Energy efficiency inside out

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Abstract
This research study applies a multi-disciplinary approach for analysing the relationships between energy supply, energy efficiency measures and indoor environment. Stakeholder interviews and a review of existing literature reveal that residents only occasionally are involved, and energy companies are rarely consulted when property owners are implementing energy efficiency strategies and measures in residential buildings. Neither the added value to indoor environment nor the impact on district heating production is properly understood when planning and implementing energy efficiency improvements.

The intuitive conclusion for district heating production is that energy savings captured during the winter season are more attractive, as winter savings lead to a lower demand during peak. This is often but not always true, as the impact from energy savings will differ based on the heat production profile of the system. District heating systems based on biomass are likely to be affected differently by energy-efficiency measures than district heating systems with waste heat as base load. Electricity generation in combined heat and power production (CHP) plants also affects the environmental and financial outcome.

Stakeholder participation can create synergies. With greater commitment to implementing energy-efficiency strategies in the residential building sector, energy utilities can support their customers to choose and implement measures that benefit residents, property owners and the company at the same time. The incentives for property owners include lower energy bills and environmentally adapted heating, and the incentives for the utilities are lower costs, reduced emissions and more satisfied customers.

Introduction
The Swedish energy-efficiency goals are ambitious. Energy consumption in the building stock should be cut by 20 percent until 2020 and by 50 percent until 2050 in comparison to 1995. Large scale energy efficiency improvements will have implications for both the energy and the housing sectors. The linkages between energy supply, energy-efficiency measures and indoor environment are complex, and knowledge on these relationships is limited. Previous research concerns the relationship either between energy-efficiency measures and energy supply or between energy-efficiency measures and indoor environments. The purpose of this recently carried out research was to apply a multi-disciplinary approach for studying the relationships in the whole chain between energy supply, energy-efficiency measures and indoor environment.

This research involved case studies of three Swedish municipalities – Östersund, Uppsala and Helsingborg. The municipalities are mid-size with 60,000–200,000 inhabitants, and district heating is the dominating choice of heating supply in the multi-family residential buildings. In addition, a significant part of the housing stock has been constructed between 1965 and 1975, and these buildings are currently in need of renovation. In order to learn more from past experiences of energy-efficiency projects, interviews were conducted with representatives of property owners of multifamily residential buildings. Interviews were carried out with both owners of rental housing

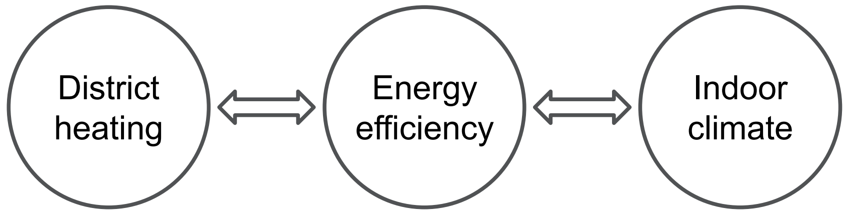

Figure 1. Connections throughout the chain analysed in the study.

and representatives of housing co-operatives. The interviews included questions on the choice of energy-efficiency measures, impacts on energy demand, consequences for indoor environments and stakeholder involvement.

The quantitative analysis was based on Sweden's energy-efficiency goal for residential buildings 2020, which can be achieved through packages of various energy-efficiency measures. For the three case study systems, the analysis assumed theoretical energy-efficiency packages that would have distinctly different impacts on the district heating production. As a basis of the calculations, production data for 2015 were kindly provided by the district heating utilities from each case study municipality.

The framework of analysis

THEORETICAL MODEL OF A DISTRICT HEATING SYSTEM

The impact on the district heating systems from energy efficiency measures was assessed using heat load duration diagrams. The duration diagram represents the annual heat load organized in a falling order from the peak hour to the lowest production period. The vertical axis measures the capacity requirement in a system in MW, see Figure 2.

The studied energy-efficiency measures result in a lower heating demand, which in turn influences supply and reduces capacity requirement. The changes in demand following from the energy-efficiency improvements can be evenly distributed throughout the year, or they can be skewed towards energy savings during the summer or winter seasons, see Figure 3. Measures with larger impact during winter than summer mainly concern insulation. Measures influencing domestic hot water supply in multifamily buildings result in an evenly distributed reduction of annual energy demand. Installation of solar panels will, on the other hand, reduce district heating demand during summer time.

APPRAISAL OF IMPACTS ON INDOOR ENVIRONMENTS

The appraisal of the energy-efficiency measures' impacts on indoor environment quality was based on the Swedish environmental certification system, "Miljöbyggnad 2.2" launched by the Sweden Green Building Council[1]. This certification system was chosen for the purpose of analysis as it is used widely within the Swedish construction sector. Miljöbyggnad 2.2 includes a set of nine quality indicators, which characterize different aspects of the indoor environment quality.

