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CASE STUDY

Feasibility of upgrading the energy performance of recent massive brick houses

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Abstract
Climate change policies imply significant reductions of energy use in buildings. For this, prevailing energy performance standards fall short, notwithstanding the emergence of stricter national building regulations. Regulations cover new built and renovation projects. New built houses that miss the best energy performance are soon candidate for energy upgrading. We investigate the architectural and economic aspects of upgrading recently built detached massive brick houses in Flanders (Belgium). For representing actual building practices, consecutive upgrading steps from lower to higher energy performance levels are considered. Questions addressed are: What is technically feasible in upgrading such houses? Which construction works are easy, which difficult? What are the architectural and financial consequences of a thorough upgrading?
The analysis shows that deep energy transformations are financially unacceptable, related to the irrevocable character of investments in energy efficiency attributes of massive brick houses. This confirms that energy performance endowment measures should be designed and implemented at the time of first construction of a building.

1. Introduction

Climate policies cover long-term perspectives but in the built environment the future is literally casted in concrete. The Energy Performance of Buildings Directive (EPBD) 2010/31/EU (EU, 2010) wants new buildings and major renovations to apply the passive or near zero energy standards from 2020 onwards. The Flemish region responds to the EPBD by prescribing tighter energy performance standards year by year (VEA, 2010).

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Frontier energy performance concepts are not widely adopted by the housing market in Flanders. Builders chose among a range of energy performance levels because current standards lack tightness. They often believe that financial returns of low energy buildings do not compensate the higher investment costs, especially not in the nearby years. This myopic perspective perceives energy efficient measures as expensive. As a result, most recently built houses are designed to harshly meet the legally imposed standards (VEA, 2011). Many, e.g., Feist (1998), Verbeeck (2007), Verbeeck and Hens (2005), Versele et al. (2009), recommend higher energy performance levels in new houses of Central-Europe. Applying proper investment theory, Verbruggen et al. (2011) show that installing the frontier energy performance endowment is the financially sound option at first construction.

In Flanders long-lasting massive brick constructions are characteristic, especially within the housing market. Such houses own concrete floors installed in situ with raw materials or with prefabricated elements. The walls outside and inside are mostly brickwork. Outside walls are layered: inside wall, thermal insulation, a narrow cavity, and as façade some fancy brickwork. Fig. 1 shows at the top the reference house of this study. The bottom is a detail of the outer wall of the house. The insulation PUR plates are placed in cross-over for tightening the seams; the black colour outside brick is the finishing.

Currently new built massive brick houses are expected to remain part of the built environment for decades to centuries. Such buildings undergo systematic renovations in cycles of about thirty years (Liebregts and Persoon, 2009). For meeting evolving technical requirements, for maintaining market value (Eichholtz et al., 2009), (NBWO (Nederlands Bureau Waardebepaling Onroerende Zaken) [Dutch Agency Valuation of Immovable Property], 2008), for gratifying comfort demands, for minimizing energy use and associated costs, and for meeting social expectations and environmental regulations, house owners may like to improve energy performance during the midst of the house's first life cycle. Also refurbishments within usual renovation cycles must implement minimum energy performance requirements, according to article 7 of the 2010-EPBD (EU, 2010) "building components with a significant impact on the energy properties of the building envelope need retrofit or replacement".

The outside view of the nowadays brick houses in Flanders reflect the architectural taste of the owners. The long-lasting hull also covers functions like thermal insulation, water parry, security, etc. (see Fig. 1) Observed energy performance levels however do not anticipate future evolutions. This may create significant energy and sustainability challenges already within the first 30 years of the building's lifespan.

First we address the technical feasibility of upgrading recently built detached massive brick houses to higher energy performance levels, equivalent to levels owned by comparable newly built houses. Upgrading in reality is subject to physical constraints but may also pursue more sustainable living conditions in the house and in the overall built environment. The analysis adds to the knowledge about upgrading massive brick houses to a higher energy performance level, in particular within the Flemish context, on mainly three points.

First, most preceding studies can hardly stand the reality check on important issues, such as actual planning regulations in place, permanent occupation of the house during

Fig. 1 Reference house with detail of the outer wall, showing the functional layers of the house in a theoretical composition, displaying their durability (line weight) and interrelationship (overlap). (design/photo: arch. Cauchie).

retrofit works, and the demands of an integrated approach to obtain higher sustainability levels of buildings. Also social and cultural values that may be related to existing buildings are not properly considered.

Second, studies on house upgrading and recommending retrofit and efficiency measures, mostly deal with outlived houses (Verbeeck and Hens, 2005; LEHR (Low Energy Housing Retrofit), 2010; Verbruggen, 2008). The lessons from such projects are not simply transposable to contemporary newly built houses as the considerations mentioned in the previous point reveal.

