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Article

Energy-Efficient Technologies and the Building's Saleable Floor Area: Bust or Boost for Highly-Efficient Green Construction?

Agnieszka Zalejska-Jonsson [1,*], Hans Lind [1] and Staffan Hintze [2]

[1] Real Estate and Construction Management, School of Architecture and the Built Environment, KTH Royal Institute of Technology, Brinellvägen 1, Stockholm 10044, Sweden; E-Mail: hans.lind@abe.kth.se

[2] Highway and Railway Engineering, School of Architecture and the Built Environment, KTH Royal Institute of Technology, Brinellvägen 23, Stockholm 10044, Sweden; E-Mail: hintze@kth.se

* Author to whom correspondence should be addressed; E-Mail: agnes.jonsson@abe.kth.se; Tel.: +46-08-790-8019; Fax: +46-08-411-7436.

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Abstract: When the external measurements of a building are fixed, an increase in external wall thickness caused by additional insulation, for example, will lead to loss of saleable floor area. This issue has to be taken into account in the evaluation of investment profitability. This paper examines how technologies used in energy-efficient residential building construction affect the available saleable floor area and how this impacts profitability of investment. Using a modeled building and an analysis of the average construction cost, we assessed losses and gains of saleable floor area in energy-efficient buildings. The analysis shows that the impact of potential losses or gains of saleable floor area should be taken into account when comparing investment alternatives: building energy-efficient green dwellings or building conventional ones. The results indicate that constructing energy-efficient buildings and introducing very energy-efficient technologies may be energy- and cost-effective even compared with conventional buildings. Employing new products in energy-efficient construction allows benefit to be drawn from lower energy consumption during the life cycle of the building, but also from the increase in saleable floor area.

Keywords: energy-efficiency; profitability; construction cost; green residential building; low energy building

1. Introduction

There are ambitious goals in the EU to reduce energy consumption in the building stock and a crucial question is to what extent the investment in energy-efficient technologies is profitable and whether further political measures are necessary.

The process of decision-making in simple terms is based on valuing benefits against costs and against alternative solutions. In the case of investment in new property projects, initial and future costs are weighed against expected income. If we consider a scenario where a developer has the choice of constructing the same building as a conventional or as a high-performance green building, we can expect the decision to be dependent on investment viability. Research shows that initial construction costs for energy-efficient green building are generally higher than for conventional building. The difference can vary from 0% to as much as 20% [1–9]. The variation in investment cost depends on climate conditions, the developer's experience, environmental goals and the designed energy efficiency and is often related to higher material, labor and/or design costs.

On the other hand, the operation costs for a high-performance building are expected to be up to 40%–50% lower than for conventional buildings [9,10], where the predicted cost reduction depends mainly on the energy-efficiency of the building.

Finally, literature brings forward evidence that green buildings transact at 3%–12% higher prices than conventional buildings on the commercial [10–12] and the residential market [13–16,17].

This type of data can be used to calculate the profitability of the investment as is done in [9]. However, the reliability of an analysis depends on the accuracy of its assumptions. The literature has indicated a gap between the recorded and calculated maintenance and operation costs of green buildings (e.g., [18,19]). Moreover, the outcomes of the analysis have also proved to be highly sensitive to the expected rate of return [20–22] and presumed energy prices [23,24].

In this paper, we *first* show that these calculations can be misleading if they do not take into account that the choice of building with higher energy efficiency, e.g., a passive house, can reduce the saleable floor area. Thus, if the external measurements of the building are fixed, a building with thicker walls will entail less saleable floor area. *Secondly*, we show that technological development in recent years has reduced this loss and that this has contributed to the profitability of energy efficient buildings. This is shown by comparing technologies and prices from 2002 with those from 2012.

Specifications that facilitate energy-efficiency gains include compact construction, minimum thermal bridge value, a very well thermally insulated building envelope, energy-efficient windows and adequate choice of heating and ventilation systems [25,26]. For highly energy-efficient buildings, it is essential that the building envelope is airtight and very well insulated. The latter may have significant impact on the width of the external walls, roof and foundation. Consequently, external walls in energy-efficient buildings may require more floor area than those in conventional buildings. In the case of the scenario described above, where the external measurements of a building are fixed or limited, construction of an energy-efficient building has a direct effect on the amount of saleable floor area and consequently on the developer's potential income from rent or sale. Therefore, analyses that compare energy-efficient and conventional building projects should factor in the total floor area that is available for sale or rent. A significant difference in floor area availability may have an effect on potential income, but also on the potential customer segment. As far as the authors know, no earlier studies have quantified gains and loss related to saleable floor spaces in these buildings.