The nitrogen-oxide indicator was omitted in the analysis since no clear cause-effect relationship between district heating supply, energy-efficiency measures and indoor environment quality was found. One reason for this is that residential buildings generally are located at some distance from the district heating plant in Sweden. This makes claims about potentially decreasing levels of indoor nitrogen oxide emissions with declining district heating production inadequate. The remaining eight Miljöbyggnad indicators used in the appraisals are:

- Indoor acoustics
- Radon
- Ventilation
- Humidity control
- Legionella
- Thermal indoor climate wintertime (Winter)
- Thermal indoor climate summertime (Summer)
- Daylight

The impact of energy-efficiency measures on indoor environment quality was assessed qualitatively by using a four level scale (-, 0, +, ++). The initial five point scale was abandoned, since it proved to be difficult to make a distinction between large negative and small negative impacts. An additional difficulty was that the impact on the indoor indicator will depend on the baseline conditions of the building. Hence the aim of the appraisals was to assess the general cause-effect relationship from energy-efficiency measures on indoor quality. Moreover, energy-efficiency measures were assumed to be carried out in a professional manner. As a support to expert assessments, literature on energy-efficiency improvement measures in multifamily buildings and building type calculations provided guidance. Important input was gathered from the Swedish Energy Agency's networks BeBo and BeLok and a research project called HEFTIG carried out on behalf of the Agency.[2]

1. Sweden Green Building Council, 2014. Miljöbyggnad 2.2. Bedömningskriterier för befintliga byggnader.

2. The BeBo (multifamily property owners) and BeLok (commercial premises) networks aim at reducing energy demand and environmental impacts from the built environment. They carry out energy-efficiency development projects, provide exchange of information and experiences on energy efficiency projects, and have produced calculation methods and general recommendations for energy efficiency renovations. www.bebostad.se, www.belok.se, and Case studies HEFTIG, CIT, WSP and Profu, 2016.

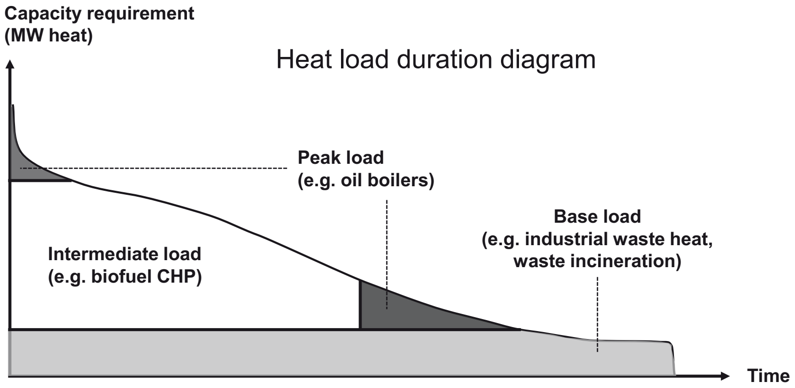

Figure 2. Heat load duration diagram of a typical district heating system with base, intermediate and peak load boilers.

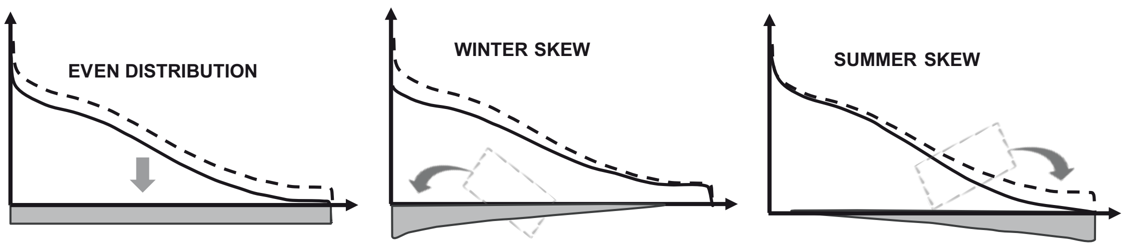

Figure 3. Theoretical outcomes of reductions in heating demand on district heating.

Impacts on the district heating systems

The analysis of the impacts on district heating systems was based on the quantitative 2020 goal for energy efficiency in Sweden. It requires the energy demand per heated floor area to be cut by 20 percent in comparison to the reference year 1995.[3] Calculations based on national data for 2013 in comparison to 1995 showed that approximately 9 percent remains to be achieved if the goal is to be met. Based on this, we assumed that the remaining 9 percent energy savings should be achieved by energy-efficiency measures leading to the same amount in decreased heat supply in the three case study district heating systems, see Table 1.

