Energy savings due to internal façade insulation in historic buildings

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Abstract – Historic buildings contribute heavily to the energy consumption of the existing European building stock. Application of internal insulation offers a possibility to improve the historic buildings' energy performance, without compromising the buildings' architectural appearance.

The paper presents desktop analyses of potential energy savings in historic buildings, carried out using standard boundary conditions for calculation of energy savings, as prescribed in the European building energy performance certification schemes.

Internal insulation of the building's façades can potentially reduce the theoretical energy demand for space heating by 9 to 43 % compared to the energy demand of the original building if installed moisture-safe. Combined with other commonly used energy saving measures, 43–78 % reduction of the energy demand was estimated. This shows that internal insulation of external walls have the potential of contributing considerable to the overall energy savings in historic buildings and highlights the need for such measures.

Keywords – energy savings; historic buildings; internal façade insulation; case study; desktop analysis

1. INTRODUCTION

In order to comply with the 2050 EU decarbonisation agenda reducing considerably the CO_2 emission caused by energy use in buildings [1], renovation of the existing building stock is required. This includes historic buildings with architectural and cultural value, as they comprise 30 percent of the European building stock [2]. Application of internal insulation to external façades of historical buildings offers a possibility to considerably improve energy performance and indoor thermal comfort, without compromising the architectural appearance of the building. As part of the RIBuild project (Robust Internal Thermal Insulation of Historic Buildings) [3], assessment of the energy saving potentials related to renovation measures including internal insulation are carried out as desktop calculation exercises in some exemplary historic building cases that has recently been renovated and at present are being monitored. A number of scenarios are involved, depending on the degree of renovation before implementing internal insulation. This paper is based on calculations of buildings' energy demand for the following situations:

- as it was originally constructed;
- with implementation of internal façade insulation on the original building;
- with a package of energy saving measures often made in addition to internal façade insulation, e.g. new windows, roof insulation, under-floor insulation, etc.

Historic buildings do often have a long list of previous interventions that may have influenced the energy performance of the building. Additionally, detailed information on the building and its constructions, which are need for carrying out an energy performance calculation, or even more demanding an energy performance simulation, may not be available. Therefore, energy performance calculations were based on available information about the building materials. Standard conditions has been used for domestic hot water, internal loads (persons, light and equipment), internal temperature, external climate, etc. The effect of internal insulation on façades is challenged by the presence of partitioning walls and horizontal divisions that makes it impossible to insulate those parts of the façade covered by these constructions. This both limits the available area for application of insulation and creates thermal bridges in the internally insulated building.

Calculations of energy savings have been carried out using the national energy performance tool of the countries involved, [4] (Denmark), [5] (Latvia), [6] (Italy), and [7] (Switzerland). In most cases, calculations were based on quasi-stationary monthly conditions in accordance with EN ISO 13790 [8]. These calculation tools are based on the European package of standards for calculating energy performance of buildings for both new and existing buildings and thus not subject for literature scrutiny. One Danish case is described in detail in Section 2, the other cases are summarised in Section 3. In all cases internal insulation has been implemented by the building owner before RIBuild got involved. In several cases alternative, comparable solutions for internal insulation have been considered by the building owner before the renovation. These were included in the case study calculations of energy savings. The full set of information on the calculations are available in [9]. Results from monitoring the hygrothermal conditions will be analysed within another work package of RIBuild.

2. A DANISH CASE STUDY

2.1 PRECONDITIONS

Three Danish cases have been calculated using the Danish compliance checking tool: Buildings energy demand 2015 (Be15) [4]. Be15 is a calculation tool based on quasi-stationary conditions, and programmed according to EN ISO 13790 [8]. Be15 calculates energy demands in primary energy, and to avoid influence of the Danish primary energy factors, which is hard-coded into the tool, direct district heating is selected as heat source. This implies a primary energy factor of 1.0 and no losses (100 % efficiency) in the heating installation. All pipes and pumps used for distribution of heat and hot water inside the building have been removed from the calculation models. Additionally, the net energy demand is being calculated for the habitable sections of the building only – the ground floor is occupied by shops. It is estimated that the energy demand is approx. 10–15 % higher if losses and efficiencies in the technical installations are included in the calculations.

Standard use of the buildings is assumed, i.e. standard load from persons, light, appliances and consumption of domestic hot water according to Table 1. The Danish design reference year [10] is used as climate data in the calculations with the following characteristics given in Table 2. In each case energy savings are calculated based on three different insulation measures, representing the different measures applied in the three case buildings.