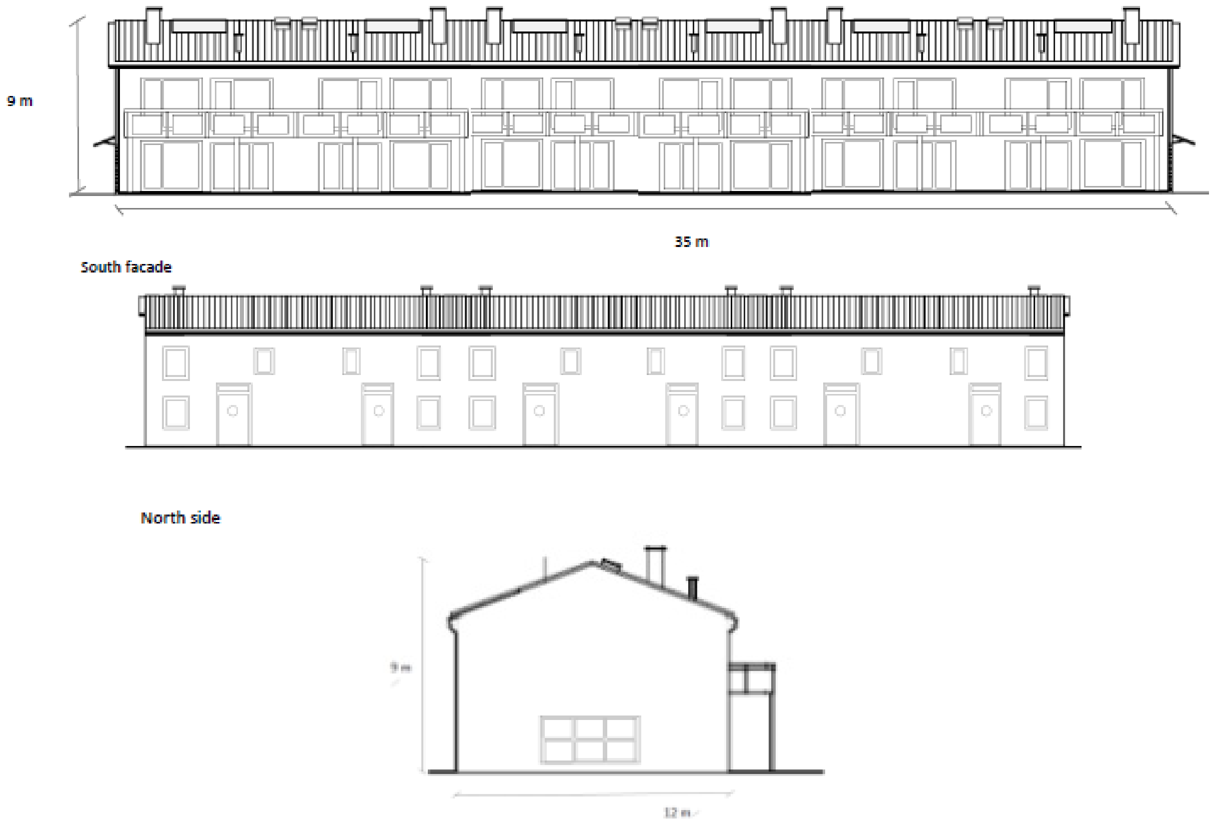
This paper contributes to the discussion on the profitability of energy-efficient solutions in green buildings [9,10,27,28] by investigating the possible impact of introducing more energy-efficient products on the economic attractiveness and profitability of constructing highly energy-efficient buildings.

2. Assumptions and Analysis

2.1. Modeled Buildings

The investigation started by modeling a building that was a typical terraced house in Northern Europe. The building consists of six dwellings, each of them two-level apartments, with total external measurements of approximately 12 m × 35 m (for details, see drawings in Figure 1 below). Initially, this building is based on drawings and information about the first passive house built in Sweden.

Figure 1. The model house.



Two building construction types are analyzed:

(A) A timber wall construction;

(B) A lightweight concrete brick wall construction.

For each of these two types of building, conventional and energy-efficient cases are modeled.

The conventional building follows the specified energy requirement in the current Swedish Building Regulations [29] for residential buildings with electrical heating, climate zone south, and therefore it is assumed that the maximum energy requirement (space heating) is 55 kWh/m^2. The basic notation for these is CVN-A (timber) and CVN-B (brick) (see Table 1).

The second building is an energy-efficient building for which the calculated annual space heating is 26 kWh/m^2. A building that fulfils this requirement is considered by current Swedish Building Regulations [29] to be a very low energy building. Additionally, it is assumed that the primary energy requirement inclusive of household electricity for the energy-efficient building is not expected to exceed 110 kW/m^2. During modeling, passive house principles were used [2,30]. The basic notation for these is EE-A (timber) and EE-B (brick) (see Table 1).

Table 1. Cases analyzed in this paper.

