Insulation and Retrofit: What is Feasible

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Introduction

deserved

Soon after the energy crisis of 1973, thermal insulation of the building envelope got the recognition it ~~devoted~~ as a means to decrease the energy consumption for heating (and cooling) in buildings. Already in the seventies, many IEA-countries adopted insulation standards. Most used a level two performance approach, imposing U-values for the different parts composing the envelope, or advancing an average U-value for the overall envelope.

In the eighties, attention shifted towards a more integral energy design, not only counting for conductive losses and gains, the ones thermal insulation diminishes, but also looking to optimal solar gains without overheating effects, a better HVAC efficiency and less ventilation losses, the last without jeopardizing the indoor climate. Passive solar, heat recovery, high efficiency boilers, low temperature heating and solar devices are well known topics since. This approach resulted in the Energy Performance concept (EP), we see today, where standardized tools for predicting a reference energy consumption are introduced and target values in kWh/m² floor surface imposed. The word reference refers to the fact that the tools does not predict the real energy consumption after construction, but a fictive consumption for default values of the free gains, the inside temperature and the ventilation rate under the assumption of perfect workmanship.

An EP-approach works well for new constructions, where building and system parameters can be manipulated. In retrofitting, however, not only the construction itself, but also city planning regulations on form and texture limit the choice of energy efficiency measures. Windows cannot be moved to facades with better orientation nor be enlarged at the sunny sides. The building may lack space to install a balanced ventilation system with heat recovery. Costs quickly rise beyond the level the builder considers acceptable. The important two questions therefore are, how effective is energy-efficient retrofitting on the long run and, what energy-efficient measures are possible after a decision for retrofitting is taken? The paper gives an answer in three consecutive steps. First the importance of energy-efficient retrofitting is commented. Then the restrictions and possible problems with retrofitting are mentioned, among them lack of ventilation, increased mold risk and worse durability after retrofit. Finally two cases are commented: a university library and a students home.

The Importance of Energy-Efficient Retrofitting

This question was analyzed in the frame of the Environmental Report Flanders, one of the two regions in Belgium [1][2]. When analyzing the impact of energy-efficient construction, the following points need an answer:

1. existing building stock and actual energy consumption?
2. demand for buildings in the years to come, confrontation with the yearly production by the construction industry in terms of new buildings, retrofits and demolition?
3. future energy efficiency regulations?
4. effects on energy consumption?

Point 1 presumes the existence of a database of all existing buildings. Although most countries have a Governments Statistical Agency (GSA), the database is never as complete one would wish. As a consequence, real buildings must be replaced by an array of fictive references, coupled to the statistical variables the GSA uses. For dwellings these are: period of construction, type of dwelling (row, apartment, stand alone, etc.), floor area, fuel used and heating system.

Table 1: Comparing heating consumption in 97 dwellings with the predictions, using the array of reference dwellings [3].

Database	Regression line, E as a function of the U_mA_T-value of the dwelling
97 dwellings taken randomly measured consumption for heating	12 329 + 229(U_mA_T) (MJ) Standard deviation on the regression coefficients: s_{12329}=53 788 s_{229}=17 Correlation coefficient: 0.66
Array of reference dwellings Calculated consumption for heating	4 495 + 217(U_mA_T) (MJ) Standard deviation on the regression coefficients: s_{12329}=15 785 s_{229}=2.3 Correlation coefficient: 0.86

A comparison was made for Belgium between the normalized heating consumption E for 97 dwellings taken randomly and the consumption predicted by the array of fictive reference dwellings. As table 1 underlines, the slope of both $E(U_m A_T)$-lines, with U_m the average U-value and A_T the total surface of the envelope, is hardly different. This allows to conclude that the array reflects the real housing stock in an acceptable way. The same was done for non residential buildings.

The total number of dwellings in Flanders in 1994 and the energy consumption for dwellings and tertiary buildings is summarized in table 2 [3][4].

Table 2: Number of buildings and related energy consumption in Flanders for 1994 [3], [4].