Table 1. Standard values per m² gross heated floor area for internal loads in Danish case study calculations

System	Internal load
Persons	1.5 W/m^2 (24 hours/day all year)
Appliances and light	3.5 W/m^2 (24 hours/day all year)
Domestic hot water	250 l/m^2 per year, heated from 10 °C to 60 °C

Table 2. Danish design reference year climate characteristics

Climate information	Data
Average outdoor temperature	7.75 °C
Minimum outdoor temperature	-21.1 °C
Maximum outdoor temperature	32.1 °C
Heating degree days (base 17 °C)	3940 HDD
Annual solar irradiation on horizontal	1025 kWh/m²

2.2 CASE: THOMAS LAUBS GADE 5

2.2.1 Description before and after renovation

Thomas Laubs Gade 5 in Copenhagen is a 4-storey residential building from 1899. An apartment on the 4^{th} floor has been internally insulated at the east-facing façade towards the street, cf. Figure 1.

The building was made with façades of bricks and presumably lime mortar. Façades are solid walls, thickness 1½ brick (350 mm) at 4^{th} floor and 2 bricks (470 mm) at lower floors.

In the calculations and the experiment setup, the accessible area of the internal façade in the selected apartment is internally insulated with 30 mm PUR-foam with channels filled with capillary active material (termed '*PUR-foam based*' in this paper) covered by 10 mm gypsum board, having a total thermal resistance equal to 1.04 m^2K/W – almost reducing the transmission loss through the insulated parts of the façade by 60 % of the original value. The U-value of the walls at the upper floor after internal insulation is thus changed from 1.49 W/m^{2}K to 0.59 W/m^{2}K, and at the lower floors from 1.19 W/m^{2}K to 0.53 W/m^{2}K (Figure 2).

Figure 1. Thomas Laubs Gade 5, with indication of renovated apartment. Photo: Tessa Kvist Hansen.

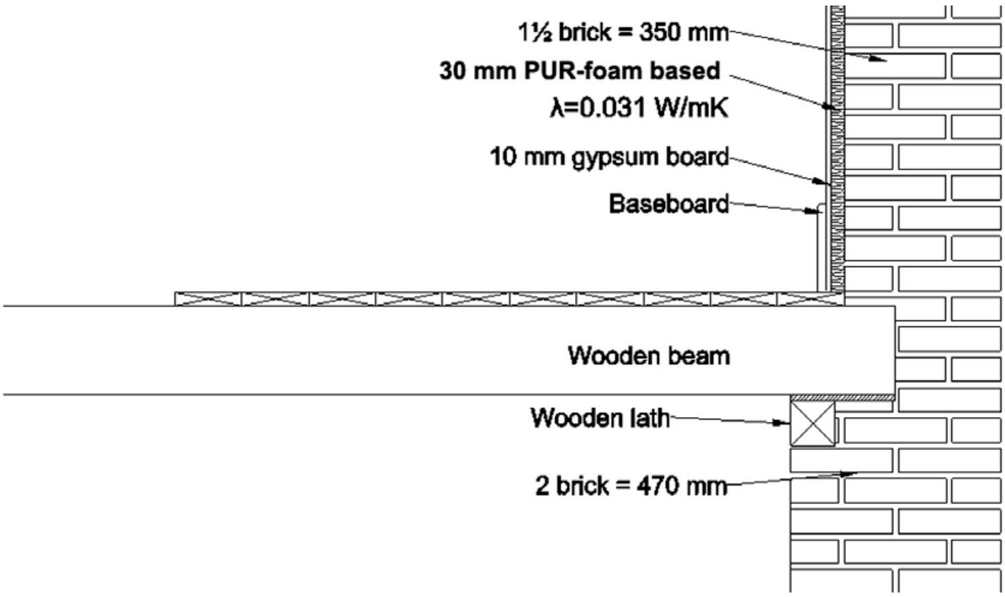

Figure 2. Section of internally insulated façade at Thomas Laubs Gade 5.

2.2.2 Calculation conditions

Calculations are only carried out for the upper three residential floors, assuming an adiabatic face between the shops and the apartments and towards the ends of the building. Due to internal walls and floors meeting the opaque façade, only a fraction of the façade can be insulated. In Thomas Laubs Gade 5, this means that only 51 % of the total façade area can be insulated (see Table 3).

Table 3. Overview of heated floor area and façade areas in Thomas Laubs Gade 5

Thomas Laubs Gade 5	m²	%
Total heated floor area, 3 floors	273	-
Heated floor areas per floor	91	-
Total façade	161.9	100 %
Opaque façade	116.7	72 %
Insulated part of total façade	83.1	51 %
Windows	45.2	28 %
Not insulated part of total façade	33.6	21 %

2.2.3 Energy saving potential – results

As an experiment, alternative internal insulation systems were investigated in the calculations, i.e. 25 and 60 mm thermoset phenolic foam (termed '*phenolic foam*' in this paper) respectively, instead of the used 30 mm PUR-foam based internal insulation (see Table 4).

