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Article

On Financing of Urban Transition Viewed from the Oresund Area: When the Political Agenda of Urban Transition Meets the Market

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Abstract: The "urban transition" agenda is as a conglomerate of ambitions derived from international policy documents and as applied in the Oresund area. Encompassing locally set goals for (i) climate change mitigation; (ii) energy efficiency; and (iii) human wellbeing in the built environment. Its implementation is largely dependent on private sector joining in, since transitioning the building stock is to be financed by the market. This paper explores strategies to meet this agenda in the Oresund area. A particular focus is on the refurbishment of multi-family housing relative to these set goals. The paper finds meaningful differences between Denmark and Sweden. In general, exceptionally high energy standards come at an additional cost that is likely to be incompatible with rational economic behavior. Furthermore, actions appropriate for one goal are likely to have modest effects on ancillary goals. The paper concludes by suggesting to revisit current strategies in the Oresund area to reflect market constraints and to promote more coherent ways to achieve the set goals.

Keywords: urban transition; CO_2; climate plans; refurbishing; economic sustainability

1. Introduction

The agenda of “urban transition” in the 21st century, as applied here, refers to strategies envisioned to attain goals set for: (i) climate change mitigation; (ii) energy efficiency and more broadly; (iii) human wellbeing in the built environment or “green cities”. The urban transition agenda can thus be viewed as a product derived from the ambitions of international policy documents, e.g., the EU Energy Efficiency Directive [1]. Within this wider context this paper sets out to explore urban transition in Sweden and Denmark with a focus on the built environment, particularly on multi-family housing and their refurbishing. Examples are drawn from both countries, while the policy strategies of the largest cities in the Oresund area, Copenhagen and Malmö, are given special attention. The paper discusses the means used for implementation, the associated investments and the results of major or typical refurbishing projects exemplified by deep renovation of large apartment blocks.

National strategies of urban transition are instituted at different governmental levels through national legislation, building regulations and other policy instruments (such as e.g., tariffs and subsidies), to municipal strategies where explicit targets are set for the level of ambition to strive for, albeit without the targets being binding commitments. Many municipalities have passed such transitional agendas, e.g., in the Oresund region, Copenhagen [2,3], Malmö [4,5] and Ballerup municipality [6]. These policy documents show common ambitions in the region for this agenda. For the built environment, substitution or expansion with new constructions represent a minor share of the total urban development, consequently urban transition policies in addition to addressing standards for new developments focus on the challenges of refurbishing existing buildings and on upgrading urban space to fit the “green city” ambition.

On a city scale, these ambitions imply investments in the existing building stock, infrastructure and supportive city functions in order to reach the self-set targets for lower CO_2 emissions (climate change mitigation), higher energy standards (energy efficiency) and “green cities”. The economic sustainability of energy saving measures within the urban transition agenda cannot easily be isolated from other objectives, due to significant interdependencies. At present it is unclear how these investments are to be distributed among the different stakeholders to meet such broad ambitions. Although investment decisions can be supported by technical calculations of possible energy savings from an economic perspective, other factors influence the long term sustainability from a broader political perspective. Identifying the most cost-effective interventions with respect to specific policy goals depends on the framework conditions for urban transition at the case level, the existing building stock as well as the technical efficiency of available energy solutions, infrastructure and construction technology.

Despite their broad scope, many transformation projects have taken a point of departure in energy policies and on financing a transformation of the built environment through savings made from lowering the energy consumption [7]. Thus, the focus on reducing energy consumption and on increased energy efficiency is not only justified by the role of energy in policies, but also by association on the potential economic savings that may provide a lever for other types of measures and implementing projects of urban transition.

The role of the government *versus* the market is a central policy issue, as upgrading of the building stock is largely to be financed by the market. Hence, achieving the set targets and ambitions will require favorable framework conditions conducive of urban transition through e.g., policy instruments aimed at stimulating the desired market behavior (incentives, removal of barriers, reduced uncertainty, *etc.*). Under market conditions, specific investment decisions will depend on the total economy of a project defined as a function of refurbishing costs *versus* capitalized energy savings' potential, running costs and value development of the concerned property over time.

The paper is structured as follows: The first section looks closer at the policy and goals of urban transition in the Oresund Region. What is the relationship between these goals? Does any goal have precedence over the others? Do Denmark and Sweden share the same points of origin and prerequisites for urban transition? What does the energy consumption look like in the building stock and what sorts of measures are likely to have a larger impact on energy consumption?

The second section provides an overview of the typology of the building stock, market segments and economics of energy refurbishing at project level with insights from specific cases of deep renovations of apartment blocks built prior to 1975 in Sweden and Denmark. What are the essential elements for a profitable total economy? What do the policy targets imply in terms of energy reductions relative to business as usual? What can we learn from projects of refurbishing multifamily housing? The last section summarizes findings on experience of energy refurbishing, the cost of different energy standards and alternative strategies. Various options for financing of refurbishing projects are discussed in respect to project economy as well as the wider outcome of deep renovations for the urban transition agenda. On this basis, the paper provides some concluding observations on the strategies to fulfilling the climate agendas in the Oresund region.

2. Policy Goals of Urban Transition in the Oresund Region

2.1. National Policy Goals and Challenges Related to the Agenda

Justification of large investments in urban transition takes its point of departure in the pertinent questions "transition to what" and "why" as explored by Eames *et al.* [8], who identified different visions of transition to a (1) Smart-Networked City; (2) Self-Reliant City; (3) Compact City; or a (4) Green City. Although the emphasis among these visions differs, they all fit into the broader, but ambiguous goal of sustainability.

The key policy documents in Sweden [9] and Denmark [10] set similar composite goals (The national security aspect of energy supply is not discussed here). In Sweden, the national goal for CO_2 emissions is for a 40% reduction from 1990's value by 2020 and for energy reductions of 20% from 1995's value by 2020 and by 50% by 2050 in the building stock. Several goals are in addition set for human wellbeing in the built environment but none as concise and measurable as the two above.

Agendas at different policy levels may or may not have overlapping objectives. For example, increasing the energy efficiency in buildings can be a means to achieving the fundamental goal of a European low-carbon economy [11,12]. However, if the fundamental goal underpinning urban transition is to lower CO_2 emissions the measure of cost-efficiency would in this case be wholly tied to the expected emission reduction of the investment, which may or may not be significantly correlated with energy consumption in buildings.

The national building and construction regulations [13,14] serve as a key policy instrument. Both the Danish and Swedish standards have been revised significantly for new constructions (for Sweden

20 times in 20 years) in tune with more ambitious policies on energy and resource conservation. For the existing building stock, no binding requirements are issued to initiate renovations, although recommendations are provided through various authority outlets. When buildings are renovated, Danish building regulations [14] set minimum energy standards for the concerned new building components (such as new windows) and for building parts (e.g., roof and attic), in the latter case dependent on a calculated positive economic return on added investments through energy savings.

Despite similarities in how the Danish and Swedish policies target both reductions in CO_2 emissions and energy consumption, they have different points of departure, since the composition of energy sources differ (water, wind, gas, oil, nuclear power, *etc.*) across the Oresund, Table 1. In comparison, the dependency on fossil fuels (oil, gas, coal) is higher in Denmark (78%) than in Sweden (31%) measured in relation to total energy supply for all sectors in 2010.