Third, upgrading measures mostly imply important trade-offs and compromises. Pursuing energy efficiency is generally the starting financial objective, balanced with or against objectives regarding comfort (changed indoor dimensions), aesthetics (changed appearance), performances (technically often dependent on power supplies), etc.

The descriptive approach of this article is complemented by an exploratory experiment (case study) and by an analysis of the results (Yin, 2009). The exploratory experiment is stylized and based on an existing representative house in Flanders. This choice has two important advantages. First, we use available realistic data (building costs, context); second, it is feasible to compare a variety of transformations on architectural, financial, and energy use aspects. For representing real building practices, consecutive upgrading steps from lower to higher energy performance levels, are considered.

The analysis is illustrative and only representative for recently built detached massive brick houses in the context of Flanders (policy, construction methods, etc.), even if the results, discussion and conclusions can be useful for other types of dwellings, buildings, and construction methods and in other regions. Set terms and conditions for the transformation as well as defined energy upgrading measures are based on practical examples. We consider these as the most relevant and representative within the context (region, building culture, upgrading case), but not as the only possible ones. The selected measures together reflect a strategy for a full and successful energy upgrade. For example, insulation materials in place are removed because reuse of materials is not guaranteeing sufficient quality. Other building components and equipments are re-used (roof tiles, furniture, doors). Floor plan adjustments often part of renovations due to design trends or changed family composition are not studied here. The focus is on economic investment costs, with exclusion of transfers like taxes, fiscal benefits, subsidies, grants, etc. Transfers are not guaranteed and differ from place to place.

The hypothesis of the analysis builds on the theoretical approach of time-sequential decision-analysis by Verbruggen et al. (2011) and Verbruggen (2012), criticizing the standard scholarly practice of applying expected value methods. At the design phase the Energy Performance Endowment (EPE[1]) of a house is decided. Different attributes and items affect the EPE of a house. These attributes and items can be classified as 'precluded' (strong irrevocability), 'rigid' (medium irrevocability) and 'adaptable/addable' (weak irrevocability). Several important EPE features belong to the strong irrevocability or preclusion class. Therefore appropriate decision analysis of attributes and items of a building's EPE leads to "Choose or Lose" (provide now to avoid preclusion) situations, opposite to the common "Wait and Learn" (defer the irrevocable investment and keep the option to decide later). The irrevocability characteristics of energy efficiency investments stimulate immediate very efficient buildings rather than standard obeying buildings. Applied here the hypothesis is: The characteristics of recently built houses according to the massive brick building method leads to "Choose now" the best energy performance endowment in order to avoid preclusion of efficiency solutions in the future.

After this introduction follow four more sections. Section 2 provides key information for the research in three Sections 2.1 situates three energy performance levels relevant within the context of Flanders, Section 2.2 describes the selected case, and Section 2.3 identifies terms and conditions for the transformations, an aspect not or only limited respected in other studies. In Section 3 the architectural research is presented. Three complementary sub-sections deal with following questions: What are the attributes and characteristics of the three energy performance levels? Which attributes need to be considered in energy upgrading transformations? What architectural interventions (measures) are required, and what are their impacts? The financial aspect of necessary architectural interventions is covered in Section 4. Section 4.1 discusses the methodology, while Section 4.2 shows the results and analyses the assessed expenses. A conclusion is offered in Section 5.

2. Assumptions/data information

2.1. Prevailing energy performance levels in Flanders

The variety and range of energy performance levels observed in the Flemish buildings stock are broad. The adopted performance level depends on several aspects: building economics, minimum legal requirements, the building function, etc.

The Flemish EPB[2] provides for three energy performance indicators: *u*-, *K*-, and *E*-values. The *u*-values reflect the heat transmission coefficients of building components (wall, floor, roof, windows), i.e., heat loss rates per square meter and per 1 °C temperature gradient between interior and exterior (W/m^2K). Lower *u*-values correspond to better insulating performance of the building component. The *K*-value expresses the overall energy performance of a building. A lower *K*-value means less heat losses through the building's envelope. The *K*-value is calculated on the basis of the *u*-values of the various building components. Size and compactness of the building also affect the *K*-value. The more compact, the smaller the *K*-value.

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[1] EPE: Acronym of 'Energy Performance Endowment', the incorporated capability (made up by attributes, structures, installations, equipment, etc.) of a house that largely determines energy use in delivering the functions wanted by the occupants.

[2] EPB: Abbreviation for 'EnergiePrestatie en Binnenklimaat' (energy performance and interior climate). In implementing the European Directive on the energy performance of buildings, the Flemish energy legislation came into force as from the 1ste of January 2006, which reflects the pursuit of a better energy performance of the Flemish building stock.