An often-seen energy saving measure in Denmark is blowing in insulation below the attic floor, which allows for approx. 60 mm insulation. This measure decreases the roof U-value from 0.45 W/m²K to 0.20 W/m²K, or a reduction of the transmission loss by approx. 55 %. Another typical measure in this type and age of building is to replace the original 1-layer windows with 2-layer windows, reducing the U-value from 4.4 W/m²K to 2.4 W/m²K or better (lower), normally done long time before considering installing internal insulation.

Table 4. Energy demands (and savings) due to selected internal insulation system and two alternative insulation systems in the building without other energy saving measures

As built	kWh/m² heated area	PUR-foam based 30 mm kWh/m²	Phenolic foam 25 mm kWh/m²	Phenolic foam 60 mm kWh/m²
Total energy requirement	129.5	108.7	106.6	100.1
Space heating	116.3	95.6	93.4	86.9
Domestic hot water	13.1	13.1	13.1	13.3
Savings (space heating)		17.8 %	19.7 %	25.3 %

In the building without additional energy saving measures applied, 30 mm PUR-foam based internal insulation results in 17.8 % savings. By replacing the windows and adding 60 mm attic floor insulation the energy demand for space heating is reduced from 116.3 to 80.5 kWh/m^2 heated floor area, or 31 %. By adding 30 mm PUR-foam based internal insulation in addition to this common package of energy saving measures, the total energy demand is 60.1 kWh/m^2, i.e. 48.3 % lower than for the original building.

Savings are calculated without considering the energy demand for production of domestic hot water as this is independent of the quality of the thermal envelope. Taking the standard consumption of domestic hot water into consideration (Table 1), energy savings drops to 16.1 and 43.5 % respectively.

The two alternative internal insulation systems, 25 and 60 mm phenolic foam, demonstrates that there are relevant alternatives to the selected internal insulation system and that a solution with 60 mm phenolic foam, upgraded windows and attic floor insulation result in 55.4 % energy savings on the space heating demand.

3. SUMMARY OF DANISH, LATVIAN, ITALIAN AND SWISS CASES

The study also included two other Danish cases (DK) and case buildings from Latvia (LV), Italy (IT) and Switzerland (CH), all summarised in Table 5. Danish case B is a four-story residential building from 1905 situated in Copenhagen, similar to the case presented in Section 2 (case A), while Danish case C is a detached single-family house from 1875 located at the Northern shore of the island Zealand. The Latvian cases included a three-story building with basement from 1910 built as a psychiatric clinic and since 1923 used as a Catholic school (Latvian case A), a one-storey public building from 1930, at present containing toilets and an exhibition room (Latvian case B), and a two-storey single-family house with basement from 1893 (Latvian case C), all from Riga. The Italian case is a three-storey single-family detached house built in 1935, located in a coastal town in the centre of Italy. The Swiss case is a six-storey residential building from 1910 situated in the centre of Lausanne.

In most cases U-values before and after renovation depend on floor level, as the wall thickness is lower at higher floor levels. Therefore, energy savings are calculated for each floor level and summarised to determine total savings. Additional energy saving measures typically includes replacement of windows, insulation of roof/attic and/or renewal of the heating system. Refer to [9] for details on cases and energy renovation measures.

Apart from Latvian case A and B, all cases are residential buildings: either multi- or single-family houses. In most cases, other measures had been implemented before internal insulation was installed, e.g. new windows or attic floor insulation, the latter being less complicated to install and therefore has a short payback period compared to internal insulation. Nevertheless, calculation of the individual energy savings was performed to make it possible to isolate the savings due to internal façade insulation from the other measures.

Table 5. Assessment of energy saving potentials in exemplary historic building cases from Denmark (DK), Latvia (LV), Italy (IT) and Switzerland (CH) based on two scenarios, one with internal insulation and one with both internal insulation and additional energy saving measures