Table 1. Share of fossil fuel in total energy supply in Sweden, Denmark and EU-27, 2010. Source: Royal Swedish Academy of Sciences (2013) [15].

Country	Total Energy Supply	Percentage of Fossil Fuel	Percentage of Energy Supply as Electricity
Sweden	551 TWh	31%	27%
Denmark		78%	
EU-27	20,400 TWh	76%	16%

Sweden's energy supply benefits from a relatively high share of electricity production (27%) stemming from nuclear and hydro power, which is virtually CO_2 free (97%). Interestingly, the contribution of CO_2 attributable to the Swedish building stock amounts to only about ≈10% of national emissions but about 30% of national energy consumption [16–18]. This suggests a weak correlation between CO_2 emissions and energy consumption in the building stock of about 0.1. The CO_2 emissions from the building stock is further distributed per energy carriers as roughly 50% from district heating, 30% from and fossil fuels about 20% from electricity [16].

The Danish building stock (Heating, ventilation, electricity) accounts for between 30%–40% of the national energy consumption [19], Table 2. Of total energy consumption in 2012 households consumed in total 30.5%, hereof in detached houses 22.4% and households in apartment blocks 8.1%.

Estimates of CO_2 emission stemming from consumptions in households (19.1%) were provided (ibid. p. 39), but no further breakdown showed what share thereof was attributed to CO_2 emissions from the building stock.

Energy reductions in buildings do not only depend on building constructions and energy supply, but varies significantly with behavior of the end users. Aggerholm [20] found individual variations in consumption patterns in the order of 30% in identical semi-detached houses and showed a rebound effect after renovation, so that the realized energy savings can be expected to be lower than technical calculations suggest.

Economic incentives for achieving reductions in energy consumption by end users include energy tariffs that are generally higher in Denmark than in Sweden, see the example of electricity prices in Figure 1 suggesting a larger incentive to reduce consumption in Denmark than in Sweden.

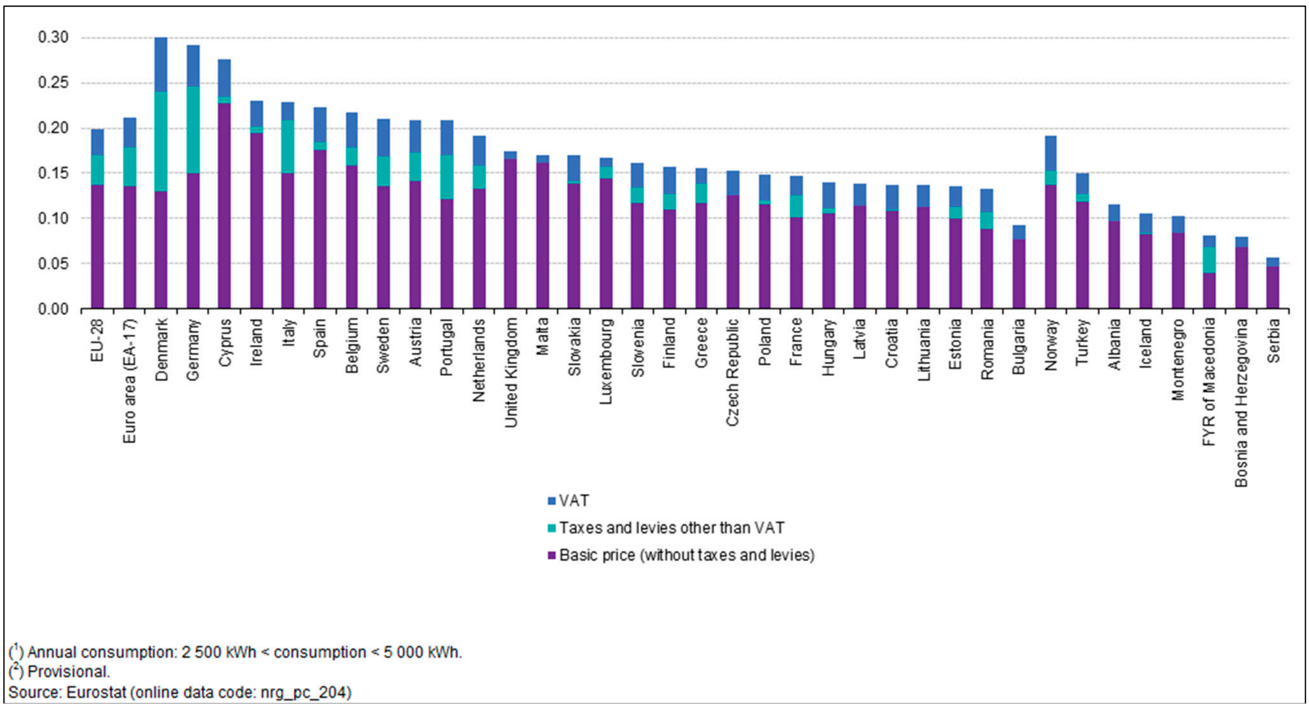
Households' total energy consumption in Denmark has stayed largely constant since 1990 despite an increase in households.

Table 2. Share of electricity and district heating in energy consumption by sector 2010, Denmark. Source: Concito and Energistyrelsen (Danish Energy Agency, 2013) [19].

Share of Electricity and District Heating in Energy Consumption 2010				
Sector	**Electricity in Percent by Sector**	**District Heating in Percent**	**Total in Percent of Total Consumption**	**Total Energy Consumption (TJ)**
Transport	1	0	1	209
Industrial production	28	5	33	138
Commerce & services	45	37	82	85
Single family houses	19	23	42	142
Apartment blocks	19	69	88	50
In total	18	17	35	635

It is concluded that the agenda of urban transition has different points of origin and prerequisites in Denmark and Sweden. For example, in the Swedish case, reducing CO_2 emissions from the built environment is difficult to achieve on the basis of its relatively low contribution to national emissions, especially if the associated cost for measures with which this is to be achieved is higher in the built environment than equivalent reductions in other sectors. Energy refurbishing of the building stock has a larger effect on the CO_2 emission in Denmark than in Sweden, as long as the energy sources are dominated by fossil fuels.

Figure 1. Electricity prices for household consumers, second half 2011 (1) (EUR per kWh)—energy tariffs and taxes make up over 50% of the electricity bill in Denmark. Source: Eurostat (nrg_pc_204) [21].



Both countries merge general climate and energy agendas, and urban transition may incorporate implicit objectives like the broader goal of improving human wellbeing in the built environment. This is further explored below in the case of the climate plans of Copenhagen and Malmö.

2.2. Local Policy Goals and Challenges of Urban Transition

2.2.1. Goals of Urban Transition in Malmö City

In 2009, the city council of Malmö adopted "Environmental Programme for the City of Malmö 2009–2020" [4] and "Energy strategy for Malmö" [5]. Malmö's set ambition, although not legally binding, is to reduce CO_2 emissions by 40% below 1990 levels by 2020 and to reduce total energy consumption per capita by 20% by 2020 relative to the average per capita value of 2001–2005. The Environmental Programme also states ambitions to improve human wellbeing in the built environment although its measurability remains ambiguous.