	Number of buildings	Energy consumption TJ
residential sector	2 186 000	221 700
tertiary buildings	- schools: 5 909 office buildings: 12 580	95 500
TOTAL		317 200

On the average, a dwelling consumes 100 000 MJ/year. All tertiary buildings together are responsible for 30% of the total building related energy consumption, which in turn amounts to 38% of the overall energy consumption in Flanders.

Building demand and offer could be analyzed for the residential sector only. Guiding principle is the evolution of the number of households. A low guess, coupled to a slow decrease of the yearly growth percentage, and a high guess, based on an extrapolation of the actual growth percentage, were used. The housing demand follows this number with some damping. The offer at the other hand equals the yearly production of the building industry. At the moment, new constructions with large floor area at the outskirts of cities dominate (39 129 new dwellings, 12 307 retrofits and 1914 demolition's in 1994. Of the 39 129 new dwellings, 28 193 had a floor area, larger than 124 m²). If this trend continues, a serious overproduction of new houses may become reality between 2000 and 2010, compensated by an unacceptable increase in unoccupied buildings in the city centers. To deflect that unwanted result, planning should intervene. Three policies were evaluated: (scenario

1) business as usual, however with a shift to retrofitting from 23% of the total number in 1990 to 38% of the total number between 2000 and 2010, (scenario 2) more retrofitting and new buildings replacing demolished constructions, the first from 23% of the total number in 1990 up to 46.5% of the total number between 2000 and 2010, the second from 3.4% of the total number in 1990 up to 24% of the total number between 2000 and 2010, (scenario 3) only retrofitting and replacement of demolished constructions by new buildings in 2010, with respectively 46.5 and 53.5% of the total number produced. The last element in the puzzle is the energy policy. Two choices were considered: (1) the actual legislation, imposing an average U-value as a function of the building compactness does not change before 2010, (2) the actual legislation replaced by an EP-standard of 50 kWh/m² energy consumption for heating in 2001. In both cases, the legislation for retrofitting remains the same, an array of imposed U-values, see Table 3.

Table 3: Array of imposed U-values for retrofitting in Belgium.

Element	U-value ≤ W/(m².K)	*Upgraded U-value ≤ W/(m².K)*
roof	0.4	*0.2*
facade	0.6	*0.3*
window	3.5	*1.8*
floor on grade	1.2	*0.6*
floor above cellar	0.9	*0.45*
floor separating inside from outside	0.6	*0.3*

Combining the three planning policies with the low and high household guess and the two energy efficiency choices gave the annual energy consumption's of table 4.

Diminishing the increase in households seems very effective in decreasing energy consumption. This sociological fact however, although quite important, is out of scope of any energy policy. Introducing an EP-standard for new constructions after 2000 may diminish the energy consumption in the residential sector in 2010 with 6 to 13% compared to 2000. An analogous conclusion should hold for a stricter retrofitting legislation, imposing for example the upgraded U-values of table 3, third column, from the year 2000 on. In that way an extra 3 to 5% will be economized in 2010, i.e. some 0.3 to 0.5% per year over a period of 10 years.

Table 4: Future annual energy consumption in the residential sector in Flanders [3].

year	planning policy	Act. energy legislation maintained TJ		EP-legislation after 2000 TJ	
		low demand	high demand	low demand	high demand
2000	scenario 1	207 700	227 600		
	scenario 2	208 600	228 500		
	scenario 3	212 200	232 700		
2010	scenario 1	195 400	233 900	175 400	213 900
	scenario 2	199 300	231 900	178 000	210 300
	scenario 3	201 500	220 450	184 300	203 260

Planning finally has a confusing effect. Business as usual (scenario 1) and a low household increase (=low demand) together give the lowest energy consumption for the residential sector in 2010. Reason: most unoccupied buildings in that case. These old, poorly insulated constructions, which were energy spenders, all cease to consume energy! Do not conclude from this, however, that scenario 1 should be promoted. The social and environmental costs are unacceptable high, a reality, which is more important than any energy benefit more energy-efficient retrofitting could produce within 10 years. An active retrofitting policy, as included in the scenario's 2 and 3, will diminish the pressure on the open space. City centers may remain attractive. Less traffic could be the result, etc. This, in combination with some energy benefit, is worthwhile on its own.