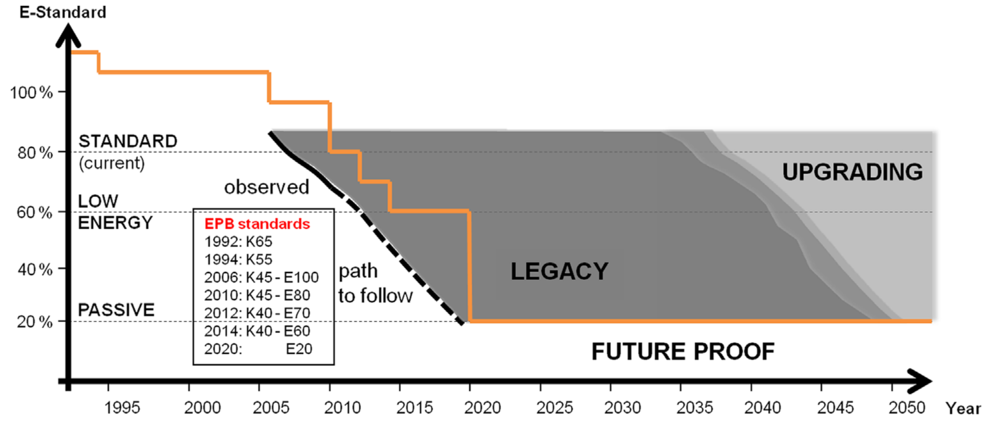

Fig. 2 Energy Performance of Buildings (EPB) standards (past, present, and expected) in Flanders; observed EPB evolution with projected “path to follow” to obey standards in 2020; dragging legacy of weak near term standards compared to the 2020 target.

The *u*-values and the *K*-value are measures of stationary heat losses. The *E*-value reflects the energy use of a building by the ratio of its calculated characteristic annual primary energy use to a reference annual primary energy use. The value is calculated using the Flemish EPB software (VEA, 2006, http://www.energiesparen.be/epb/prof/software) Determining factors of the *E*-value are the *K*-value, the type and amount of ventilation, the air tightness of the building envelope, the efficiency of the heating and heat distribution systems, etc.

The statutory requirements for the energy performance of buildings have been tightened according to the EPB regulation and will become stricter in coming years.

The stepwise decreasing curve in Fig. 2 shows the past, present and expected EPB standards in Flanders. Insulation values of individual building components (*u*-values) must meet minimum requirements: wall ≤ 0.4; roof and ceilings ≤ 0.3; floors ≤ 0.4; etc., minimal ventilation demands, limit the risk of overheating, and a maximum overall energy use of E80 since 2010 (E80 is called ‘E80 standard’ in this article).

Fig. 2 also reveals the EPB of houses built during 2006-2010 that own the overall insulation level K45 or below. In Flanders, about 16% of recently built houses meet the energy level E60 (VEA, 2011). The observed curve is extrapolated over the decade 2010-2020 to end in the standard announced for the year 2020. By following this curve a dragging legacy is created for the next 30 years (the length of the first life cycle of a brick house), shown as the shaded area in Fig. 2. The legacy corresponds to a lock-in by the initial construction and utilities choices, lasting for 30 years. At the end of the period an upgrading of the house is expected.

Unlike the ‘E80 standard’, ‘low energy’ is not well described what results in different ways to achieve the ‘low energy’ level in houses. A small number of houses realize more stringent *E*-values by adopting the ‘passive’ house concept. This concept refers to a specific construction method for buildings with good indoor comfort conditions in both winter and summer, with heating and cooling systems of very limited capacity. In order to claim a passive house certificate in Flanders, three criteria must be met: the net energy demand for heating is limited to 15 kW h/m^{2}a, the building has an air tightness of $n50 \leq 0.6$ per hour, and the frequency of exceeding 25 °C indoor temperature must be less than 5%. The passive building features are calculated using the PHPP software (Passivhaus Projektierungs-Paket, or Passive House Planning Package) developed by the German Passivehaus Institut (2003), http://www.passiv.de). Satisfying the conditions requires an excellently insulated building shell together with airtight sealing of the building; a good indoor climate is guaranteed by mechanical ventilation with highly efficient heat recovery during the heating season (Passiefhuisplatform).[3]

2.2. Selected case study

A stylistic case study is helpful in fixing the numbers and limiting the amount of simulations.

A pilot project by Wienerberger and Recticel Insulation[4] was selected. In collaboration with the owner-builder and the architect, Kristof Cauchie (http://www.architectcauchie.be), they realized one of the first massive brick houses in Belgium with a passive energy performance level (Wienerberger, 3Db Studio, Recticel Insulation, 2010). While planning the project, they constantly evaluated the goals compared to the legally imposed E80 standard in energy performance.

