European climates. Setting targets on the level of primary energy for space heating, ventilation and domestic hot water leads to a strong dependency on the type of heat generation. It must be decided whether this higher degree of freedom is wanted.

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