Restrictions and Problems when Insulating Existing Buildings

Especially facades and windows pose restrictions. Some are embedded in the esthetics, one must respect. In cities with an historical value, it is not allowed to change a nice brick facade into a rendered surface. As a consequence: no exterior insulation is permitted, inside insulation remaining the only alternative. Brick facades may bear so much decoration that cladding is out of question. Also here, the only solution left is inside insulation. Windows sometimes have such a specific form that retrofitting must respect them. Using new windows is out of question as is the inclusion of additional windows. Even the application of low-e-double glazing may end in controversy. The difference in color and glare, when compared with clear single or double glazing is obvious and for some designers and civil servants not acceptable.

Insulating a floors is also not always evident. With floors on grade the existing slab must be removed and replaced by an insulated solution. Otherwise, not enough height at the doors is left. Vaulted floors above cellars are very difficult to insulate. In some cases however the floor tiles and sand bed underneath can be removed and replaced by an insulating fill. The same is true with vaulted floors separating the inside from outside.

What is left? Flat and slopes roofs are quite easy to insulate. In the case of non-monumental buildings, also windows and glazing panels may be exchanged for a thermally better type. Floor insulation is easily done in 19 and early 20 century buildings, where floors on grade were composed of a sand layer with tiling on it. Finally, more recent constructions may have cavity walls, which can be filled in a percentage of cases, while massive wall buildings with a simple form and restricted ornamental features may be converted into a construction with exterior insulation.

As far as roofs and floors are concerned now, problems and the performance based solutions which should be applied to avoid them, does not differ from new construction. Typical points however are:

1. reduced ventilation rates after exchange of the old, leaky windows for new, airtight types. This reduction is reinforced if at the same time local heating, included all chimneys, are removed and replaced by a high efficiency central heating system. Less ventilation increases mold and mildew risks
2. no warning left for too high relative humidity when single glass panels are exchanged for low-e gas filled double glass types
3. higher damage risk after inside insulation is applied

<u>Mold and mildew</u>

The risk on mold and mildew tends to 1, once the relative humidity on a surface goes beyond 80% during a substantial length of time. Annex 14 decided to take 4 weeks as the reference time period [5]. This allows to use a steady state approach for judging the risk.

The temperature ratio with h_i=8 W/(m^2.K) for single glazing is 0.28. If surface condensation is a fact there, mold growth may start on all opaque surfaces, which have a temperature ratio below the values, given in table 5.

Table 5: Surface condensation on single glazing, temperature ratio threshold to get mold germination (room with a volume of 40 m², n=0.5 h^{-1})

outside temperature + RH	Constant inside temperature (21°C) f_{hi}	Maximum vapor production g/h,	Inside temperature function of θ_e (= poorly heated) θ_i	f_{hi}	Maximum vapor production, g/h
0 / 90	0.44	55	13	0.52	36
5 / 90	0.49	59	14.9	0.62	41
10/ 85	0.60	68	16.7	0.79	53

Apparently, mold is most likely to occur in poorly heated rooms. At 10°C outside temperature, germination may even start on surfaces with a temperature ratio beyond 0.7. The admissible average vapor production per hour is also low, hardly an equivalent for 1 person! Question left: can we have surfaces with a temperature ratio as low as 0.44? Experience learns that the favorite mold locations are corners and window reveals in sleeping rooms. Lets take a reveal in a 30 cm thick massive wall. With single glazing, 0°C outside and 21°C inside, the reference temperature seen by the reveal is 15.2°C. This ends in a temperature ratio of 0.52 close to the frame, i.e., higher than 0.44 but low enough to get mold when surface condensation appears on single glazing during cold weather in a poorly heated room (figure 1).