It is not possible to discern the relative importance of the local building stock in lowering CO_2 emissions. The energy strategy attributes local CO_2 emissions in 2005 solely to: road traffic (36%), other traffic (2%), industry and energy (58%) and machinery and equipment (4%).

Energy consumption in multifamily homes and detached houses, excluding other buildings, represents ≈30% of total energy consumption. The energy strategy estimates the potential for reductions to be between 20%–50% suggesting a full implementation of energy saving measures could lead to a 6%–15% reduction in total energy consumption, a significant contribution to the goal of 20%. However, assuming a correlation of 0.1 with CO_2 emissions this would only have marginal effects on that goal. Furthermore, as no comprehensive quantitative data is available for already undertaken energy efficiency measures in the building stock, the actual scope of the potential for energy reductions may be smaller or larger than the national averages the assumption is based on.

The energy strategy proposes the following actions to achieve the reductions: targeted information campaigns about possible energy efficient measures to property owners, installment of individual energy meters in the municipalities own buildings, training operational staff in energy efficiency and by erecting new buildings with high energy standards. The anticipated effect of the recommended actions is not quantified and no cost estimates are provided.

2.2.2. Goals of Urban Transition in Copenhagen City

The city council of Copenhagen passed an ambitious "Climate plan" in 2009 setting a target for a 20% CO_2-reduction by 2015, a goal achieved in 2011. A new climate plan KBH 2025 reached out for CO_2 neutrality in 2025 [3].

The Copenhagen climate plan KBH 2025 (ibid. p. 10) [3] defined six main areas of intervention for goal achievement, including:

- Conversion from fossil fuels to renewable energy (75% of CO_2 reduction);
- Climate friendly transport system (10% of CO_2 reduction);
- Construction and retrofit of the building stock to reduce energy consumption and increase indoor climate (10% of CO_2 reduction);
- Adaptation of behavior of citizens and companies (4% of CO_2 reduction);

- Development of urban structures that underpin climate adaptation (1% of CO_2 reduction).

Moreover, as a large business entity Copenhagen municipality itself represents 5% of total heating and electricity consumption, so refurbishing of municipal floor space counts both through direct savings and by setting a good example of applying higher targets.

Beyond the overarching goal of CO_2 neutrality, the climate plan targets other subgoals and envisions spin-off effects in terms of better urban quality, public health and of quality of life (ibid., p. 9) [3]. CO_2 reductions (75%) are to be achieved through converting energy production to renewable energy, by lowering energy consumption and through technical solutions such as e.g., heating pumps. The expected contribution to the climate plan of energy savings from construction and retrofit of the building stock is relatively small, 10% (ibid., p. 15) [3].

Considering that the largest share of CO_2 emission in Copenhagen stems from electricity, Table 3, it can be seen that the goals of urban transition have a wider scope than merely reducing energy consumption for heating. Irrespectively, heating is often at the center of attention in building renovation projects, in part since energy cost savings serve as a motivational factor.

Table 3. Contribution of CO_2 by consumption type, Source: Copenhagen climate statistics, Copenhagen municipality and COWI (2010, 2013) [22,23].

Percentage of CO_2 Emissions From	2009	2012
Electricity	49	44
District heating	25	25
Traffic	20	27
Individual heating & gas	2	2
Other	4	2
Total	100	100
Estimated total CO_2 emissions	2,654,129 tons	1,958,886 tons

According to the Copenhagen climate strategy investments in a transition to a CO_2 neutrality are assumed to be a healthy business strategy with expected returns on investments, e.g., on the presumption that investments will pay back through preventing damages and through market spin-offs associated with knowhow that can be exported [3] (pp. 4–5), although it is unclear from the strategy if or how benefits and costs are aligned among market participants, or what is the aggregation level of economic analysis in this respect. A problem of principal-agent arises, if societal goals are to be achieved at private costs.

It is concluded that justification of large investments in refurbishing of the building stock is sought in accordance with the urban transition agenda both in Sweden and Denmark, although the relationship between CO_2 and energy consumption is much stronger in Denmark than in Sweden.

2.3. Macroeconomic Potential of Energy Refurbishing the Building Stock by Building Segment

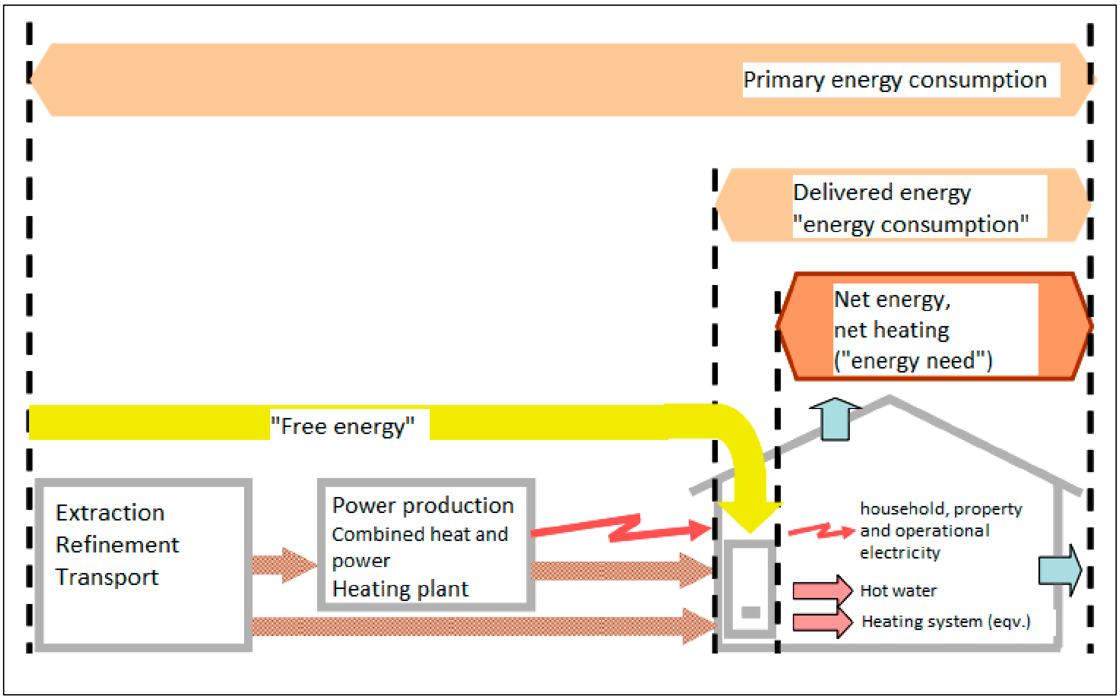
Statistics on energy consumption in buildings and in private households serve as baseline data for calculating the energy saving potential and economics of renovations of the existing building stock, Table 4. Documentation of the economics at project level are available on construction and refurbishing according to new energy standards under different assumptions of technical solutions and performance, energy prices, and interest rates [20,24,25]. In Sweden the building stock represents about 30% of total energy consumption [16]. This energy consumption is broken down per housing type and energy carrier in Table 4.