Flanders has a moderate maritime climate (Peel et al., 2007) with fresh and humid summers and relatively mild and rainy winters. The urban conditions of the pilot project are representative for this type of houses: an allotment in a non-urban environment with individual detached houses. The program of requirements consisted of an entrance hall, a toilet supplemented with a checkroom, a living room, a kitchen with a separate pantry, a landing, a main (double) bedroom, three single bedrooms, two bathrooms, an office space and an attic (Fig. 3). The requirements are realized on two floors with a total useful surface of 155 m^2. The construction has a compactness of 1.26 (envelope

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[3] [Passive House Platform] A non profit organization in Flanders whose goal is to stimulate the construction of energy efficient buildings, based on the Passive House concept (http://www.passiefhuisplatform.be).

[4] Two leading Belgian building products manufacturers respectively of bricks and roof tiles, and insulation materials (http://www.wienerberger.be) (http://www.recticel.com).

Fig. 3 Selected case Wienerberger/Recticel project; 1. entrance hall/toilet/checkroom 2. living room 3. kitchen 4. pantry 5. main double bedroom/office space 6. bathroom 7. landing 8. single bedroom 9. attic 10. carport (design: arch. Cauchie).

area/heated area), a north–south orientation, no roof overarching, a flat and pitched roof (slope: 35°), no specific zoning or compartments, no greenhouse neither a basement nor a crawl basement underneath. The building design is representative for the building culture of Flanders: the shell is a massive brick construction (concrete foundation, brick walls, cavity walls, hollow core slabs, wooden roof structure), while the default heating system consists of a condensing (gas) boiler and radiators with thermostatic valves (a heat pump is the alternative option). Applied materials are: clay roof tiles, PU and PIR insulation, wooden external windows and doors, floor as well as wall tiles, and inside walls plastered.

2.3. Terms and conditions of upgrading projects

The great variety of urban, architectural, social and legislative aspects, and the terms for upgrading a mediocre energy performance, need explicit consideration. Five influencing factors are identified: (1) government regulations; (2) comfort; (3) cultural elements; (4) technical and physical properties; (5) process quality. The five factors and their specific content consider the social and cultural dimensions of sustainable housing and assign realism to our study.

The nature and content of the terms and conditions of Table 1 is important for the outcome of the research. Therefore, a further clarification and motivation are provided:

2.3.1. Government regulations

Given the high building and population density in Flanders, the planning regulations are very extensive and strictly mandatory. Renovations must meet the applicable requirements as well. Two trends are important. First, renovations aiming to reduce the energy consumption may adjust the building size horizontally and vertically. Second, concerning the visual appearance of buildings entire neighborhoods and districts may be characterized by a specific use of prescribed materials, due to mandatory regulations. Both in new and renovation projects, several municipalities require that facades and roofs remain consistent with surrounding buildings.

2.3.2. Comfort

Renovation works are often complex and expensive. In lowering renovation difficulties and correspondingly costs, comfort levels may be threatened, e.g.,: reduction of useful living area or volume, lowered passage height of doors, failing the new positioning of fixed furniture and equipment (stairs, sanitary appliances, electrical equipment, kitchen and bathroom furniture). Such loss in comfort is not allowed in our study because the house would no longer own the same degree of comfort as before. The appreciation by owner and residents would decrease which might even result in earlier vacancy or demolition, what is not a sustainable course.

2.3.3. Cultural elements

Buildings are created with some vision on the overall concept: design, typology, materials, etc. Built artifacts own identity and architectural value that one should respect from an architectural, social and historical point of view when planning renovations. Design, form and material characteristics should be conserved; modifications should preserve the initially intended architectural value.

2.3.4. Technical and physical properties

The popularity of the massive brick construction method in Flanders has cultural and historical roots; the brick tradition provides identity, social integration, and status to owners and residents. Bricks also own specific technical and physical properties like thermal inertia, strength, acoustics, moisture

Table 1 Terms and conditions set for five main factors during thorough energy upgrading of a typical Flemish family house.

Influencing factors of energy upgrading	Terms and conditions
1. **Government regulations**	
• Land use (area of plot) width and height	Adjustment of the building size is admitted
• Material use (exterior)en	Different material use is not admitted
2. **Comfort quality**	
• Dimensions	Changed dimensions (inside and outside) are not admitted
o Useful surface/volume (internal)	
o Door heights	
o Position of fixed elements (stairs, sanitary, electricity, furniture (kitchen, bathroom,...))	
o Windows (curtains)/entrance doors	
3. **Cultural quality**	
• Appearance	Changed (outside) appearance is not admitted
o Application of new type of facade	
o Change facade appearance	
4. **Technical/physical quality: performances/requirements**	
• Free of health risks	Initial characteristics must be maintained
• Heat capacity/convection	
• Strength	
• **Surfaces/texture**	
• Applicability of materials, constructions, utilities	
5. **Process quality**	
• Accessibility and usability of the building	Alternative accommodation during works is admitted

control, texture, comfort feeling, and low maintenance costs. During renovations, materials and techniques must be chosen to preserve the beneficial properties.