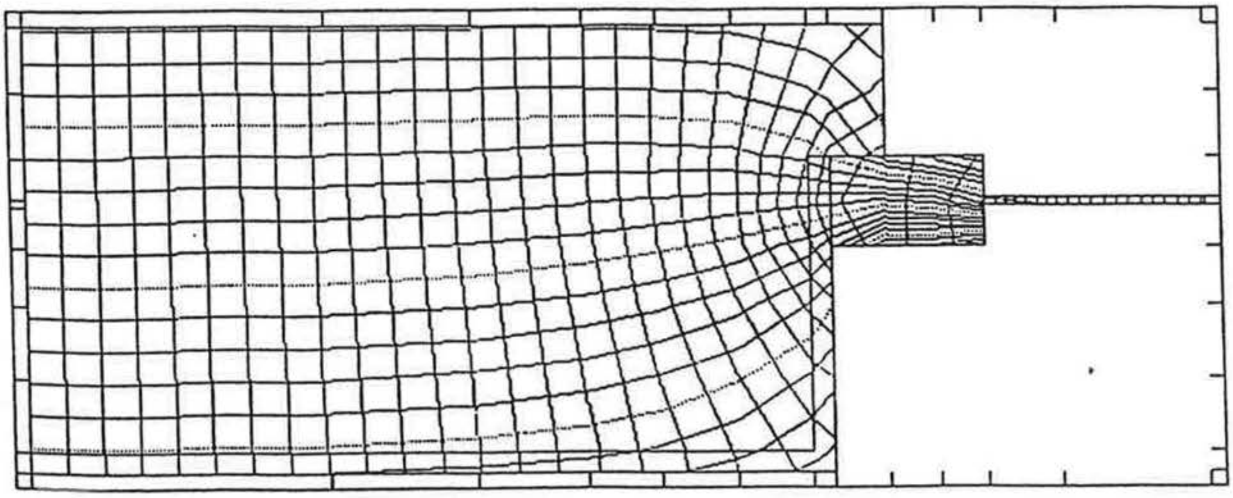

Figure 1: Window reveal in a massive wall.

Suppose we exchange the window for a low-e, gas filled double glazed frame. The temperature ratio on the glazing rises to 0.84 now. The reference temperature, the reveal observes, becomes 20.3°C, giving a temperature ratio of 0.6 close to the frame, i.e. lower than the glazing. As a consequence, mold will start long before surface condensation on the glass panel warns for high RH. At first sight, this seems a problem. At the same time however, the humidity tolerance of the room increases substantially. The allowable vapor production for example goes up to 187 g/h at 0°C outside,21°C inside and n=0.5 h^{-1}, before mold germination on the reveal may start.

The ventilation effect is more substantial. If n goes down from an average of 0.5 h^{-1} to an average of 0.15 h^{-1}, the result in a room with a volume of 40 m^3 is the same as if the vapor production increased from 55 g/h to 187 g/h. Experiences in the past learned that, when putting airtight windows and removing most of the chimneys, a decrease of the average ventilation rate with that magnitude is not impossible.

<u>Higher damage risk</u>

Inside insulation has important drawbacks. Average temperature and humidity differences between winter and summer in the wall increase. This provokes more expansion and shrinkage, resulting in a higher cracking risk at corners and the junctions between in- and outside walls and outside walls and floors. The masonry further becomes colder in wintertime. This keeps it wetter, while frost may reach the insulation, extending the zone of potential frost damage to the interface masonry-insulation material. Summer condensation against the vapor retarder at the inside of the thermal insulation is not impossible. Thermal bridging at all junctions between in- and outside walls and outside walls and floors becomes more pronounced, etc. To avoid some of the problems mentioned, it suffices to respect a few performance based rules:

1. use a vapor retarding insulation material. This removes the necessity to apply a separate vapor retarder and solves the problem of summer condensation in cold and cool climates
2. take care for a correct caulking of all joints between the insulation at the inside and the floor and ceiling in each room. This avoids inside air intruding top-down between the insulation and the wall with very negative consequences for the thermal and hygric quality of the system.
3. restrict the application of inside insulation to walls with a potential for deformation without damage. Lime mortared brick walls with timber floors are an exemplary case.