The district heating system in Östersund, owned by Jämtkraft AB, is almost entirely biomass-based. The system includes a biomass fired combined heat and power plant (CHP) at Lugnvik, which provides the system's main capacity of 110 MW heat (of which 30 MW from flue gas condensation) and three smaller boilers, each with a capacity of 25 MW. In periods with low heating demand, energy is provided from the smaller boilers. When capacity requirement increases, production shifts to the CHP plant. For the coldest periods with peak demand, Jämtkraft's peak load capacity is based on oil.

In Uppsala the district heating system is owned by Vattenfall Värme AB. This system's baseload heating is generated from waste incineration. This is supplied from Uppsala Block 5, a plant with a heat capacity of 75 MW. Peat and biomass make up the intermediate load fuels, partly fired in a CHP plant. Heat pumps support the intermediate load boilers. A new plant is under construction, which will substitute the system's remaining peat with biomass. The Uppsala peak load is based on electricity and oil.

The district heating system in Helsingborg is owned by Öresundskraft AB. This system's baseload is a combination of industrial waste heat and household waste incineration. The waste incineration plant at Filborna co-generates heat and electricity, with a heat capacity of 60 MW. A biomass-fired CHP plant and heat pumps account for the intermediate load, and the peak load is generated in a natural gas boiler.

All three district heating systems in the analysis rely to some degree on co-generation of electricity and heat in CHP plants. Electricity is in most cases generated during periods of intermediate load.

ANALYSIS OF THE DEMAND REDUCTION ON PRODUCTION OF HEAT AND ELECTRICITY

The impacts of energy-efficiency measures vary depending on the production profile of the district heating system, i.e. boiler capacities, load order and fuels consumed in the systems. Three calculations were carried out in each case study. The first assumed that the reduction in demand was evenly distributed throughout the year. The second calculation assumed that the energy savings were skewed towards a larger reduction during the winter time and the third calculation assumed that savings primarily concerned the summer season. The results are shown in Table 2.

3. Governmental proposition 2005/06:145. Definition of floor area excludes e.g. stair well and basement from overall floor area, while electricity for operation of the buildings and energy for hot water production are included, see Energy indicators 2015, Swedish Energy Agency, 2016.

Table 1. Case study district heating systems (2015) and 2020 energy-efficiency goal, GWh.

		Fuel	Boiler	GWh
Östersund	Base load	Biofuel	Heat boilers	
	Intermediate load	Biofuel	Cogeneration	
	Peak load	Oil	Heat boilers	
Goal until 2020				-52
Uppsala	Base load	Waste incineration	Heat boilers	
	Intermediate load	Electricity	Heat pumps	
	Intermediate load	Peat/biomass	Cogeneration	
	Intermediate load	Peat/biomass	Heat boiler	
	Peak load	Electricity and oil	Heat boiler	
Goal until 2020				-143
Helsingborg	Base load	Industrial waste heat	Process heat	
	Base load	Waste incineration	Cogeneration	
	Intermediate load	Biomass	Cogeneration	
	Intermediate load	Electricity	Heat pumps	
	Peak load	Natural gas	Heat boiler	
Goal until 2020				-94

Table 2. Decline in district heating supply by 9 percent as a result of energy savings, GWh per annum.

	Boiler and fuel	Even distribution	Winter skewed	Summer skewed
Östersund	Biomass	18	13	24
	Biomass (CHP)*	43	50	36
	Peak boiler (oil)	1.6	1.9	1.1
	District heating in total	**52**	**52**	**52**
	Electricity in total	**11**	**12**	**9**
Uppsala	Waste incineration	53	6	74
	Heat pumps	9	4	13
	Peat/biomass (CHP)*	50	97	21
	Peat/biomass, heat boiler	47	66	43
	Peak boiler (oil, electricity)	1	3	0
	District heating in total	**143**	**143**	**143**
	Electricity in total	**17**	**33**	**7**
Helsingborg	Industrial heat	0.4	0.0	4.0
	Waste (CHP)*	51.9	14.2	79.1
	Biomass (CHP)*	31.5	66.7	10.4
	Net imports (bio+waste)	15.3	11.7	14.3
	Heat pumps	17.1	26.2	7.9
	Peak (natural gas)	0.3	0.7	0.1
	District heating in total	**94.0**	**94.0**	**94.0**
	Electricity in total	**22**	**26**	**22**

** Fuel use in combined heat and power plants (CHP) include fuel for electricity generation. Hence the district heating does not sum in total.*

Table 3. Assessment of greenhouse gas emission reductions from energy savings with respect to seasonality.