Notation	Explanation
CNV-A	conventional building, timber construction, insulation mineral wool, lambda 0.036 W/(mK)
CNV B	conventional building, brick construction, insulation mineral wool, lambda 0.036 W/(mK)
EE-A1	energy-efficient building, timber construction, insulation mineral wool, lambda 0.036 W/(mK)
EE-A2N	new technology, energy-efficient building, timber construction, insulation mineral wool, lambda 0.033 W/(mK)
EE-A3N	new technology, energy-efficient building, timber construction, insulation pir (polyisocyanurate), lambda 0.024 W/(mK)
EE-B1	energy-efficient building, brick construction, insulation mineral wool, lambda 0.036 W/(mK)
EE-B2N	new technology, energy-efficient building, brick construction, insulation mineral wool, lambda 0.033 W/(mK)
EE-B3N	new technology, energy-efficient building, brick construction, insulation pir (polyisocyanurate), lambda 0.024 W/(mK)

In the course of the analysis, the energy-efficient building envelope is adjusted so that these values stay constant. No changes are made in the construction of roof and foundation, for which U-values are U(foundation) = 0.10 W/(m^{2}K) and U(roof) = 0.08 W/(m^{2}K). The airtightness of the building envelope is assumed to be the following for the conventional and the energy efficient building: 0.6 and 0.4 h^{-1}, at +/−50 Pa. It is further assumed possible to use air heating and heat recovery ventilation with an efficiency of 75% in both buildings. It is also assumed that, if necessary, the supplementary electric heating may be used in the buildings. The main assumptions are summarized in Table 2.

The energy-efficient building is modified step by step by applying new technology and using products with low thermal conductivity (described in the paper as lambda). It was essential that all the products used in the modeling were available on the market. Prototypes and early innovations were not considered. The reason for selecting innovative products that had already entered the market was to examine cost and potential benefits of using these products.

The important rule for this exercise was that, regardless of construction type and the novelty of the products, the building had to fulfill specified energy requirements. This premise allows for changes in the envelope (external wall), and consequently the benefits of using more energy-efficient products can be quantified. In the exercise, we have used the PHPP program (The Passive House Planning Package).

Table 2. Basic assumptions.

Assumed requirements	**Conventional building**	**Energy-efficient building**
Building dimensions (external)	12 m × 35 m	12 m × 35 m
Height (to the roof top)	9 m	9 m
Number of apartments	6	6
Number of levels	2	2
Basement	no	no
Annual space heating (kW/m^2) *	55	26
Annual primary energy including household electricity (kW/m^2)	not specified	110
Airtightness (at +/−50 Pa)	0.6 (h^{-1})	0.4 (h^{-1})
U-value (fundament) [$W/(m^2K)$]	0.14	0.10
U-value (roof) [$W/(m^2K)$]	0.14	0.08

Note: * calculated according to guidelines in Swedish Building Regulations.

2.2. Construction Cost

In this stage of the analysis, we calculated the average cost for producing our modeled buildings. All the prices used in the calculations are based on average market prices, which means that no special offers or discounts were considered. A price discount is possible to negotiate, but it is safe to assume that the same discount can be negotiated on all the products and therefore not relevant in the present analysis. The analysis excludes taxes and labor costs. The costs of constructing our model buildings were calculated using construction material prices from 2002/2003 and 2012/2013, as available in Sweden (sources: Sektionsfakta NYB 02/03 and NYB 12/13 [31,32]). All prices from 2002/2003 were adjusted for inflation. The cost assessment of new energy-efficient products was based on prices received from suppliers or sales representatives in 2013.

2.3. Difference in Floor Area

The next step of the analysis aimed at identifying losses and gains of saleable floor area caused by the difference in external wall measurements. The different technological improvements described in this paper may have an impact on energy requirement or on available living space. Considering that the energy requirement in our modeled buildings must be the same, regardless of the technology that has been applied, the building envelope was adjusted and this determines the effect that particular innovations may have on available living area. First, only the impact of different insulations was analyzed—see Table 3—and, secondly, the impact of better windows on possible adjustments to the building envelope was analyzed. In order to simplify the presentation, the second case is reported in Appendix 1–3 only. It is possible that some solutions may involve higher risks regarding such aspects as airtightness guarantee, mold issues or fire safety, and these problems are commented on in the discussion section below.

Table 3. (**a**) Loss in floor area between conventional and energy-efficient building, year 2002. (**b**) Loss in floor area between conventional and energy-efficient building, year 2013.

Year	Type	Loss in floor area building as a whole, m^2	Compared to
(**a**) 2002	EE-A1	−12.8	CVN-A
	EE-B1	−18.4	CVN-B
(**b**) 2013	EE-A1	−12.8	CVN-A
	EE-B1	−13.8	CVN-B

2.4. Appraising Economic Losses and Gains Based on Saleable Floor Area

In order to assess whether the living floor area gains can defray the costs of construction, it was assumed that the developer can sell or rent one square meter of floor area at a given price. Two different price levels are used: p_s1 represents the average price that the developer can sell a dwelling for in midsized cities or in the suburbs of large cities (p_r1—assumed rental fee); p2 represents the average price at which the developer can expect to sell a dwelling located in the city centre in major cities like Stockholm, Goteborg or Malmö (p_r2—assumed rental fee); see Table 4. The prices are based on the current situation but they are applied both for 2002 and 2012 in order not to introduce more aspects than necessary. The role of price changes is commented upon in the discussion. The assessed income losses or gains in relation to difference in saleable living area are presented as a total value, *i.e.*, as a result of multiplying the difference in saleable area and price per square-meter.