2.3.5. Process quality

The type of renovation measures is often influenced by permanent habitation of the house during the period that renovation activities are taking place. This will affect the process quality because renovation works cannot be executed fully or thoroughly or materials and techniques of lower quality are used, etc. This study assumes upgrading to equivalent quality of the newly built reference house, implying that occupants must leave the house for alternative accommodation during the works.

3. Architectural research

3.1. Attributes of energy performance levels applied in the case study

Buildings are characterized by several variables such as the urban environment, its typology, its spatial design, constructive and material properties, available utilities, etc. Also measures to achieve higher energy performance levels are specific by project.

Three energy performance levels – E80 standard, low energy and passive – are applied on the case, requiring three different packages of measures considered representative in the Flemish context. Research by Wienerberger and Recticel provides full information on the 'E80 standard' and 'passive' energy performance measures (Wienerberger, 3Db Studio, Recticel Insulation, 2010). By consulting published guidelines of the Flemish Energy Agency (VEA, http://www.vea.be, http://www.energiesparen.be) and adapting design by using energy performance software we assembled the 'low energy' performance package. According to Van Loon and Mlecnik (2007), the E-level cannot be used as an indicator for passive houses. Therefore calculations by the Flemish EPB software are in view of the energy demand for heating supplemented by calculations with the German PHPP software.

Table 2 provides an overview of the packages by energy performance level. The first part of Table 2 describes the performance levels, the second the insulation, and the last some major building utilities.

3.2. Attributes of energy upgrading transformations

An upgrading of a building's energy performance level first considers its insulation and utilities (Table 2). Three energy performance levels correspond with three packages of measures that realize to step up: (1) from E80 standard to low energy, (2) from E80 standard to passive, and (3) from low energy to passive.

Every package considers the construction (roof, wall and floor insulation, window frames and glazing). Improved air tightness and exclusion of thermal bridges are inherent to a high performance of buildings. When thermal integrity is changed, utilities too require adjustments, such as: ventilation systems in the upgrade from E80 standard to passive and from low energy to passive, and heat generation and distribution systems when upgrading from E80 standard to low energy and from E80 standard to passive.

Table 2 Energy performance and building utilities attributes of three single family brick houses, according three levels of energy performance.

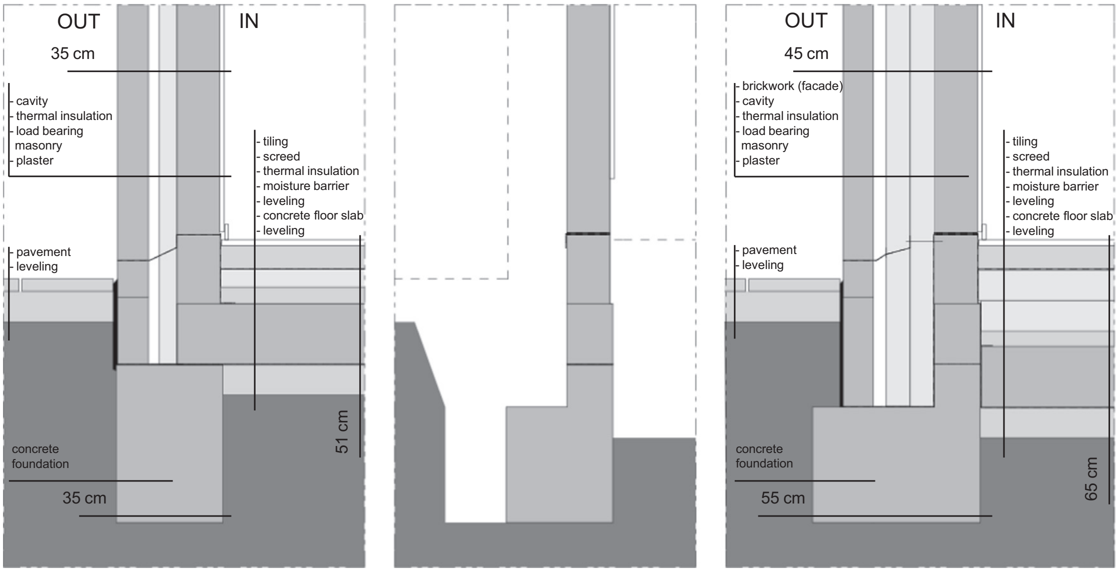
Attributes	Energy performance level		
	E80 standard	**Low energy (1)**	**Passive**
Energy performance (2)			
E-level EPB	80	60	48
K-level EPB	39	25	16
Energy demand for heating (kW h/(m^{2}a) PHPP	86	60	15
Air tightness (m^3/h m^2) (3)	6	6	0.5
Building insulation shell			
Floor	60 mm/PU	120 mm/PU	200 mm/PU
Wall			
Cavity wall	60 mm/PU	120 mm/PU	165 mm/PU
Other walls (gables)	80 mm/PIR	120 mm/PIR	200 mm/PIR
Roof			
Pitched roof	80 mm/PIR	120 mm/PIR	200 mm/PIR
Flat roof	80 mm/PIR	120 mm/PIR	240 mm/PIR
Window profiles			
Insulation (W/m^2 K)	2.2	1.3	0.87
Glass spacer (W/mK)	Standard	Improved	0.048/0.061
Glazing			
Insulation (W/m^2 K)	1.1	1.1	0.5
Total solar energy transmittance (g)	0.6	0.6	0.59
Avoidance of thermal bridges (4)	Yes	Yes	Yes
Building utilities			
Sunprotection	None	None	None
Energy	Gas	Gas	Gas
Energy generation (condensing boiler)	101%	109%	109%
Heating system (space/water) (with hot water storage)	Radiators with thermostatic valves	Oversized radiators with thermostatic valves	Oversized radiators with thermostatic valves
Ventilation system (5)	Ventilation system C	Ventilation system C	Ventilation system D