Two Retrofitting Examples

University library

The university library in Leuven has been reconstructed in the forties, after being bombed during world war 2 [6]. This reconstruction had to fulfill strict fire safety rules. A consequences was that the load bearing part of all slopes roofs consisted of concrete trusses, covered with thin stony elements and finished with slates. After 50 years of intensive use, the building needs a retrofit. Slates fall down and parts of the tower are in very bad conditions. The university couples this retrofitting necessity to less energy consumption through better insulation. Insulating the walls and changing the windows however is out of question. The only possibility left was to insulate the 7160 m² large roof. Actual mean U-value: 2.44 W/(m².K). A performance based analysis was conducted to find the best solution. Two possibilities were open: inside insulation or outside insulation (see figure 2, next page). In both cases, 10 cm mineral fiber was proposed. With outside insulation, thicker could not because of the specific roof details. With inside insulation, thicker had no sense, mainly because of the important thermal bridging effects. Results of a hygro-thermal performance analysis: see table 6. Energy saving on yearly basis reached 72 000 m^3 gas with inside and 104 400 m^3 gas with outside insulation (both calculated values). Hence, the best choice from a performance point of view was quite obvious: outside insulation. The consequences for the roof details however are tougher than with inside insulation.

Table 6: The university library [6]

Performances	inside insulation 10 cm MF	outside insulation 10 cm MF
Air-tightness	excellent	excellent
U-value, incl. thermal bridging	0.91 W/(m².K)	0.32 W/(m².K)
Transient thermal response	maximum temperature in the loft during a hot day, n=1 h^{-1}: 28.8°C	maximum temperature in the loft during a hot day, n=1 h^{-1}: 26.9°C
Thermal and hygric stressand strain	Temperature fluctuation on yearly basis in the stony elements 80.8°C	Temperature fluctuation on yearly basis in the stony elements 3.0°C
Moisture response	vapor retarder a benefit but difficult to mount	no problems