A descriptive division of the energy consumption can be made by dividing energy need into two distinct categories: heat loss compensation and operational needs, as illustrated in Figure 2.

Table 4. Energy consumption per energy carrier in the Swedish building stock, 2005; Source: Boverket (2010); Mattsson (2010); SCB (2012) [16,17,26].

Energy Consumption in the Swedish Building Stock, 2005	Sqm Floor Space	Percentage of Total Energy Consumption for Buildings	Hereof Percentage of Consumption for Heating and Domestic Hot Water by Energy Carrier			
			District Heating	Electric Heating	Sawdust, Wood, Pellets	Other Sources
Detached housing	301 million m^2	45%	16%	45%	35%	4%
Multifamily housing	238 million m^2	30%	93%	4%	-	3%
Commercial and public buildings	128 million m^2	25%	83%	10%	-	7%

Figure 2. Components of energy consumption and heat loss; Source: Boverket, 2010 (adapted to English) [16].



The building envelope is where the largest energy losses occur and household electricity is where the operational needs are largest, followed by hot water. On average the largest heat losses occur from exterior walls and windows, see Table 5. [16,17] has calculated energy loss and consumption related to the national building stock, while still accounting for the heterogeneity of the building stock in terms of construction year, typology *etc.*

Table 5. Energy needs in buildings [16].

Approximate Energy Needs	Detached Housing	Multifamily Housing
Heat loss compensation		
Building envelope	61%	44%
Air circulation	14%	25%
Operational needs		
Domestic hot water	8%	10%
Household electricity	15%	18%
Fans/pumps	2%	3%

Since this is technical data, it is presumed here to be indicative of the relative energy loss in Danish buildings, as well, although the claim cannot be substantiated. The aggregated energy saving potential in respect to the national energy accounts is significantly larger in detached houses than in apartment buildings both in Denmark and Sweden.

Total energy consumption by Danish households represented 30.5% of total energy consumption in 2012, and 22.4% of total energy was consumed by households in detached houses. Household energy consumption was predominantly used for heating (81.9%, 2012), while 16.5% was used for electrical devises [19]. Thus, about 25% of total energy consumption in Denmark in 2011 was used for heating of private homes (18% detached housing and 7% multifamily housing).

Summing up, the potential energy savings are likely to be larger on average when renovating the building envelope, particularly with measures targeting exterior walls and windows. This potential is likely to be more significant on average for detached houses relative to multifamily housing.

3. Typology of the Building Stock, Market Segments and Economics of Refurbishing

3.1. The Economics of Refurbishing

Experience with energy savings in the built environment has accumulated following the first oil crisis in the 1970s and the more recent focus on climate and energy policies. New building standards and energy savings' technology has matured through numerous refurbishing projects. Wide application, particularly by municipal housing companies, of technologies combined with statistics on the resulting savings open the door for evidence based assessment of the economics of refurbishing at project level. Similarities are found between Denmark and Sweden at a technical level, so experiences in refurbishing can potentially be shared and compared. For this purpose, the typology of the building stock classified by construction year and by segment (Detached housing, apartment blocks, commercial buildings, *etc.*) serves as indicators of the need for energy renovations.

3.1.1. Total Economy of Refurbishing

At project level the key to profitability is a favorable "*total economy*", *i.e.*, an assessment of investment costs, energy consumption and running costs over the lifetime of the building in due consideration of the lifecycle of the construction components. Calculating net present value in an assessment of "total economy" permits comparison of scenarios of investments, where on one side initial investment costs are higher, but maintenance, running costs and energy consumption are lower.

Overall assessments of the economic returns on individual projects also depend on expected value development in the property market, although this is not an independent parameter from the lifetime and running cost components of total economy calculations. On the other hand, property market value may reflect qualitative improvements of the building stock and its environment beyond total economy calculations. Property value is therefore an important and sensitive indicator in monitoring softer policy goals of urban transition.

Access to financing depends on the collateral value of the property, either as assessed market value or by imputed income calculations relative to the investment horizon. This means that in case of commercial properties a higher net profit from reduction in business running costs will result in higher assessed asset value. In this manner, a positive total economy of a given renovation project could potentially increase access to real credit.

Prolonging the lifetime of buildings and improving energy standards are generally impacting positively on market value, as confirmed by statistical analysis of EMO-certificates and sales prices [27]. However, the relation is not simple, since other aspects are strong determinants of property market value (location, style, *etc.*). Market preferences may cause properties to lose market value irrespective of their higher energy standards.

Functional improvements can provide good economy in the short run, the so called "low hanging fruits". Limited improvements like insulation of the attic, low energy lamps and upgrading of some technical installations (boilers, e.g.,) that have a short period of return on investments, are usually "low hanging fruits". Similarly, continuous savings by optimizing facility management, controlling room temperatures, and by prudent user behavior belong in this category.

Awareness campaigns to improve energy saving behavior complement the economic incentive structure of energy tariffs and subsidies for refurbishing works.

3.1.2. Costs of Reducing Energy Consumption in Swedish Building Stock

In Sweden, the building stock comprises 2.1 million buildings of which 165,000 are multifamily housing, 1.89 million are detached housing and 47,000 are commercial and public buildings [16], see Table 6. Boverket [16] provides a cost estimate for reducing energy consumption in the building stock by 50% in 2050, relative to 1995. By implementing technically feasible energy saving measures in the most cost-effective order, the cost expressed as net present value would be about 217 billion €, excluding transaction costs [18]. The results were based on a calculation period of 40 years; costs calculated as annuities of investment and maintenance costs in 2009 prices. The marginal cost curves clearly illustrate the law of diminishing returns [28], see Figure 3.

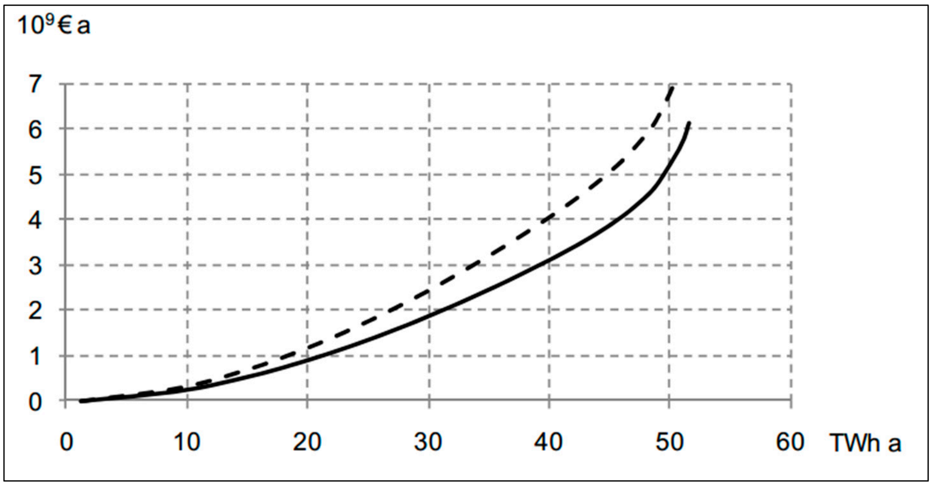
The estimated cost for *residential housing* (detached and multifamily housing) was about 371 €/m^2 and about 132 €/m^2 for commercial and public buildings. Prerequisites for favorable total economy should on average be greater in commercial and public buildings.