Table 4. Assumed selling and renting prices for new residential construction in the city centre and in the suburbs.

Location	Assumed selling and renting prices
Sale price of m^2 in the suburbs (p_s1)	2500 (Euro/m^2)
Sale price of m^2 in the city centre (p_s2)	6000 (Euro/m^2)
Rent price per year of m^2 in the suburbs (p_r1)	100 (Euro/m^2)
Rent price per year of m^2 in the city centre (p_r2)	150 (Euro/m^2)

There are reasons to believe that the square-meter price of an energy-efficient building may be higher than that of a conventional building [16,17,33]; however, for better comparability, the price of one square meter is the same regardless of building type or energy-efficiency level. It is assumed that there is no extra willingness to pay for the energy-efficient building.

3. Study Results and Discussion

It is possible to make calculations for an almost infinite number of cases based on the assumptions above, therefore only the cases that seem most interesting are reported below. Results for cases where we also take into account the effect of window quality are reported in Appendix 1–3 (Tables A1–A5), but they are also included in the discussion.

3.1. *Conventional* versus *Energy-Efficient Building with Standard Products—Difference in Floor Area*

The floor area benefits or losses are presented in the form of difference in total living floor area (m^2) calculated for the whole building. The comparison is made between a conventional building (CNV-A or CVN-B1) and an energy-efficient building with old techniques (EE-A1 and EE-B1). The results are reported in Table 3 below and in Table A1 for different assumptions about windows.

In the case of timber construction, floor area lost to external walls in energy-efficient buildings in 2002 was 12.8 m^2, but for brick construction, the difference was 18.4 m^2 (Table 3a). In the ten-year period, new dimensions of lightweight concrete bricks became available on the market. The greater range of products affected prices and allowed adjustments in brick wall construction. With products available on the market in 2012/2013, we were able to reduce the latter gap to 13.8 m^2 (Table 3b).

3.1.1. The Situation in 2002

3.1.1.1. Timber Houses

Table 5 below reports the cost difference between conventional and energy-efficient timber houses in 2002, indicating that cost difference in construction was approximately 14,000 Euro (as calculated for the whole building, with prices adjusted for inflation to year 2013). The assessed income losses in relation to difference in saleable living area indicate that for the house constructed in the suburbs, where m^2 prices are relatively lower, the anticipated income loss is approximately 32,000 Euro, but the income decrement is even higher in the city centre 76,800 Euro.

Table 5. Cost difference and assessed living area lost between conventional and energy-efficient building constructed in 2002, timber house.

Difference in cost, living floor area and income	**CVN A-EE-A1 2002**
Construction cost difference *	
Cost difference (Euro/m^2 wall section)	−6.56
Cost difference (Euro, total wall construction)	−3,256
Cost difference windows (Euro)	−10,997
Total cost difference (windows + wall) (Euro)	−14,253
Gains/losses in living floor area (m^2)	−12.8
Assessed income losses/gains due to area difference *	
p_s1 = 2,500 Euro/m^2	−32,000
p_s2 = 6,000 Euro/m^2	−76,800
p_r1 = 150 Euro/m^2	−1,920
p_r2 = 100 Euro/m^2	−1,280

Note: * Cost difference and assessed income loss/gains are presented as a total value for a modeled building.

3.1.1.2. Brick Houses

Table 6 below summarizes the result from conventional and energy-efficient brick houses in 2002 and the result shows that, taking into account loss of saleable area, the cost for the energy-efficient building was 110,400 Euro higher in the central location and nearly 46,000 Euro higher in the suburban location.

Table 6. Cost difference and assessed living area lost between conventional and energy-efficient building constructed in 2002, brick house.

Difference in cost, living floor area and income	CVN B-EE-B1 2002
Construction cost difference	
Cost difference (Euro/m^2 wall section)	−26.25
Cost difference (Euro, total wall construction)	−13,025
Cost difference windows (Euro)	−10,997
Total cost difference (windows + wall) (Euro)	−24,022
Gains/losses in living floor area (m^2)	−18.4
Assessed income losses/gains due to area difference	
p_s1 = 2,500 Euro/m^2	−46,000
p_s2 = 6,000 Euro/m^2	−110,400
p_r1 = 150 Euro/m^2	−2,760
p_r2 = 100 Euro/m^2	−1,840

3.1.2. The Situation in 2012

3.1.2.1. Timber Houses

Table 7 below reports a cost difference between conventional and energy-efficient timber houses in 2012 of 5500 Euro, indicating that the construction cost difference are lower than that in 2002. The relative price of the more energy-efficient products had fallen. The optimal envelope for the modeled building in 2002 and in 2012 was the same; therefore, the difference in living floor area between conventional and energy-efficient building was the same (12.8 m^2). Consequently, the result shows that when taking into account loss of saleable area, the cost for the energy-efficient building was 76,800 Euro higher in the central location and 32,000 Euro higher in the suburban location. Results for different assumptions about windows are reported in Tables A2 and A3.