		Even distribution	Winter skewed	Summer skewed
Reduction of CO_{2-e} emissions, (tons CO_{2-e}) (electricity excluded)	Östersund	1,440	1,560	1,290
	Uppsala	28,400	38,500	23,200
	Helsingborg	8,800	6,600	10,000
Critical emission factor of CO_{2-e} (kg/MWh replacement electricity)	Östersund	65<x<89	0<x<65	x>89
	Uppsala	–	0<x594	x>594
	Helsingborg	–	–	x>0

In Östersund, the energy savings goal of 9 percent corresponds to a reduction of 52 GWh district heating per year. Since the oil-fired peak boiler is used primarily during the winter, the impact on the peak production in Östersund would be largest in the case of winter-skewed energy savings. This would be positive both from an environmental and a financial perspective. There would be less need for fossil fuels and the savings would occur during the period when expensive fuels are used in peak production. At the same time, the use of Jämtkraft's CHP capacity would decrease. This would lead to reduced electricity generation.

In Uppsala the simulated energy savings correspond to a reduction of 143 GWh heat supplied in 2020. The use of the peak boiler would decline significantly with winter-skewed savings, while the impact on peak load is negligible for summer-skewed savings. The implications for Vattenfall's base load waste incineration would vary significantly between the winter and summer cases. Waste incineration would decline considerably when assuming evenly distributed savings or a summer-skewed distribution, while a winter-skewed distribution of energy savings has very little effect on the base load. The difference between winter and summer-skewed energy savings would be approximately 70 GWh heat from waste incineration in 2020. In addition, the difference in the loss of electricity production between winter and summer skewed savings would be approximately 25 GWh larger in winter. The environmental impact of the loss in electricity generation depends on how the co-generated electricity would be replaced.

In Helsingborg the 2020 goal of 9 percent reduction would imply savings corresponding to 94 GWh heat in the district heating system. The impact on peak production is not as significant in Helsingborg as in the other two cases. Likewise, the effect on electricity supply of different saving profiles would be relatively small in Helsingborg, since Öresundskraft's two CHP plants cover different periods in the heat load distribution diagram.

ANALYSIS OF THE DEMAND REDUCTION ON GREENHOUSE GAS EMISSIONS

The decrease in fuel consumption has positive implications on greenhouse gas emissions. In order to find the order of magnitude, carbon dioxide emission factors agreed on by the members of the Swedish Heating Market Committee (VMK) 2015 were applied.[4] In Östersund and Uppsala, winter skewed energy savings give rise to larger reductions in greenhouse gas emissions than summer skewed or evenly spread energy savings, see Table 3. This result is particularly clear in Uppsala. In Helsingborg, summer skewed savings lead to the most significant CO_{2e} reductions.

Another important consideration is the trade-off between emission reductions caused by lower heat demand on the one hand, and the loss in electricity generation on the other. It was previously found that the largest loss in electricity occurs with winter skewed savings. This result is significant for Uppsala and less obvious for the two other cases. The outcome of the trade-off will depend on the assumptions about how replacement electricity will be generated. In order to specify the limits, emission factor intervals were calculated for replacement electricity, see Table 3.

When accounting for reduced electricity generation, the outcome of Östersund changes if the emission factor of the replacement electricity exceeds 65 kg CO_2 per MWh. An emission factor between 65 and 89 kg CO_2 per MWh electricity results in evenly distributed energy savings providing the best environmental performance for Östersund. For emission factors above 89 kg CO_2 per MWh electricity, energy savings during the summer season have the best environmental performance. As a comparison, the emission factor of Nordic residual mix was 336 kg CO_2 per MWh[5] in 2015. This suggests that summer skewed savings are rated as the best when replacement electricity is based on the Nordic residual mix.

In Uppsala, the winter skewed energy savings bring about superior environmental performance as long as the emission factor of replacement electricity is below 594 kg CO_2 per MWh, which implies that winter skewed savings are best for Uppsala.

Helsingborg differs from the other two case studies by having the highest greenhouse gas emission cuts with summer skewed energy savings. Since the reduction in electricity generation is lowest when savings occur in the summer season, the emission factor of replacement energy has no influence on the environmental performance.

The intuitive conclusion from the heat production perspective is that energy savings captured during the winter season are more attractive, as they lead to a more even district heating production. This conclusion is often, but not always, valid. The subsequent changes in electricity generation in CHP plants that

4. http://www.svenskfjarrvarme.se/Statistik--Pris/Miljovardering-av-fjarrvarme/ accessed 13.01.2017. The emission factors are based on life-cycle emissions, including energy conversion in the heat plant, production and transportation of fuels.

5. http://www.ei.se/sv/for-energiforetag/el/ursprungsmarkning-av-el/ accessed 13.01.2017.