A collaborative study by Boverket and the Swedish Energy Agency (2013) [12] suggest that gradual energy upgrades added to regular maintenance and renovations cycles together with current incentives will yield energy reductions of 26%–40% by 2050. On total economy, the study concludes that profitability will ultimately depend on assumptions about discount rates, returns, economic lifespan, whether the property owner is located in a strong or weak market and on the calculation method included and used for projections. This conclusion is similar to other findings [29–32].

Table 6. Building stock typology in Sweden, Source: Boverket (2010); [16,17].

Building Stock by Construction Year, Sweden	Detached Housing–Number of Buildings in Thousands (%)	Multifamily Housing–Number of Buildings in Thousands (%)	Detached Housing–Heated Floor Area/Million m² (%)	Multifamily Housing–Heated Floor Area/Million m² (%)
–1960	846 (45%)	77 (47%)	146 (48%)	99 (41%)
1961–1975	500 (26%)	32 (20%)	82 (27%)	76 (32%)
1976–1985	313 (17%)	12 (7%)	44 (15%)	14 (6%)
1986–1995	154 (8%)	31 (19%)	19 (6%)	38 (16%)
1996–2005	77 (4%)	12 (7%)	11 (4%)	11 (5%)
Total	1888 (100%)	165 (100%)	301 (100%)	238 (100%)

Figure 3. The solid curve shows the reduction of energy demand per annum (x-axis) and the cost for material and labour, in billion € per annum (y-axis) for residential buildings left, and commercial and public buildings right. The dashed curve signifies that the total cost for the building owner is higher. From: Mattsson (2010) [18] (Figures 1 and 2).



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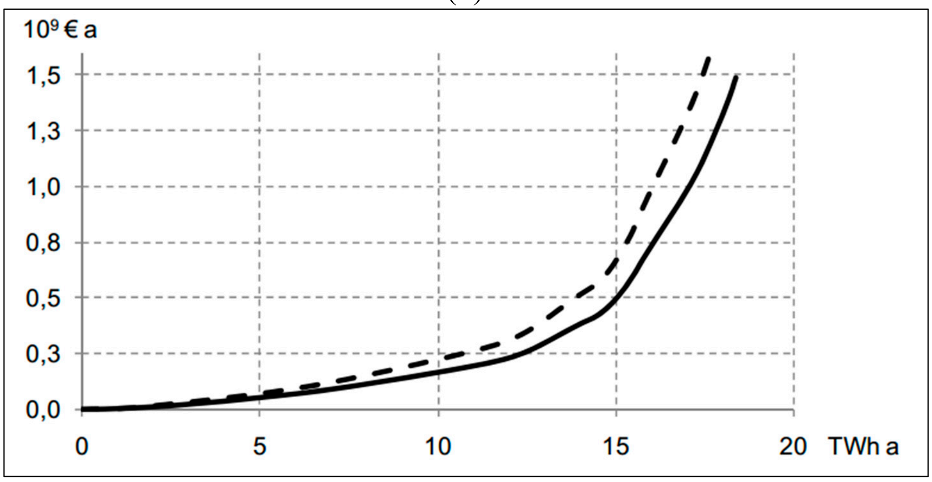


(**b**)

3.1.3. Energy Refurbishing and Building Maintenance

The Danish building stock includes 2.52 million buildings (of which 1.4 million detached houses and summer houses) with a total floor area of 716 million m^2. The building topology has been mapped out and estimates made of potential energy savings in different sectors [33–35].

The building stock built before 1930 accounts for 22% of the total heated floor space, and is expected to be renovated towards the end of the normal lifecycle of building components. Buildings built during 1961–1972 represent 21% of heated floor space, a segment generally representing poor energy standards [32] (Figure 6, p. 19).

Previous estimates of total costs of energy refurbishing by Aggerholm (2009) [24] amounted to 150–900 dkk/sqms (2009 prices) by use of optimal technical solutions, equivalent to between 21.000 and 126.000 dkk for a standard house of 140 sqm. These estimates are below realized costs of extensive renovations, but are here assumed to cover replacement of certain building components and works such as insulation of the attic. New research [32] focuses on net-energy savings potential and investments required for energy refurbishing the building stock gradually during regular maintenance cycles over the years until 2050, up to valid construction standards at the time of renovation.

Scenarios show the different effects of performing maintenance of the building envelope as usual following the future standards set by the Danish building and construction regulations (BR), Energistyrelsen (2014) [14], or further upgrading of the energy standards. The energy savings by 2050 relative to the 2011 level range from 29.2% (business as usual) to 41.1% [32] (Tabel 3, p. 10).

Table 7 shows that interventions beyond the normal renovation and lifecycle investments with a baseline savings potential of 60.845 TJ/year in 2050 are delivering between 4% and 40% further reductions in expected energy savings, the latter only in case of tightened regulations on ventilation and heat recycling (A.4). Scenario A.1 + A.2 + A.3 is delivering an estimated 11.7% added annual reduction by 2050 at the accumulated additional cost of 16.7 billion dkk. The highest potential in increasing energy savings beyond the regular standards could be generated by installing mechanical air-conditioners with heat recycling (Table 7, option A.4), but improvements come at the cost of a higher up-front investment and affect electricity consumption. Thus, the study shows limited marginal benefits of applying higher energy standards than the standards already defined, at high marginal costs. The higher standards will be successively implemented as buildings are renovated anyway according to [32] (p. 7), with the exception of some 20% of the buildings for a variety of reasons.

Aggerholm [20] analysed the cost optimality of the energy requirements in the Danish Building Regulations 2010 in respect to new buildings and to existing buildings undergoing major renovation. The costs and macroeconomic effects of upgrading to different energy standards were calculated under a range of defined assumptions on energy price development, interest rates, *etc.* While some energy standards turned out to be economically justifiable on the given assumptions, other energy standards were not so. The law of diminishing returns on investments also applies in the case of energy standards in Denmark.

Below the renovation and refurbishing costs are further discussed in relation to specific building segments and cases.

Table 7. Calculated net savings in energy for heating, and total investments in 2050 relative to year 2011 and to scenario A (Ad-hoc replacement of building components). From Wittchen & Kragh (2013) [32] (Tabel 3, p. 10).