Table 7. Cost difference and assessed living area lost between conventional and energy-efficient building constructed in 2013, timber house.

Difference in cost, living floor area and income	CVN A-EE-A1 2013
Construction cost difference	
Cost difference (Euro/m^2 wall section)	−7.66
Cost difference (Euro, total wall construction)	−3,801
Cost difference windows (Euro)	−1,746
Total cost difference (windows + wall) (Euro)	−5,547
Gains/losses in living floor area (m^2)	−12.8
Assessed income losses/gains due to area difference	
p_s1 = 2,500 Euro/m^2	−32,000
p_s2 = 6,000 Euro/m^2	−76,800
p_r1 = 150 Euro/m^2	−1,920
p_r2 = 100 Euro/m^2	−1,280

3.1.2.2. Brick Houses

The relative costs for the energy-efficient building in 2012 are lower than in 2002 due to greater product availability. Considering cost efficiency and product range, we were able to reduce the gap in saleable living floor area between conventional and energy-efficient building from 18.4 m^2 in 2002 to 13.8 m^2 in 2012. Table 8 below reports the result from conventional and energy-efficient brick houses in 2012 and the result shows that, taking into account loss of saleable area, the cost for the energy-efficient building was 82,800 Euro higher in the central location and 34,500 Euro higher in the suburban location.

Table 8. Cost difference and assessed living area lost between conventional and energy-efficient building constructed in 2013, brick house.

Difference in cost, living floor area and income	CVN B-EE-B1 2012
Construction cost difference	
Cost difference (Euro/m^2 wall section)	−28.98
Cost difference (Euro, total wall construction)	−14,380
Cost difference windows (Euro)	−1,746
Total cost difference (windows + wall) (Euro)	−16,127
Gains/losses in living floor area (m^2)	−13.8
Assessed income losses/gains due to area difference	
p_s1 = 2,500 Euro/m^2	−34,500
p_s2 = 6,000 Euro/m^2	−82,800
p_r1 = 150 Euro/m^2	−2,070
p_r2 = 100 Euro/m^2	−1,380

At this point, it is important to discuss how the initial assumptions could have affected building envelope construction in 2002. First, it was assumed quite strictly that buildings must be airtight, delivering 0.4 h^{-1} at +/−50 Pa. A decade of learning and sharing the experience of energy-efficient building construction resulted in a significant improvement in the airtightness of new buildings in the Nordic countries. Ten years of experience translate into a reduction of labor hours to perform highly accurate work. Secondly, for convenience of analysis, it was assumed that products like tapes, foil or thermal-free bridge connections are available and commonly used. It is possible that the construction cost of an energy-efficient airtight building could have been much higher in 2002 due to the higher cost and lower availability of those products on the market.

3.2. Energy-Efficient Building with New Products—Difference in Floor Area

The floor area benefits or losses are presented in the form of difference in total living floor area (m^2) calculated for the whole building. The comparison is made between a conventional building (CNV-A or CVN-B) and an energy-efficient building with old techniques (EE-A1 and EE-B1), as well as an energy-efficient building with newly developed products (EE-A2N, EE-A3N, EE-B2N, EE-B3N). The results are reported in Table 9 below and in Appendix 2 and 3 for different assumptions about windows.

Table 9. Loss in floor area for different energy-efficient technologies, only changes in wall construction, 2013.

Type	Loss in floor area building as a whole, m^2	Compared to
EE-A1 *	−12.8	CVN-A
EE-A2N	−9.1	CVN-A
EE-A3N	3.9	CVN-A
EE-B1	−13.8	CVN-B
EE-B2N	−9.2	CVN-B
EE-B3N	20.3	CVN-B

Note: * Area loss/gains calculated as a difference in total living area between conventional and energy-efficient building.

3.2.1. Timber Houses

The analysis shows that applying new energy-efficient solutions in the construction helps achieve energy goals and may also be more profitable for the developer. By applying more energy-efficient components in constructing the building envelope, it was possible to adjust external wall width so that the very low space heating level was maintained and the gap in living floor area between conventional and energy-efficient building decreased to approximately 9 m^2 in the case of EE-A2N (insulation at lambda = 0.033). In the case of EE-A3N (insulation at lambda = 0.024), the saleable floor area increase was almost 4 m^2 more than in a conventional building (Table 9).