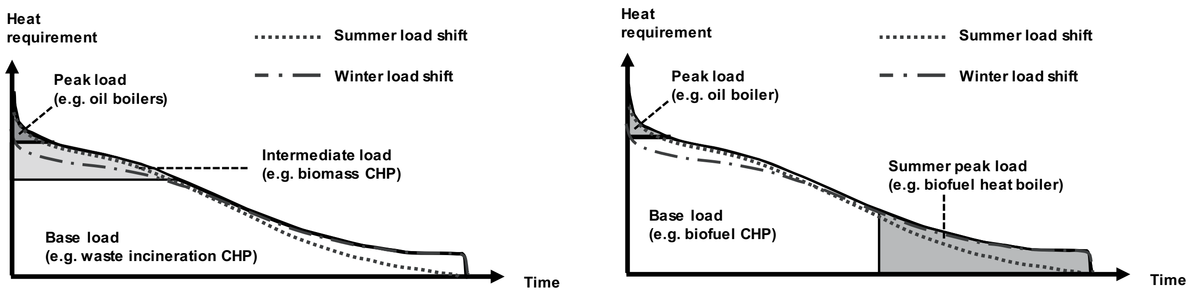

Figure 4. District heating system appropriate to Winter skewed energy savings (left) and a district heating system appropriate to Summer skewed energy savings (right).

follows from reduced heating demand also have an impact on the results. The environmental and financial outcomes depend on how the electricity deficit will be replaced. The case studies show that district heating systems based on biomass, resembling that of Östersund's, are affected differently by energy-efficiency measures than district heating systems where waste heat serves as base load, either in terms of waste incineration as in Uppsala or a combination of industrial waste and waste incineration as in Helsingborg.

In order to generalise the conclusion drawn from the case studies, two hypothetical heat load duration diagrams for district heating systems are illustrated. One of them is appropriate to winter skewed energy savings and the other appropriate to summer skewed energy savings, see Figure 4.

Both systems are assumed to have peak load oil boiler capacity for cold winter days. In the system appropriate to winter skewed energy savings, waste incineration in a co-generation plant provides base load heat and electricity. Since waste is a fuel that cannot be stored, this system would run and secure electricity generation throughout the year. Waste is also a fuel with negative costs, and it makes economic sense for the utility to run the waste incinerator even during periods when most of the produced heat cannot be sold. Intermediate load is supplied from a biomass fired CHP plant.

The district heating system appropriate to summer skewed energy savings uses a large biomass based CHP plant as the main heat source during the colder part of the year. This CHP plant is assumed to have a minimum load capacity, under which it cannot run. Below this level, a biomass based heat boiler provides the heat to the system. The minimum capacity for the CHP plant limits the period when electricity production will be reduced as a result of summer skewed energy-efficiency measures. Reducing the heat demand in the summer will thus result in negligible reduction in electricity generation. Winter skewed energy efficiency measures will, on the other hand, cause significant reductions in electricity generation, as the CHP plant provides most of the heat during the cold winter period.

Energy-efficiency measures

Major energy-efficiency measures are often implemented in multifamily residential buildings when the buildings are undergoing significant renovations. Generally this occurs every 40th to 50th year. The most expansive housing construction period in Sweden was between 1965 and 1975. During this period the housing stock expanded by one million new flats. Today this stock age group corresponds to approximately one third of the total Swedish multi-family residential building stock, and the current age of these buildings imply that a large part of the residential housing stock is in need of renovation.

HOUSING STOCK IN NEED OF RENOVATION

In order to define the relevant housing stock in the three case studies, the number of apartments in need of renovation was calculated based on official national statistics on buildings constructed during the time period 1961–1980.[6] Other studies have shown that approximately 17 percent of the multifamily buildings constructed in 1961–1970 and 11 percent of those built in 1971–1980 have already been renovated.[7] The remaining number makes up the potential for energy-efficiency improvements in these buildings. When defining the 2020 energy-efficiency goal for multifamily residential buildings, it seems reasonable to assume that the 9 percent savings level for multifamily residential buildings should be based on their share of district heating supply. The market share of district heating sales to multifamily houses is approximately 50 percent in the case studies, see Table 4.

In Östersund, for instance, the savings level assigned to multifamily buildings would be approximately 25 GWh by 2020. Based on the task savings level, there are approximately 7,200 flats in need of renovation in Östersund and the neighbouring municipality Krokom, which is supplied with district heating from the same system as Östersund. Without additional energy-efficiency measures, it was assumed that the average energy demand per apartment is approximately 10,000 kWh per year,[8] implying that current aggregated energy demand is approximately 72 GWh per annum. Energy-efficiency measures that reduce the energy demand by 40 percent would be necessary in order to reach assigned savings level. The results for Uppsala and Helsingborg are similar.

Energy-efficiency measures implemented in standard houses from the 1960's and 1970's were studied in a report to the Swedish Energy Agency.[9] Two packages of energy-efficiency

6. Statistics Sweden, Dwellings by region, type of building and period of construction, 2015. Matrix BO0104AB.

7. Fallstudier HEFTIG (Case studies HEFTIG, in Swedish), CIT, WSP and Profu, 2016.

8. Data from the annual housing survey of Statistics Sweden were consulted for the case study municipalities, but data did not imply there are any significant differences in energy use depending on location in Sweden. Source: Statistics Sweden 2016, Energy use per square meter in residential buildings by type and period of construction.