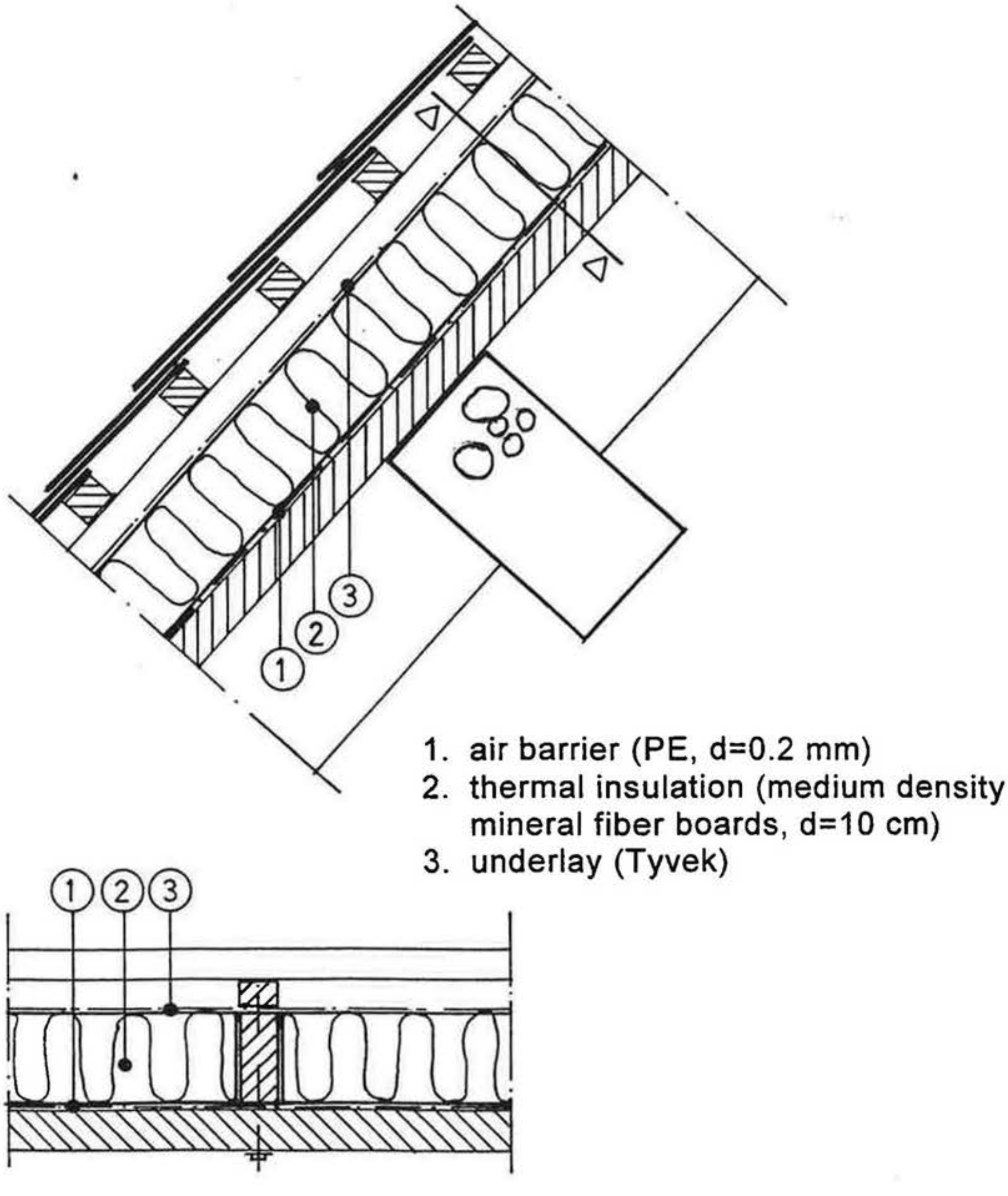

Figure 2: The University Library, roof retrofit proposed.

Students home

The students home dates from the fifties [7]. The architect who designed the brick building was quite famous. This fact excludes a lot of retrofitting possibilities. The brick walls for example cannot be rendered nor clad. So, forget outside insulation. Replacing the existing windows by a new type changed the outlook in a way the architectural society may not accept. The concrete structure of the building is too stiff to use inside insulation. Cavity filling is excluded because of the concrete framework being left as one big thermal bridge. To be short, the only surface which could be upgraded thermally was the flat roof. The existing concrete roof was vented beneath the watertight layer, as was common in the fifties. U-value: 1.29 W/(m².K). The proposal was to turn it into a warm roof, by adding 12 cm mineral fiber on top of it. The existing felt however was in such bad conditions that it had to be removed. The overall renovation therefore existed of (see figure 3)

- stripping the roof
- burning a vapor retarder on the existing floor
- adding 12 cm of mineral fiber
- covering it with a new watertight layer.