If account is taken of the gain in saleable area, the energy-efficient building with new products (EE-A3N) can generate 23,700 Euro more income in the central location than the conventional building (Table 10), which is enough to defray the extra cost. The income generated from the gain of saleable area (EE-A3N) in the suburban location was calculated at 9700 Euro (Table 10).

Table 10. Cost difference and assessed living area lost between conventional and energy-efficient building constructed with new product, timber house.

Difference in cost, living floor area and income	CNV A-EE-A2N	CNV A-EE-A3N
Construction cost difference		
Cost difference (Euro/m^2 wall section)	−7.3	−38.5
Cost difference (Euro, total wall construction)	−3,635	−19,084
Cost difference windows (Euro)	−1,746	−1,746
Total cost difference (windows + wall) (Euro)	−5,381	−20,831
Gains/losses in living floor area (m^2)	−9.1	3.9
Assessed income losses/gains due to area difference		
p_s1 = 2,500 Euro/m^2	−22,750	9,750
p_s2 = 6,000 Euro/m^2	−54,600	23,400
p_r1 = 150 Euro/m^2	−1,365	585
p_r2 = 100 Euro/m^2	−910	390

When highly energy-efficient windows were also applied in the buildings, the increase in living floor area was 3.9 m^2 for EE-A2N and 7.4 for EE-A3N more than that in conventional building (CVN-A) (Table A1) and was sufficient to defray the higher cost of highly energy-efficient windows and new insulation in the case of EE-A3N (Table A2, Appendix 2). Taking into account loss of saleable area, the income for the energy-efficient building (EE-A3N) was approximately 44,000 Euro higher in the central location and 18,500 Euro higher in the suburban location (Table A2). The results imply that constructing energy-efficient buildings with highly energy-efficient components may be more attractive than producing conventional buildings.

The analysis shows that using highly energy-efficient new components in the construction of energy-efficient timber houses results in an increase in saleable floor area and is often more profitable (Table 11). Furthermore, according to the results (Tables A2 and A3, Appendix 2), by applying both highly-energy efficient windows and new insulation, a developer can build an energy-efficient instead of a conventional building, which allows more living space to be sold and consequently increases income. This is even before considering potential energy and environmental savings.

Table 11. Cost difference and assessed living area lost between energy-efficient and energy-efficient building constructed with new product, timber house.

Difference in cost, living floor area and income	**EE-A1-EE-A2N**	**EE-A1-EE-A3N**
Construction cost difference		
Cost difference (Euro/m^2 wall section)	0.3	−34.8
Cost difference (Euro, total wall construction)	166	−17,268
Cost difference windows (Euro)	−1,746	−1,7464
Total cost difference (windows + wall) (Euro)	−1,580	−19,014
Gains/losses in living floor area (m^2)	3.7	16.7
Assessed income losses/gains due to area difference		
p_s1 = 2,500 Euro/m^2	9,250	41,750
p_s2 = 6,000 Euro/m^2	22,200	100,200
p_r1 = 150 Euro/m^2	555	2,505
p_r2 = 100 Euro/m^2	370	1,670

3.2.2. Brick Houses

In the case of a brick wall construction, potential saleable floor area increases when highly energy-efficient products are employed in the building envelope construction. Applying the new technological solutions enables the developer to increase income by as much as 50,000 Euro in the suburbs and approx. 121,000 Euro in the city centre (Table 12). Using the new products in energy-efficient building construction increases saleable floor area, which in the case of EE-B2N was 4.6 m^2 and in EE-B3N 34 m^2, compared with energy-efficient building using old technologies (Table 13).

Adopting more energy-efficient windows and new insulation also encouraged favorable changes in light-concrete wall construction. In the case of EE-B3N (light-concrete brick construction with PIR insulation at lambda 0.024), by adopting windows with average U = 0.7 W/(m^{2}K), it was possible to re-design the external wall so that gains in living floor area could defray the additional cost of the new component. The benefit is 30 m^2 greater living floor area compared with a conventional building (Table A3).

Table 12. Cost difference and assessed living area lost between conventional and energy-efficient building constructed with new product, brick house.

Difference in cost, living floor area and income	**CNV B-EE-B2N**	**CNV B-EE-B3N**
Construction cost difference		
Cost difference (Euro/m^2 wall section)	−30.4	−62.1
Cost difference (Euro, total wall construction)	−15,100	−30,802
Cost difference windows (Euro)	−1,746	−1,746
Total cost difference (windows + wall) (Euro)	−16,846	−32,548
Gains/losses in living floor area (m^2)	−9.2	20.3
Assessed income losses/gains due to area difference (Euro)		
p_s1 = 2,500 Euro/m^2	−23,000	50,750
p_s2 = 6,000 Euro/m^2	−55,200	121,800
p_r1 = 150 Euro/m^2	−1,380	3,045
p_r2 = 100 Euro/m^2	−920	2,030

Table 13. Cost difference and assessed living area lost between energy-efficient and energy-efficient building constructed with new product, brick house.