Scenarios		Savings in 2050 Rel. to 2011		Savings Rel. to Scenario A		Investment Until 2050 Rel. to A
		TJ/year	**%**	**TJ/year**	**%**	**Million dkk**
A	Business as usual	60.845	29.2	-	-	-
B	Full BR10	67.981	32.7	7.136	11.7	16.406
A.1	Higher standards—roofs	61.471	29.5	626	1.0	5.818
A.2	Higher standards—outer walls	62.546	30.0	1.701	2.8	10.589
A.3	Higher standards—when changing windows	60.845	29.2	0	0,0	248
A.4	Ventilation with VGV	83.271	40.0	22.425	36.9	111.621
A.5	Solar heating	66.559	32.0	5.714	9.4	19.409
A.6	Extended life cycle +25%	60.520	29.1	−325	−0.5	−1.602
A.7	All roofs insolated to 2050 standard	62.964	30.2	2.119	3.5	8.547
	Combined A1, A2, A3	63.172	30.3	2.326	3.8	16.654
	Combined A1, A2, A3 and A4	85.597	41.1	24.752	40.7	128.275

3.1.4. Deep Renovations of Apartment Buildings of the 1960s and 1970s Exemplified

In Sweden, there were 650,000 apartments constructed during 1961–1975, 40% of these are owned by municipal housing companies [29]. The buildings are associated with socio-economic weak tenants and slum lords who neglect maintenance needs [36]. This particular context is arguably highly suited for the policy goal of improving human well-being in the built environment.

Estimates of needed investments in 200,000 of these apartments *excluding* energy efficiency measures are between 70–98 billion SEK (8–11 billion €) or some 5000–7000 SEK/m^2 (570–790 €/m^2) [37].

Social housing in Denmark comprising in total 477,306 apartments (all typologies) was in 2006 estimated in need of investments of about 160 billion dkk accumulated over a 20 year cycle [33] (pp. 22–23 and p. 100), but estimates differ [25].

EXAMPLE Brogården, Alingsås, Sweden

Costs of deep renovations are illustrated with an example of 300 apartments in 16 housing blocks built 1971–1973 [31]. The buildings belonged to a municipal housing company who decided to undertake deep renovations as a demonstration project to show that is was possible to meet ambitious energy standards. The buildings are located in an attractive location. Calculated renovation costs were 750,000 SEK/apartment (85,000 €/apartment) equivalent to 10,700 SEK/m^2 (1200 €/m^2) [37], Table 8. Renovations began in 2008 and are running until 2014.

When comparing calculations of the costs with the available figures it is obvious the calculations were overly optimistic as current figures suggest nearly a doubling of costs. In terms of energy savings, the 60% reduction is impressive but fails a cost-benefit analysis. Energy savings of 200 SEK/m^2 is trivial compared to energy refurbishing costs 5600 SEK/m^2. For the energy investments to be profitable within a 50 year calculation period, unlikely assumptions about energy price increases of 4% over inflation per year is needed. Under this assumption, the energy investments will show positive returns after about 48 years [31]. Rent levels on the other hand will increase as a result of the extensive renovation by on average 40%, motivated by the improved living standards, Table 8.

Table 8. Brogården renovation of 300 apartments or 19,500 m^2 2008–2012. Source: ÅF Infrastructure (2012) [31].

Energy Consumption		**Reduction**		**Renovation Costs**		
2008	**2012**	**Reduction 2008–2012**	**Saved Energy Costs/Year**	**Total Costs**	**Costs SEK/sqm**	**Costs SEK/Apartment**
216 kWh/m^2/year	86 kWh/m^2/ year	60%		386 million SEK or 44 million €	19,800 SEK/m^2 (2250 €/m^2)	1.28 million SEK (145,000 €)
Energy savings					Hereof costs for energy retrofit	
			200 SEK/sqm (23 €/m^2)		5600 SEK/m^2 (630 €/m^2)	370,000 SEK(42,000 €)

EXAMPLE Gårdsten, Gothenburg, Sweden

Taking a different approach, the municipal housing company Gårdstensbostäder undertook extensive renovations of 255 apartments in 10 buildings built in 1969–1972 [31]. The renovations were executed in 1998–2000. Gårdenstensbostäder uses balanced scorecards in decisions about their properties [38]. These scorecards include considerations for the well-being of their current tenants. Although, achieving energy savings was a concern [39] it was not the main objective with the renovations. Careful considerations of costs and a limited, fixed budget for energy efficiency measures was applied, and a policy of only carrying out maintenance and exchanging components where the technical lifespan would justify it were all imposed on the renovations [31].

Table 9. Gårdsten Renovation of 255 Apartments or 18,700 m^2, 1998–2000. Source: ÅF Infrastructure (2012) [31].

Energy Consumption		**Reduction**		**Renovation Costs**		
1998	**2000**	**Reduction 1998–2000**	**Saved Energy Costs/Year**	**Total costs**	**Costs SEK/sqm**	**Costs SEK /apartment**
274 kWh/m^2	164 kWh/m^2	Approx. 40%		105 million SEK (nearly 12 million €)	5615 SEK/m^2 (638 €/m^2)	412,000 SEK (47 000 €)
Energy savings					Hereof costs for energy retrofit	
			53 SEK/m^2 (6 €/m^2)		1070 SEK/m^2 (120 €/m^2)	78,500 SEK

Under the assumption of no energy price increases over inflation, the energy efficiency measures show positive results after 14 years [31] (Table 9). An interesting measure with which to compare these two examples is the cost per reduced kWh. For Brogården, this cost amounts to 47 SEK/kWh (5.3 €/kWh) and for Gårdsten 8 SEK/kWh (1 €/kWh). In Gårdsten, rent levels were increased by an average of 7% after the renovations.

Empirical studies seem to suggest that positive socio-economic benefits arose from the Gårdsten renovation and that they have been sustained over time, the most significant being lower criminality and higher employment rates in the tenant population [40,41]. A 2009 study suggests the willingness to undertake deep renovations, in particular with high energy ambitions, is significantly larger in municipal housing companies relative to private housing companies [29]. The study argues that this suggests such renovations are simply not economically profitable.

EXAMPLE Langkærparken, Tilst, Denmark

Costs of deep renovations are illustrated by an example of a large scale deep renovation of in total 860 apartments in 35 housing blocks in 3-storeys built 1969–1971 with prefabricated concrete elements, "Langkærparken" located in Tilst close by Aarhus, Denmark. An innovation project was at first implemented in one of the 35 standard housing blocks comprising 22 apartments in 2010–2011, and the performance of the pilot project before and after was monitored systematically October 2011 to September 2012 [42], Table 10.

Table 10. Key information on renovation of Langkærparken, Tilst, Denmark. Pilot project and full scale renovation.

Langkærparken, Tilst, Aarhus municipality, Denmark
- Owner: Boligselskabet al2bolig.
- Construction: 35 Apartment (3-storey) blocks in concrete, built 1969–1971 comprising:
- In total 860 apartments (1–5 rooms) and 73.227 sqm rental area.
Costs of Pilotproject, "Klimablokken" 2010-2011:
- Pilot project conducted in one apartment block "Climate block",
- 22 lejligheder, 2736 m^2 floor area retrofit to best energy standard (LEK 2020)
- Total costs*: dkk 30 million, (materials and works only, excluding consultancy costs) of which estimated 15 million were needed for maintenance and modernization.
- Total costs per sqm: dkk 10.965 (approximately the costs of constructing a new building).
Costs of Full scale renovation of 34 apartment blocks, 2013–
- 4 blocks to Low Energy Class 2015, (LEK 2015).
- 30 blocks to Low Energy Class BR10 (LEK 2010).
- In total 70.491 sqm.
- Total costs *: 514 million dkk.
- Total costs per sqm: 7.292 dkk.