(1) Low energy: Since the 'low energy' level can be achieved in different ways, mentioned measures, calculations were also performed for a design with the same amount of floor insulation as E80 standard. Calculations for other building insulation components have been made in order to find out how to achieve the required performance (other walls and roofs: 160 mm instead of 120 mm).
(2) Range: 5%.
(3) According to VEA (architect Dedeyne) the air tightness of massive houses is obtained by inside wall plastering.
(4) We assume that cold bridges are avoided, according to Flemish regulation on 'building knots'.
(5) Ventilation system: Four kinds are possible:
- System A: natural supply and natural exhaust.
- System B: mechanical supply and natural exhaust.
- System C: natural supply and mechanical exhaust.
- System D: mechanical supply and mechanical exhaust (possibly supplemented with heat recovery).

3.3. Definition and technical description of measures

The pitched roof construction consists of industrial prefabricated wooden trusses with insulation added by mechanical fixation, followed by battens and roof tiles. To ensure air tightness oriented strand boards (OSB) are placed on the inside of the trusses (attic) and seams are sealed. To install the quantity of insulation materials that the energy upgrading requires, demolition works are required. Apart from components on waterproofing such as gutters, eaves, laps, etc., removal of the roofing is needed. The installed insulation is pierced by battens, and therefore damaged, requiring its removal. After implementing the measures, some building components need adaption or replacement (gutters, eaves) while others can be re-used (roof tiles).

The load bearing structure of the flat roof consists of hollow concrete core slabs. On top of the slabs are added



INITIAL **RECONSTRUCTION** **UPGRADED**

Fig. 4 Wall–floor connection detail showing the initial, reconstruction and upgraded phase.

successive layers: a layer of cement mixture in order to create a slight roof slope, a vapour barrier, insulation and finally the waterproof roofing. The ceiling inside consists of a stucco finish, which also serves as a vapour and air sealing. Apart from the concrete slabs and cement sloping layer the entire roof construction needs to be removed together with eaves, flashings, drainpipes, drains and gargoyles. On the accessible slope layer the selected amount of insulation can be placed. Apart from replacing the removed layers and demolition of specific components, the wall masonry should be raised because of the more voluminous insulation layer on the roof.

The outer walls of the house consist of a load bearing masonry on the inside, brickwork (facade) on the outside, with in between a cavity filled with insulation (see Fig. 1). The inside of the cavity wall is covered with plaster (vapour and air sealing). When the insulation needs to be replaced, following components have to be removed: the facade, flashing and films, drainpipes, window and door sills, pavement outside, and all other components linked to the facade. The adaptation works consist for this measure of: the broadening of the foundation/base (soil excavation, casting concrete, masonry foundation), the installation of waterproof layers, replenishment of soil and stabilized sand, a new facade, window and door sills, drainpipes, and the replacement of the pavement around the house (within a range of 1 m from the building).