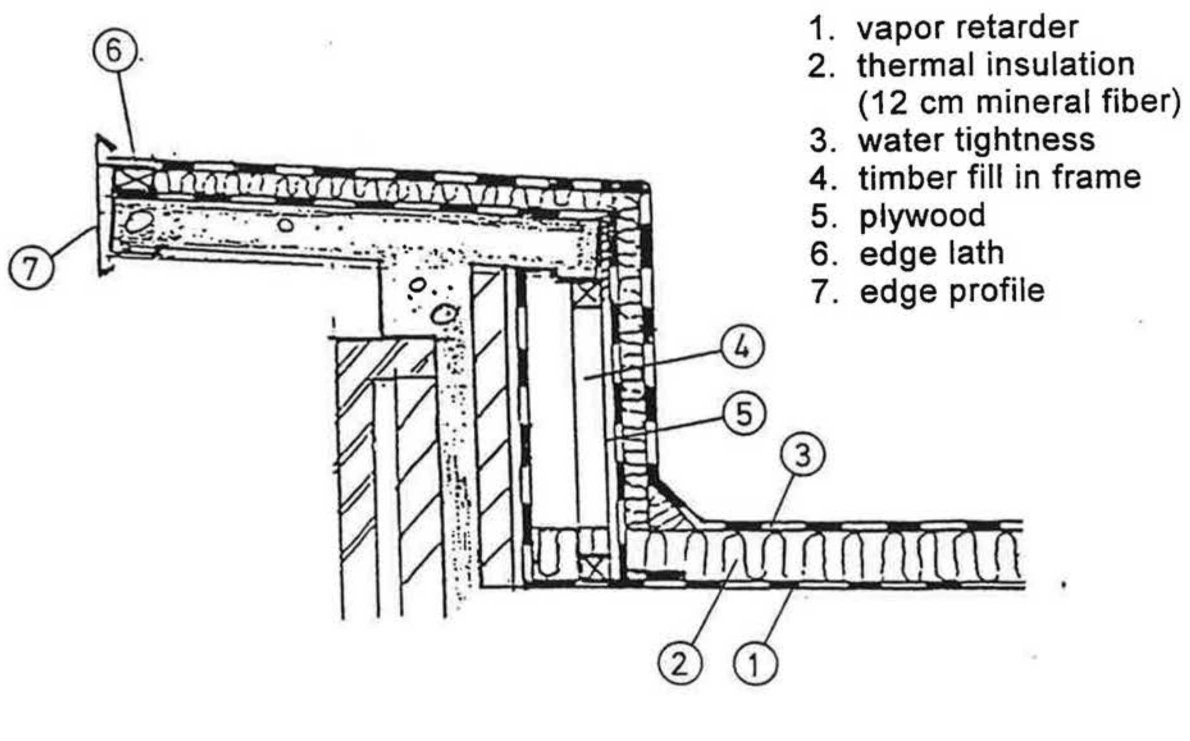

Figure 3: Students home, roof retrofit proposed.

Performances before and after retrofitting: see table 7.

Table 7: Students home, roof performances before and after retrofitting [7].

Performances	existing situation	changing into a warm roof insulation: 12 cm MF
Air-tightness	excellent	excellent
U-value, incl. thermal bridging	1.29 W/(m².K)	0.23 W/(m².K)
Transient thermal response (24 hours period)	temperature damping: 5.7 dynamic thermal resistance: 1.6 m².K/W admittance: 3.5 W/(m².K).	temperature damping: 79.1 dynamic thermal resistance: 10.9 m².K/W admittance: 3.6 W/(m².K) This much better values however did not change the transient response on room level.
Thermal and hygric stress and strain	Temperature fluctuation on yearly basis in the load-bearing concrete floor 12.7°C.	Temperature fluctuation on yearly basis in the load-bearing concrete floor 7°C.
Moisture response	no problems	no problems
Thermal bridging	Roof edges. Consequence: large temperature fluctuation in the concrete, moist concrete,cracking by corrosion of the reinforcement.	Roof edges packed in an insulation layer. The operation only dampens the temperature fluctuations.

Energy consumption for the roof with an area of 1672 m² reached 26 150 m^3 gas per year before insulation. After retrofitting, the number went down to 4480 m^3 (both calculated values). Economy: 21 670 m^3/year or 12 m^3/(year, m² roof). This number was coupled to the investment one could do to get an actualized total cost 0 after 20 years of lifetime.

Conclusions

1. Even if energy-efficient retrofitting is promoted by all means, the impact on the total energy consumption by the residential sector remains marginal. The example commented is clear on that point. Of course, for other countries, this conclusion may be somewhat different. Sociological realities such as trying to slow down the increase of households, political measures and very strict EP-standards for new constructions have a much larger impact. Retrofitting should be promoted primarily to relieve the pressure on the open space and to upgrade the city and village centers
2. The combination of highly insulating glazing systems and lower ventilation rates increases mold risk in retrofitted buildings
3. Inside insulation, in many cases the only measure left to insulate facades, has so many durability related drawbacks, that the solution does not devote too much promotion
4. In monumental buildings or architectural benchmark examples, the insulation possibilities go hardly beyond roof insulation. Although the energy conservation results may be impressive, the overall impact is modest.

References

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All references, except 5, are written in Dutch.