Source: AL2BOLIG, 2012, * Total costs for intermediate rehousing of tenants represented about 2½% of total costs (Ibid. p. 17) [42].

A new tender process provided refurbishing costs for upgrading to different energy standards. On this basis the design of the refurbishing of the remaining 34 housing blocks was adjusted and initiated in 2013. Based on the lowest of six bids, calculations were made on the costs and profitability of refurbishing standards [43].

Table 11 shows investments and the years to reach a break-even point for the extra investment in raising the refurbishing standard from the minimum (BR08) to Low Energy class 2010, and the additional years to reach break-even for the investment in further upgrading to higher energy standards. According to this example, it takes about 33 years to recover the extra costs through energy savings, when upgrading from BR08 to LEK 2, an additional 36 years from LEK 2 to LEK 1, and finally +14 years to reach the highest energy class, LEK 0, under the assumptions stated.

Table 11. Total costs of deep renovations excluding consultancy costs, Langkærparken, Tilst, Denmark, and calculated number of years to reach profitability of the investment in energy refurbishing to different standards through energy savings under assumptions ("*Simpel*": Repayment time calculated without interests on mortgage or increased energy prices; "*7% and 4%*" Repayment time with a 4% annual increase in energy prices and an annual financing cost of 7%). Sources: From Heiselberg (2010) [43], and AL2Bolig (2012) [42] (p. 23).

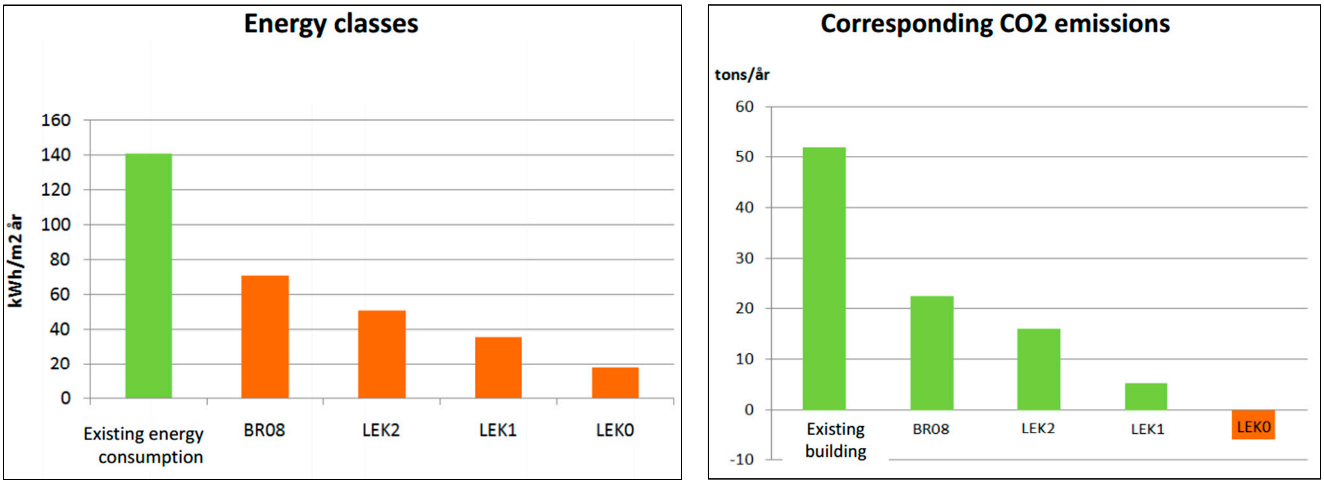
Langkærparken, Tilst, Århus, Denmark, Deep Refurbishing 2010-			**Total Investments (Incl. Qualitative Improvements) by Energy Standard**				**Investments Required for One Step Higher Energy Standard**			
Profitability of Investments Through Energy Savings	**Energy Savings**		**Investment**		**Years to Reach Profitability**		**Investment**		**Extra Years to Reach Break Even**	
	Dkk/sqm	**Kg CO^2/sqm**	**Dkk**	**Dkk/sqm**	**Simpel**	**7% and 4% ***	**1000 Dkk**	**Dkk/sqm**	**Simpel**	**7% and 4% ***
Building standard: As is, App. 140 kWh/m^2 year	0	0								
BR08 ref	46	8								
BR08 (required) App. 70 kWh/m^2 year	50	9	24,803,246	8.568	172	86				
Low Energy Class 2 LEK2010, App. 50 kWh/m^2 year	65	12	26,341,046	9.099	140	79	531	183	35	33
Low Energy Class 1, LEK2015, App. 35 kWh/m^2 year	74	15	27,432,626	9.476	129	77	908	313	38	36
Low Energy Class 0 LEK2020, App. 18 kWh/m^2 year	86	18	29,428,750	10.162	118	72	850	293	16	14

The refurbishing costs per apartment in the pilot project, energy class 0, reached a staggering 1.36 million DKK/apartment (The costs included rehousing costs during some months of the construction), rendering construction of a similar new building a more economical solution. The pilot project costs were 5 million dkk above energy retrofit to actual standard energy class, "BR 2008", and it was found that the investment to the best energy standard could not be recovered through energy savings and higher rent (subject to a regulatory ceiling). The remaining 34 apartment blocks were renovated to a lower energy class (30 blocks to LEK2 and four blocks to LEK1) leaving open the option of later upgrading to LEK0. The total costs of renovation and modernization of the 30 apartment blocks (544 million dkk) were equivalent to dkk 7429 per sqm (Euro 1000/sqm).

The rent was raised following the renovation (max 680 dkk/sqm excluding utilities), but Danish house rent legislation prohibits full cost recovery over the rent and the project remained economically dependent on annual subsidies [42] (p. 9).

In conclusion, the pilot project of "climate" refurbishing an apartment block was found not to be economically feasible, even in a long term scenario with possible significant increases in energy prices. The final report recommended not to upgrade the remaining apartment blocks to the highest energy standard [42] (pp. 5, 36). Extensive renovations are complex both technically and organizationally, and there is mounting evidence that energy savings cannot finance extensive renovation costs even within a very long investment horizon. As regards to savings in CO_2 emissions, the highest marginal effect can generally be achieved when upgrading existing buildings to current minimum standards for new constructions, Figure 4.

Figure 4. Danish energy standards of buildings and corresponding CO_2 emissions, From: Rasmussen (2009) [44].



(**a**) (**b**)

3.1.5. Targeted Renovations Rather than Full Refurbishing?

Targeted or limited energy saving interventions and utility management may provide favorable returns on investment over shorter time spans, as shown by Aggerholm [20] and evidenced by examples of ESCO/EPC projects conducted in the municipal building stock in Sweden and Denmark [45].

In the first phase of an ESCO/EPC project, comprehensive energy screening of the building is made to identify savings potential and possible interventions. On this basis, contractors design targeted solutions for implementation in phase two. In the third phase, the contractor takes on the responsibility for energy performance and facility management during the agreed duration in cooperation with the clients' technical team.