Cases	**DK-A**	**DK-B**	**DK-C**	**LV-A**	**LV-B**	**LV-C**	**IT**	**CH**
Insulation material	PUR-foam based 30 mm	Phenolic foam 25 mm	PUR-foam based 100 mm	Mineral wool 50 mm	PIR 100 mm	Mineral wool 150 mm	EPS 60 mm	Aerated con-crete 60 mm
Thermal conduc-tivity [W/(m K)]	0.031	0.02	0.031	0.035	0.023	0.035	0.035	0.042
Average heating degree days	3940	3940	3940	4060	4060	4060	2165	3854
Average outdoor temperature [°C]	7.8	7.8	7.8	6.2	6.2	6.2	13.4	9.4
Heated floor area [m^2]	273	314	221	2410	65	339	288	1563
Insulated part of total façade (incl. windows and doors)	51 %	47 %	66 %	51 %	85 %	73 %	69 %	64 %
U-value of façade [W/m^2 K]								
Before renovation	1.19-1.49	1.19-1.49	0.62	0.78-0.89	1.23	2.14-2.52	1.76-2.58	1.60
After renovation	0.53-0.59	0.46-0.50	0.30	0.35-0.38	0.19	0.21	0.48-0.53	0.25
Reduction	58 %	64 %	52 %	55 %	85 %	91 %	77 %	84 %
Space heating [kWh/m^2]								
Before renovation	116.3	125.5	112.3	171.6	564.4	194.4	213.0	141.3
+ internal insulation	95.6	103.7	97.0	156.6	383.8	125.8	141.5	79.8
+ additional energy saving measures	60.1	71.7	55.6	96.5	123.9	54.0	111.7	35.7
Savings (space heating)								
+ internal insulation	18 %	17 %	14 %	9 %	32 %	35 %	34 %	43 %
+ additional energy saving measures	48 %	43 %	51 %	44 %	78 %	72 %	48 %	75 %

The buildings' energy demand for space heating after application of internal façade insulation is reduced by 9 to 43 % compared to the energy demand in the buildings' initial state (as they were originally constructed) and the U-value of the façade is reduced by 52 to 91 %. A full renovation, will boost the energy savings to somewhere between 43 and 78 % compared to the buildings' original energy demand for space heating.

As expected, it helps to achieve high energy savings from applying internal insulation at the external wall if the building has a high amount of accessible area for such measure. However, the results also show that considerable energy savings can be achieved even in the case of a non-accessible façade, making up 50 % of the total façade area.

In all cases the energy saving measures included in the calculations are either implemented or planned to be. National requirements in Denmark, Latvia, Italy and Switzerland for thermal performance of buildings after renovation, do not necessarily request several measures to be implemented at once. In Denmark and Italy, requirements refer to specific components being renovated, e.g. windows or roof, while the Swiss Standard SIA 380/1 includes a global renovation limit [11]. Only a deep renovation scenario that also includes insulating the roof and the slabs, as well as changing the windows, will be able to reach the Swiss requirements.

4. DISCUSSION

Theoretical results from simulations like those summarised in Table 5 are not expected to provide the same savings as those measured in a renovated building. This is due to simplifications and standard assumptions in the simulations, e.g. system efficiencies, internal loads and domestic hot water usage, even though these may have changed in connection with the renovation. The calculation thus only analyses energy demands and savings for space heating due to upgrading of the building façade. Additionally, the real savings will, in most cases, deviate even more from the theoretical results, both due to standard assumptions about energy performance in the pre-renovated buildings overestimating the actual consumption, known as the prebound effect [12] and due to residents' tendency to improve the indoor climate in the renovated building, known as the rebound effect [13].

Internal insulation of the building façade is normally done in combination with or after implementation of other energy saving measures, i.e. the isolated effect of internal insulation is difficult to verify on real buildings. However, the results underline the great benefits solely deriving from application of internal insulation, provided this can be installed moisture-safe, i.e. without resulting in critical hygrothermal conditions in the building envelope increasing the risk of mould growth or frost damage. Whether this is the case is studied in other parts of the RIBuild project, not yet published.

Derived effects of insulation of façades such as improved indoor thermal comfort, e.g. improving the use of the indoor area close to the outer wall due to higher temperature, often has more value for the user than the energy saving which should be taken into account when considering whether such a measure is cost-effective. Affordability of energy saving measures in the Italian case is presented in [14] but has not been part of this study. Furthermore, the results of the assessments performed, can be used as target points to perform Life Cycle Assessment "at building scale", providing useful reference values to building designers, owners, stakeholders, etc.

5. CONCLUSIONS

Desk-top analyses of theoretical energy saving measures in selected historic case buildings in Denmark, Latvia, Italy and Switzerland showed the potential of using internal insulation, provided it can be installed in a moisture-safe way, i.e. without increasing the risk of mould growth, frost damage, etc. The case buildings' energy demand for space heating was reduced 9–43 % solely due to installation of internal façade insulation, disregarding both the prebound and rebound effect. By combining internal façade insulation with other often-used energy saving measures, e.g. new windows, attic or basement insulation and/or renewal of heating systems, savings between 43 and 78 % were found.

The case studies show that application of internal façade insulation in historic buildings have the potential of considerably reducing the energy need for space heating also when considering insulation of the façades as a single measure. These achievements constitute an effective starting point for future developments, within not only RIBuild, but also in future projects in the field of energy savings in buildings and LCA improvements when renovating historical buildings.

6. ACKNOWLEDGEMENTS

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