Difference in cost, living floor area and income	**EE-B1-EE-A2N**	**EE-A1-EE-B3N**
Construction cost difference		
Cost difference (Euro/m^2 wall section)	−1.5	−33.1
Cost difference (Euro, total wall construction)	−720	−16,422
Cost difference windows (Euro)	−1,746	−1,746
Total cost difference (windows + wall) (Euro)	−720	−16,422
Gains/losses in living floor area (m^2)	4.6	34.0
Assessed income losses/gains due to area difference (Euro)		
p_s1 = 2,500 Euro/m^2	11,500	85,000
p_s2 = 6,000 Euro/m^2	27,760	204,000
p_r1 = 150 Euro/m^2	690	5,100
p_r2 = 100 Euro/m^2	460	3,400

The advantage of applying new highly energy-efficient components might also be qualitative: for example, more advanced window solutions help to minimize the thermal bridges, which reduces heat loss and the risk of draughts, and consequently delivers better indoor comfort for occupants. However, there are certain risks which should be discussed, for example, risks related to density of insulation material, airtightness of the building envelope and the moisture level of other components used in the construction, particularly organic material like timber. Checking for moisture level is as important as ensuring that the building envelope is airtight. One of the consequences of failure to produce an airtight building is heat loss and therefore an increase in energy consumption; however, sealing a building envelope with a high moisture level may also lead to problems with moisture and even mould. Ensuring that the moisture level in a building construction does not exceed safe parameters is essential for occupants' well-being and a healthy indoor environment.

3.3. Limitations

This paper has shown the effect of employing new technologies on the profitability of producing energy-efficient buildings; however, the analysis has certain limitations. During the investigation, it became clear that the innovative products are still in the prototype phase. Their use and availability on the market is relatively low. The standard energy-efficient products available on the market and used in this exercise as new technology were launched as few as 8–10 years ago. Unfortunately, solutions presented at building fairs or in manufacturers' catalogues were so new that detailed descriptions of the product or prices were sometimes not available. Detailed technical information was obtainable only on request, often directed or re-directed to the manufacturer.

It is unclear what total impact new energy-efficient technologies may have on the environment and peoples' health, as life cycle analysis and toxicity analysis of the presented solutions are outside the scope of this paper, but we hope that future studies will address those issues. Furthermore, the presented results are based on a simulation exercise, where certain assumptions had to be made, for example, regarding building positioning or installation system. It should be pointed out that there are virtually endless design alternatives among which we have presented only a few. The differences in saleable floor gains or losses depend on comparable design alternatives. Finally, prices used in the cost assessment are only based on purchasing material prices; costs of logistics, labor and external works were not considered.

4. Concluding Comments

The intention of this paper was to investigate how new energy-efficient products affect construction cost and profit. As noted in the literature (see extensive literature on economics of energy efficiency, innovation and technological development for example [34–37]), one of the greatest barriers to diffusion and commercialization of new environmental technologies is that benefits are spread out over time (e.g., energy savings) or not observable directly (e.g., environmental impact). It is thus important to demonstrate that implementing new energy-efficient technologies in the construction of buildings can have a more direct effect, which may positively impact on the profitability of highly energy-efficient buildings in the form of saleable floor area.

The impact of potential losses or gains of saleable floor area should be taken into account when comparing investment alternatives: building energy-efficient green dwellings or building conventional ones. The paper shows that constructing energy-efficient buildings and introducing very energy-efficient technologies may be both energy- and cost-effective when compared with conventional buildings. Employing new products in energy-efficient construction allows not only for benefits to be drawn from lower energy consumption during the life cycle of the building, but also from the increase in saleable floor area. This may have a significant effect on investment appraisal, particularly for projects in the city centre and other areas with high prices.

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Conflicts of Interest

The authors declare no conflict of interest.

Appendix 1. Loss in Floor Area in Relation to Windows of Different Quality

The calculations are made in the same way as in the main text. The table below presenting results for EE-A2N, EE-A3N, EE-B2N and EE-B3N include changes in insulation and highly energy-efficient windows. No changes were made to CNV A, CVN B and EE-A1 and EE-A2.

An average energy-efficiency (U) value for windows used in conventional buildings CVN-A and CVN-B was approximately 1.1 W/(m^2K); an average energy-efficiency (U) value for windows used in energy-efficient houses was 0.9 W/(m^2K); In this stage windows of 0.9 W/(m^2K) in cases EE-A2N, EE-A3N, EE-B2N and EE-B3N were replaced with more energy-efficient windows where average U value was 0.7 W/(m^2K). The average energy-efficiency value (U) for EE-A1 and EE-B1 were kept the same, *i.e.*, 0.9 W/(m^2K). The simulation is done only for 2013 construction.