In Sweden, the average contract period is 10 years and average cost recovery takes 10–12 years [46]. The municipal sector is the predominant client. ESCO/EPC contracts come at a cost, and not all renovation projects are suited for this kind of contractual setup. The duration of the ESCO/EPC contracts is evidence of the time taken to recover investments and suggests a reliance of the contracts on reaping low-hanging fruits.

4. Summary and Discussion

Ambitious urban transition agendas are currently being applied to the highly complex reality that is the built environment. The ambitions for lower CO_2 emissions, better energy standards and improvements of well-being in the built environment are obviously well intentioned but will inevitably come with associated costs.

In Sweden, the built environment consumes a third of national energy, but to extrapolate this energy consumption onto national CO_2 emissions is to make an incorrect inference as only about one tenth of national CO_2 emissions can be attributed to the built environment. In Denmark the correlation between energy consumption and CO_2 emissions is higher and accordingly a larger magnitude of the effects on both goals can be assumed if energy efficiency measures are pursued, but CO_2 emissions from buildings are not measured in the national energy accounts.

However, if national CO_2 emissions are to be lowered with contributions from increased energy efficiency in the built environment, it is crucial to know the relative contribution from the sector. If the correlation is low, like in the Swedish case, even the most ambitious energy efficiency targets will not more than marginally lower CO_2 emissions.

The economic sustainability of energy saving measures within the urban transition agenda cannot easily be isolated from other objectives, due to significant interdependencies. Although investment decisions can be supported by technical calculations of possible energy savings, other factors influence the long term sustainability. Higher energy standards of buildings shift the focus to lifestyle and consumer behavior. Total economy is then hinged on consumption, while property value development will be impacted by market preferences, both factors that are rather difficult to control or predict over the longer term.

Exceptionally high energy standards come at an additional cost that is likely to be incompatible with rational economic behavior. In locations where land and property prices are low, refurbishing costs of deep renovations cannot be expected to be outweighed by a higher property value. The study suggests that for energy efficiency, to turn the strategy of refurbishing upside down by seeing to regular maintenance cycles in the building stock as a lever for energy renovations.

In general, energy savings from measures to increase energy efficiency can only marginally finance the costs of deep renovations. The degree of cost recovery through energy savings depends on the initial energy standard. Marginal costs of renovation increase non-linearly with higher energy standards in full accordance with the law of diminishing returns [28,47].

Including third parties such as in ESCO/EPC contracts can be a way to put energy savings and better facility management in focus. In particular, ESCO/EPC includes an initial evaluation of the proportionality of the energy savings potential that can inform reasonable reduction levels to be attempted.

The case for deep renovations and energy savings depends in particular on building quality and character. Detached housing and commercial buildings represent a larger potential than apartment blocks in energy savings through refurbishing in both Denmark and Sweden. Even if renovation costs cannot be recuperated over a reasonable time by energy savings, better space economy and other socio-economic benefits may render particular projects feasible.

Deep renovations, especially in areas where substandard living conditions are present, offer salient opportunities to improve human well-being in the built environment. However, further efforts should be made to define measurements of relative changes in this dimension. Two implicit and distinct strategies can promote this goal:

(1) improvements with the existing tenant population as the reference point, where the target is to increase their well-being (as in the example of Gårdsten) or;
(2) improvements with the existing buildings as the reference point, where the target is independent of the existing tenant population's well-being and efforts are instead made to increase the well-being of (subsequent) tenants who can afford the associated rent hike after the renovations (Brogården).

Locality and market attractiveness of concerned buildings are likely two important parameters that can inform the choice of appropriate strategy.

On the side of the market, the financial crisis may have served urban transition well by effectively ceasing quick property investments. Instead, the crisis has increased the focus in the construction industry and mortgage banks on renovation. Moreover, a low property market means higher attention to viable and competitive projects in due consideration of market preferences.

This may in turn have a mitigating effect on (overly) ambitious policy goals. Arbitrary deadlines such as 2020, 2025 or 2050 for meeting specific targets may have been determined largely uniform by economic rationality or technologic feasibility. Closer attention to costs as well as benefits, as implied by a somewhat reticent market, may well prove to be beneficial for all, when the next round of goals and their associated deadlines are to be set.

Profitability in terms of total economy will ultimately depend on assumptions about discount rates, returns, economic lifespan, whether the property owner is located in a strong or weak market and on the calculation method included and used for the projections. In general, the longer time horizon needed for cost recovery, the higher sensitivity to uncertainty and risks of unforeseen changes in the basic assumptions, e.g., concerning technical solutions, prices and market preferences.

5. Conclusions

Both Denmark and Sweden have adopted ambitious urban transition agendas, as in Copenhagen and Malmö. Upgrading the building stock is seen as a necessity for a transition to lower CO_2 emissions, higher energy standards and better well-being in the built environment. Financing is not specified in the climate plans, and investments are assumed to be absorbed within general government budgets and by the market *i.e.*, carried as private costs. For this reason, financial sustainability becomes a pivotal issue. What matters at the specific project level for financing decisions are calculations of total economy of the intervention, including running costs, rent and expected asset appreciation of the concerned property.

Reducing energy consumption in the built environment is not the same as reducing CO_2 emissions or for that matter improving urban quality, public health and quality of life. These are three different goals and cannot be assumed to be satisfactorily addressed by measures designed to achieve improvements in only one of the three. As the correlation is low between the goals, it is argued that measures or actions claimed to address them all call for a reevaluation according to the expected effect on each separate goal. In the case of deep renovations in Sweden, significant increases in rent for areas populated by socio-economically challenged tenants may follow the renovations, hence generating adverse distributional effects not transparently accounted for in current climate plans.

It is evident that for energy efficiency measures, the target set needs to be informed by the state of the building and the current energy consumption. The increasing marginal costs of energy reductions are highly significant and cannot be overlooked or considered irrelevant for target setting. On average, high ambitions for energy reductions is likely to be more appropriate for housing with relatively high energy consumption, as the marginal cost of reducing the energy consumption will be significantly lower than for housing with average or low energy consumption. Including third parties as with ESCO/EPC contracting may help identifying appropriate ambition levels.

In Sweden, reducing energy consumption in the built environment is not an effective way to lower CO_2 emissions as the sector represents only about 10% of national emissions. To reach the target of CO_2 emissions cost-effectively, measures aimed at lowering emissions from larger contributors should first be exhausted before more marginal contributions are to be considered.

In conclusion, evidence from both Denmark and Sweden suggests that the costs of higher energy standards dwarf the energy savings potential in apartment blocks, and different studies show that extensive energy refurbishing is generally not economically feasible but may be made more so if incorporated into regular maintenance cycles or conducted within a broader context which may justify the investment. Moreover, costs of extensive renovation of apartment blocks are disproportionate to the expected limited reduction in CO_2 emission resulting from the intervention in both Sweden and Denmark. Accumulated experience with energy refurbishing projects points towards a need to revisit the strategies of climate and energy plans currently being implemented in the Oresund region in this regard.

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Author one and author two equally contributed to the ideas and joint sections of the paper, while the case material from Denmark and Sweden were prepared by author one and two respectively.

Conflicts of Interest

The authors declare no conflicts of interest.

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