9. Fallstudier HEFTIG (Case studies HEFTIG, in Swedish), CIT, WSP and Profu, 2016.

Table 4. Assignment of savings levels to 2020 to multifamily housing in need of renovation.

	Östersund/ Krokom	Uppsala/ Knivsta	Helsingborg/ Ängelholm
District heat to multifamily housing, share of supply	49 %	47 %	55 %
Total energy-efficiency goal until 2020, GWh/year	52	143	94
Task savings level for multifamily housing, GWh/year	25	67	52
Apartments in buildings in need of renovation	7,200	16,900	15,300
Total energy demand, GWh/year	72	169	153
Energy savings 25 %, GWh/year	18	42	38
Energy savings 40 %, GWh/year	29	68	61

Table 5. Energy-efficiency measures, indoor environment, seasonal distribution and profitability.

Energy-efficiency measure	Impact on indoor environments	Seasonal distribution	Share of 50 percent package	Private profitability to property owner*
Façade insulation	Acoustics (++) Winter (++) Summer (+)	Winter skewed	12 %	High cost.
Attic insulation	Acoustics (+) Winter (+)	Winter skewed	7 %	Profitable.
Window replacement	Acoustics (++) Winter (++) Summer (++) Daylight (-)	Winter skewed	6 %	High cost.
New front doors	Acoustics (+) Winter (+) Summer (+)	Winter skewed	5 %	Profitable
Individual metering and billing of domestic hot water	No impact	Even distribution	5 %	Profitable.
High performance tap water mixers	No impact	Even distribution	6 %	Profitable.
Improved ventilation with heat recovery	Acoustics (-) Radon (+) Ventilation (++) Winter (++) Summer (++)	Winter skewed	35 %	High costs.
Heat load control	Winter (++) Summer (++)	Winter skewed	13 %	Profitable.

** The profitability statements are based on life-cycle cost benefit analysis which rest on simplified assumptions including e.g. current energy prices during the lifetime of the measures.*

measures were put together for multifamily buildings: one with measures that would improve the energy performance by 30 percent and another that would improve the energy performance by 50 percent. Using life cycle costing (LCC), the report shows that the 30 percent package is profitable to the owner of the building and the 50 percent package is close to being profitable. The costing approach assumes constant energy prices during the life time of the energy-efficiency measures. The study also indicates that no single measure is sufficient in achieving the major savings. In order to meet the 2020 goal it will be necessary to implement packages of energy-efficiency measures.

IMPACTS ON INDOOR ENVIRONMENTS

The 50 percent package includes eleven energy-efficiency measures. Eight of them are shown in Table 5. Together they make up about 90 percent of the reduced energy demand of the 50 percent package. LED lighting with occupancy sensors, adjustment of ventilation and heat recovery from domestic hot water are exempted. The eight energy-efficiency measures were appraised according to their impact on indoor environment quality (based on the Swedish environmental certification system Miljöbyggnad 2.2), whether they lead to an evenly distributed or a seasonal energy efficiency improvement and financial profitability to the owner of the building.

The result of the appraisals suggested that most impacts on the indoor environment quality would be positive. In addition to improving indoor thermal comfort wintertime, measures for upgraded insulation of the building envelope and window replacements affect indoor acoustics by reducing noise levels. The energy-efficiency measures would only have few potential negative impacts, including less daylight from energy-efficient windows and more indoor noise from improved ventilation with heat recovery. Another implication is that measures for improved climate shell performance, ventilation with heat recovery and improved heating distribution control measures have the best potential to improve the indoor environment in a cold climate.

A majority of the energy savings measures in the 50 percent package were assessed to have larger impact in cold weather conditions, thus causing a winter skewed reduction of the district heating demand. The assessment also suggests that profitability can be a problem for some energy-efficiency measures, including façade insulation, window replacement and ventilation with heat recovery. High investment costs imply that market prices might not provide sufficient incentives to undertake these energy-efficiency measures. At the same time these measures entail significant positive impacts on indoor environment quality.

CHOICE OF MEASURES IN PAST PROJECTS

Interviewees confirmed the assumption that energy-efficiency improvements generally are undertaken in buildings in need of renovation. High energy costs were also mentioned as a potential motive. There is, however, an important distinction between municipal housing companies and private housing co-operatives in terms of knowledge and motivation. While municipal housing companies have a professional management organisation and most often energy-efficiency or environmental performance targets, interest and experience in energy-efficiency improvements is low in private housing co-operatives. A mere 10–15 percent of the private housing co-operatives are interested in energy-efficiency performance according to one of the representatives of a housing co-operative management association.