The reference house has no crawl space. The foundation consists of a concrete floor slab casted on a moisture barrier with the soil functioning as base. The finish consists of a further levelling, a moisture barrier, insulation, screed and a tiling with plinths. Adjusting the amount of floor insulation means, in the first place, a considerable amount of demolition works: fixed furniture (kitchen, bathroom, checkroom, etc., which can be re-used), interior doors (for re-use), the entire floor composition (see above), technical components (underground and overhead lines, sanitary appliances, etc.), and the concrete floor slab (for the larger thickness of insulation only downward space is available). Before inserting the insulation, the pit should be excavated further and underground pipes (sewerage), stabilized sand, a new concrete floor and justification with moisture barrier must be put in place. Moreover, utilities have to be reconnected, a pump has to be installed (sewage level), technical components, screed, tiling, plinths, fixed furniture, doors and sanitary appliances have to be replaced. In addition, unforeseen extra renovation works might emerge (e.g., damage to plastering because of the works) (Fig. 4).

For installing more adequate window frames with glazing, existing ones are removed; this entails trimming of the plaster and removing sills. Once the new windows have been installed, plaster, sills, wall joints and sealants, etc. have to be restored.

Measures related to the building utilities are less extensive. For adjusting heating and ventilation systems, demolition and adaptive works relate primarily to making transit drillings, removing or inserting plate finishes and restoring plaster.

4. Economic research

4.1. Estimation of upgrading costs

The measures of the different transformations imply demolishing and/or adaption works. A detailed survey of works and corresponding quantities holds three groups: demolition, adaptation and specific attributes of the particular measures. Estimations of the expenses are based on upgrading before the end of the first 30-year life cycle. The earlier date may result from stricter energy performance regulations or from increasing energy prices. To the costs of the measures as such are added overhead costs (renting alternative housing, architect, engineer, safety coordinator, coordination fee contractor, etc.).

4.2. Cost assessment

Table 3 shows cost assessments for initial construction and for upgrading to improved energy performance.

Table 3 Initial construction costs of E80 standard, low-energy and passive houses, and costs of upgrading energy performance.

	Initial costs		**Upgrading costs**			**Final costs**		
	euro	euro/m^2		euro	euro/m^2	euro	euro/m^2	%
E80 standard	171,000 (1)	1103				171,000	1103	100
			> Low energy	168,000	1083	339,000	2186	198
			> Passive	197,000	1270	368,000	2373	215
Low energy	182,000	1174				182,000	1174	106
			> Passive	190,000	1225	372,000	2399	217
Passive	206,000 (1)	1329				206,000	1329	120

(1) Costs of the E80 standard and the passive version is similar to the ones by the construction partners in our case study.

Table 4 Initial and upgrading costs of various attributes or measures to attain low-energy and passive housing.

Attribute/measure	**Low energy**			**Passive**		
	Initial costs (1) euro	Transformation costs (2)(3) euro	Energy demand for heating (4) (kW h/(m^{2}a)	Initial costs (1) euro	Transformation costs (2)(3) euro	Energy demand for heating (4) (kW h/(m^{2}a
Building construction						
Pitched roof insulation	6,600	16,200	84	9,600	19,250	78
Flat roof insulation	1,250	5,800	81	2,600	7,150	68
Window frames and glazing	17,850	20,650	74	24,150	26,950	43
Floor insulation	5,050	44,000	70	7,450	44,950	38
Cavity wall insulation	8,000	50,250	60	10,350	52,900	22
Building utilities						
Ventilation	4,950	0	60	13,150	14,650	15
Heating	8,500	8,850		5,500	5,850	

(1) Cost of actual measure plus related works by initiation.
(2) Demolition, adaptation and actual costs of measures of transformation from E80 standard to low energy/passive.
(3) The sum of the extra costs does not meet to the total costs mentioned in Table 3 because overhead costs (architect, engineer, ...) are not included.
(4) The energy demand for heating of the initial E80 standard (86 kW h/(m^{2}a), see Table 2) is stepwise reduced by the influence of the ordered measures, ending in the maximum energy demand for heating of the aimed upgrade (low energy or passive).

From E80 standard to low energy the initial construction costs increase by about 6%, and to passive by about 20%. In case of upgrading energy performance levels, the final costs are significantly higher than in case the levels are included ab initio (see Table 3). By square meter the retrofit costs 1083 euro from E80 standard to low-energy; 1225 euro from low-energy to passive; and 1270 euro form E80 standard to passive. Versele et al. (2009) mention 1379 euro per square meter from E80 standard to low-energy and from E80 standard to passive 1602 euro, considering the retrofit and enlargement of a house dating from the 1950s. Passiefhuisplatform assesses upgrading to the passive standard at 25% cost increase.