Table A1. Loss in floor area between conventional and energy-efficient building and between energy-efficient building with different technologies, year 2013.

Type	Loss in floor area building as a whole, m^2	Compared to
EE-A1	−12.8	CVN-A
EE-A2N, $U_{windows}$ = 0.7 W/(m^2K)	3.9	CVN-A
EE-A3N, $U_{windows}$ = 0.7 W/(m^2K)	7.4	CVN-A
EE-B1	−13.8	CVN-B
EE-B2N, $U_{windows}$ = 0.7 W/(m^2K)	25.8	CVN-B
EE-B3N, $U_{windows}$ = 0.7 W/(m^2K)	29.5	CVN-B
EE-A2N, $U_{windows}$ = 0.7 W/(m^2K)	16.7	EE-A1
EE-A3N, $U_{windows}$ = 0.7 W/(m^2K)	24.1	EE-A1
EE-B2N, $U_{windows}$ = 0.7 W/(m^2K)	39.6	EE-B1
EE-B3N, $U_{windows}$ = 0.7 W/(m^2K)	43.3	EE-B1

Appendix 2. Results When Taking Window Quality into Account

The Situation in 2002

Highly energy-efficient windows are considered as new products; therefore, simulation could not be performed.

The Situation in 2013

Timber Houses

Table A2. Cost difference and assessed living area lost between conventional and energy-efficient building with new products constructed in 2013, timber house.

Difference in cost, living floor area and income	**CNV A-EE-A2N**	**CNV A-EE-A3N**
Construction cost difference		
Cost difference (Euro/m^2 wall section)	−0.3	−38.5
Cost difference (Euro, total wall construction)	−146	−19,084
Cost difference windows (Euro)	−7,233	−7,233
Total cost difference (windows + wall) (Euro)	−7,380	−26,317
Gains/losses in living floor area (m^2)	3.9	7.4
Assessed income losses/gains due to area difference (Euro)		
p_s1 = 2,500 Euro/m^2	9,750	18,500
p_s2 = 6,000 Euro/m^2	23,400	44,400
p_r1 = 150 Euro/m^2	585	1,110
p_r2 = 100 Euro/m^2	390	740

Brick Houses

Table A3. Cost difference and assessed living area lost between conventional and energy-efficient building constructed in 2013, brick house.

Difference in cost, living floor area and income	**CNV B-EE-B2N**	**CNV B-EE-B3N**
Construction cost difference		
Cost difference (Euro/m^2 wall section)	−4.6	−27.3
Cost difference (Euro, total wall construction)	−2,267	−13,558
Cost difference windows (Euro)	−7,233	−7,233
Total cost difference (windows + wall) (Euro)	−9,500	−20,792
Gains/losses in living floor area (m^2)	25.8	29.5
Assessed income losses/gains due to area difference (Euro)		
p_s1 = 2,500 Euro/m^2	64,500	73,750
p_s2 = 6,000 Euro/m^2	154,800	177,000
p_r1 = 150 Euro/m^2	3,870	4,425
p_r2 = 100 Euro/m^2	2,580	2,950

Appendix 3. Comparison of Energy-Efficient Buildings with Different Technology

Table A4. Cost difference and assessed living area lost between energy-efficient and energy-efficient building constructed with new product, timber house.

Difference in cost, living floor area and income	EE-A1-EE-A2N	EE-A1-EE-A3N
Construction cost difference		
Cost difference (Euro/m^2 wall section)	7.4	−30.8
Cost difference (Euro, total wall construction)	3,654	−15,283
Cost difference windows (Euro)	−7,233	−7,233
Total cost difference (windows + wall) (Euro)	−3,578	−22,516
Gains/losses in living floor area (m^2)	16.7	24.1
Assessed income losses/gains due to area difference (Euro)		
p_s1 = 2,500 Euro/m^2	41,750	60,250
p_s2 = 6,000 Euro/m^2	100,200	144,600
p_r1 = 150 Euro/m^2	2,505	3,615
p_r2 = 100 Euro/m^2	1,670	2,410

Table A5. Cost difference and assessed living area lost between energy-efficient and energy-efficient building constructed with new product, brick house.

Difference in cost, living floor area and income	EE-A1-EE-B2N	EE-A1-EE-B3N
Construction cost difference		
Cost difference (Euro/m^2 wall section)	24.4	1.7
Cost difference (Euro, total wall construction)	12,113	821
Cost difference windows (Euro)	−7,233	−7,233
Total cost difference (windows + wall) (Euro)	4,879	−6,411
Gains/losses in living floor area (m^2)	39.6	43.3
Assessed income losses/gains due to area difference		
p_s1 = 2,500 Euro/m^2	99,000	108,250
p_s2 = 6,000 Euro/m^2	237,600	259,800
p_r1 = 150 Euro/m^2	5,949	6,495
p_r2 = 100 Euro/m^2	3,960	4,330

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