In discussions on the choice of measures, the interviewees found it difficult to point out how choices had been made when selecting energy-efficiency measures in past projects. One interviewee, representing a municipal housing company, mentioned that designing the package of measures was the task of the engineering department. Another interviewee reported that their goal is to improve energy performance by 30 percent, but projects covering both climate shell measures and ventilation often perform better. At the same time, architectural design restrictions make up a possible obstacle for changes of the façade, implying some buildings have lower savings potential. Several interviewees brought up ventilation with heat recovery. As disadvantages, they mentioned high investment costs and potential problems to find enough space for ducts in existing buildings. Advantages that were mentioned included significant contribution to energy performance and indoor environment quality improvements. It was also pointed out that these advantages are more pronounced in the north of Sweden than in the south. Several interviewees reported that improvements in heating energy performance had led to increased demand for electricity. The reason is that heat-recovery measures require additional fans and pumps.

In the interviews, the representatives of municipal housing companies reported that energy-efficiency measures are generally not eligible for rent adjustments. In Sweden, rents are set in negotiations between the tenants' association and the property owner (or the property owners association). The base for negotiations is the utility value of the apartment. Rents are to a large degree based on "visible" factors including kitchen and bathroom equipment[10]. For this reason, the costs of energy-efficiency improvements cannot easily be transferred to tenants. In housing co-operatives, on the other hand, there is a direct link between property management costs and the monthly fee the residents pay to the co-operative. Information from interviews implies that residents in private housing co-operatives are sensitive to increases of the level of the fee. Since the fee has an impact on the selling price of an apartment, it is sometimes difficult to back up investment decisions on energy-efficiency improvements. International studies, however, propose that there is not a general lack of interest in energy-efficiency improvements among residents. Research from Switzerland and New Zealand suggest residents are willing to pay higher rents for improvements in energy performance (measures included in the reported choice experiments were façade insulation, ventilation and window replacement).[11] In both studies, replacement of windows is assigned the highest willingness to pay. The authors suggest this could relate to windows being the most visible among the energy-efficiency measures included.

Linkages between district heating and indoor environment quality

Interviews with property company representatives indicate that there are hardly any contacts with energy companies prior to the property owners' investments in major energy-efficiency measures. The interviewees do not seem to consider energy suppliers as potential partners in energy-efficiency projects. Neither do the concerned energy utilities include energy-efficiency consultation in their business model. Incentives provided by local heat prices seem to have potential influence[12], but price information is not in systematic use. Only one interviewee reported that their organisation base investment decisions on current heat tariffs. Lack of transparency in how tariffs are designed is considered to be one reason for not making more use of tariff information. Other interviewees express dissatisfaction with the fact that adjustments of the fixed capacity tariff are set one to three years subsequent to the lower level of energy demand, implying there will be a time gap between implementation and reaping full cost savings from energy-efficiency measures. This dissatisfaction seems to be related to a low level of knowledge of tariff design and structure among property owners.

10. The utility value includes aspects that relate to the standard and modernity of the apartment and its equipment.

11. Phillips, Y. 2012 Landlords versus tenants Information asymmetry and mismatched preferences for home energy efficiency, Energy Policy 45, pp. 112–121. Banfi, S., Farsi, M., Filippini, M., Jakob, M., 2008. Willingness to pay for energy-saving measures in residential buildings. Energy Economics 30, 503–516.

12. All of the three case study utilities charge for heat according to a three part tariff system.

Table 6. Linkages through monetary and non-monetary costs and benefits of energy-efficiency improvements.

	Energy utilities	Property owners	Tenants
Monetary costs	Lower revenues Production costs?	Investment costs Capital costs Higher electricity costs	Adjustment of fee/ rent?
Monetary benefits	Production costs?	Lower heat costs Property value? Adjustment of fee/rent*?	*
Non-monetary costs	Potential decrease in customer loyalty for slow adjustment of heat tariffs	(Lack of knowledge; private housing co-operatives)	
Non-monetary benefits	Customer satisfaction Environmental performance	Environmental performance Less complaints	Indoor environment quality

** Savings from lower heating and hot water bills are reaped by the property owners.*

In order for property owners to make adequate choices of measures, information is also needed about the energy performance and the quality of the indoor environment. Interviews show different levels of ambition concerning the documentation of pre-project energy performance. In some cases, energy performance is well documented, while in other cases only post-project energy performance information has been available. This makes it difficult to draw conclusions on achieved improvements. Furthermore, interviews suggest a large variation in tenant involvement, from no involvement at all in some cases, to extensive participation processes in others. One interviewee, representing a municipal housing company with no tenant involvement, reports that they received fewer complaints after the implementation of the energy-efficiency improvements. Previously many complaints concerned draught. Currently there are no such complaints. However, no interviewee reports use of surveys for detecting the tenant level of satisfaction with indoor environments. Neither were green building certification systems consulted when investments in energy-efficiency measures were implemented.