Table 4 provides costs by attributes or measures. The seven upgrading measures are ordered based on the energy effectiveness of the measures (lowest euro/kW h reduced first). The table reveals the higher expenses in case of transformations than when initial implementation occurs. Obvious also is that the major expense is due to demolition and adaptation works. Once the latter are undertaken it is a limited extra cost to go for passive beyond low-energy. Table 5 shows a breakdown of the expenses. This confirms that construction works require 76 to 81%, where utilities take 5 to 10% with the remaining about 13% spent on overhead. The latter are quite significant due to the necessarily complicated activities undertaken. Of the expenses for constructive measures more than 50% are needed for cavity wall and floor insulation.

The breakdowns over demolition, adaptation, and actual measure provide further insight, and show that overall demolition and adaptation take about two thirds of the budget. This explains the big gaps in costs between initial and later execution of high performance measures.

Table 5 shows that renovating utilities, window frames and glazing are by far the easiest to implement. Upgrading

Table 5 Detail of the upgrading expenses.

Attribute/measure	Cost shares (%)											
	E80 standard to low energy (168,000 euro)				E80 standard to passive (197,000 euro)				Low energy to passive (190,000 euro)			
	Over measures	Within measures (1)			Over measures	Within measures (1)			Over measures	Within measures (1)		
		De	Ad	Ac		De	Ad	Ac		De	Ad	Ac
Overhead	**13.4**				**12.8**				**12.9**			
Building construction	**81.3**				**76.7**				**79.3**			
Pitched roof insulation	9.6	25	41	34	9.7	21	35	44	10.1	21	35	44
Flat roof insulation	3.4	23	45	32	3.6	19	38	43	3.7	19	38	43
Window frames and glazing	12.2	7	6	87	13.6	5	5	90	14.2	6	5	89
Floor insulation	26.1	19	69	12	22.8	19	70	11	23.6	19	70	11
Cavity wall insulation	29.8	17	69	14	26.8	17	66	17	27.7	17	66	17
Building utilities	**5.2**				**10.4**				**7.6**			
Ventilation					7.4	4	8	88	7.6	4	8	88
Heating	5.2	4	0	96	2.9	6	0	94				

(1) De = Demolition, Ad = Adaptation, Ac = Actual measure.

roof insulation is also quite affordable. Cavity wall and floor insulation are the most difficult to implement due to high demolition and adaptation costs.

Table 6 Upgrading measures classified according degree of irrevocability.

Measures	Classification
Construction components	
Pitched roof insulation	Rigid/addable
Flat roof insulation	Rigid/addable
Cavity wall insulation	Precluded
Floor insulation	Precluded
Window frames and glazing	Adaptable
Building utilities	
Ventilation	Adaptable/addable
Heating	Adaptable/addable

5. Conclusion

Energy performance upgrading of recently built detached massive brick houses in Flanders, taking account of set terms and conditions, is only possible at high costs due to the necessity of extensive demolition and adaptation works. Different attributes affect the energy performance of a building. Therefore, different measures are required to realize a successful energy performance transformation. With our detailed cost analysis, the measures can be classified in three degrees of irrevocability: 'precluded' (strong irrevocability), 'rigid' (medium irrevocability) and 'adaptable/addable' (weak irrevocability) (Verbruggen et al., 2011).

Table 6 shows that cavity wall insulation and floor insulation, two important attributes of a higher energy performance level, belong to the strong irrevocability or preclusion class. 'Costs to adapt or add them after finishing the construction of these attributes are higher than the costs of realization during construction and even remain higher during the building's lifetime' (Verbruggen et al., 2011). Therefore, the decision to build a massive brick house with a given energy performance endowment is strongly irrevocable, ruling out full upgrading meeting set terms and conditions, to a higher energy performance because of financial concerns.

The analysis validates the 'choose the most energy performing endowment at the initial design of a house, or lose the opportunity to obtain a high energy performance level' (Verbruggen, 2008). This implies lessons for future designs of massive brick houses. E80 standard energy performance levels in newly built massive brick houses are not recommended. Aiming at total energy performance transformations in time is inadvisable due to several irrevocable characteristics of massive buildings. Instead, in order to create houses that are 'future-proof', energy performance investments should be implemented from the start. At best, these investments should achieve the highest energy performance level possible, e.g.,: the passive house concept. At least, owners should invest in energy transformation-precluded attributes and measures, such as cavity wall and floor insulation, and not accept the lower quality prescribed by standard regulations.

The objection against this firm recommendation generally is that house builders (often young families) do not own the financial capacity to buy the best solutions. Mostly this objection fails the proof of a clear and well-balanced weighing and ranking of the priorities, with the architect playing an important role. But assume the financial constraints are very biting; then the builder and architect should foresee more flexibility for irrevocable attributes and measures. Such flexibility facilitates later transformations to higher energy performance levels, without compromising the specific characteristics and culture of the building. Questions especially relevant for massive brick construction require further investigation: Can flexibility be incorporated and at what price?

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