Table 6 maps the linkages between the various stakeholders by categorising them into monetary and non-monetary costs and benefits. The analysis of the district heating systems showed that as long as winter skewed energy savings only cut the winter peak, energy efficiency improvements will be beneficial. The savings in production costs for energy companies, will cover lower revenues. Moreover, the utilities' environmental performance improves when use of peak load fossil fuels can be cut. Since the environmental performance of heating distribution is valued by certain property owners, this is a potential non-monetary benefit. However, energy utilities are rarely consulted when implementing energy-efficiency strategies and the limited understanding of the implications on the district heating production could influence the outcome differently. The outcome could instead imply revenue losses exceeding savings from production costs. Three part tariffs safeguard to against short time fluctuations, but this tariff design has a negative impact on customer loyalty, i.e. non-monetary costs.

From the energy utility perspective, successful implementation of energy-efficiency packages implies potential cuts in peak load capacity and resumed customer loyalty. In the traditional business model of utilities, where revenue comes from selling kWh of district heating to customers, improved energy efficiency leads to losses for the heat provider. There is thus little incentive for utilities to help their customers to carry out energy-efficiency measures. If the customers are improving their energy performance, encouraged by environmental targets and potential economic benefits, the utilities risk to encounter other losses from not participating in the process. Utilities can take a more active role in ensuring that the implemented energy-efficiency measures have positive effects on their district heating production. This will require them to develop business models that can decouple revenues from sold kWh of heating and focus more on providing energy as a service.

Property owners commonly accept additional investment costs of energy-efficiency improvements when buildings are in need of renovation. The subsequent savings in energy costs, might not balance potential capital costs. Tenants benefit from improved indoor environment quality, but there is little influence on rents. It is possible though, that better indoor quality reach property owners in terms of a non-monetary benefit in terms of fewer complaints and less relocations. In the long run, property owners expect a positive impact on property values, but empirical evidence between property prices and energy performance is weak.[13] In private housing co-operatives there is a connection between the sales price of the apartments and the fee, but this suggests lower levels of energy-efficiency improvements will be accepted.

Conclusions

The impacts of energy-efficiency measures vary, and they will differ between district heating systems. Energy savings captured during the winter season are generally more attractive, as they lead to a more even district heating production. In some systems though, winter skewed savings limit the co-generation of electricity more than summer skewed savings. Furthermore, energy savings captured during the summer season are more attractive

13. Evidence is available for Austria, Belgium and Ireland, see: Sayce, S., Sundberg, A. and Clements, B., 2010, Is sustainability reflected in commercial property prices: an analysis of the evidence base, RICS Research Report, January 2010.

in systems that have boilers dedicated for the low demand period. These circumstances suggest local energy companies should analyse the impacts of energy-efficiency measures on their individual system and act accordingly. In order to influence decisions on measure choices, energy suppliers could, for instance, adjust tariffs or offer consultation services to property owners. Most often energy companies try to provide incentives through tariff design.

Energy-efficiency measures most often lead to winter skewed energy savings and the implications on indoor environment quality are generally positive. As long as winter skewed energy savings only cut the winter peak demand, energy efficiency improvements will benefit all stakeholders. Additional challenges are expected for the energy utilities as the energy-efficiency goals will imply large scale cuts in energy demand.

Besides the impact on district heating demand, energy-efficiency measures have implications on the supply and demand for electricity. Promoting measures that reduce the demand for electricity are particularly important in district heating systems including co-generation capacity to the left in the heat load duration diagram. There are two reasons for this. Firstly significant winter-skewed energy savings imply a loss in electricity supply, and secondly several energy-efficiency measures increase the demand for electricity.

It is important to note that the assessment has been based on a short term analysis in which fixed district heating capacities were assumed. Winter skewed energy savings and decreases in the maximum heat requirement in buildings can have further benefits in the long run. This is valid especially for expansive municipalities. Instead of building new plants, energy utilities will be able to serve and supply district heating to new customers from the existing capacity. District heating and co-generation plants enjoy economies of scale, but in order to overcome inefficiencies this requires long term operation, implying that an aspiration towards winter skewed energy savings in many cases contributes to a cost-effective production in the long run.

Although some communication exists between property owners and energy utilities, there is in general no involvement of the utility when the property owners are carrying out energy-efficiency measures. Due to split incentive structures, increased cooperation will be necessary in order to achieve energy efficiency in a manner which is favourable for several parties. Improved design of the district heating price models can provide better incentives for efficiency improvements, but these models are often complex and can be too difficult for property owners to understand the consequences. Neither is there systematic involvement of tenants by property owners prior to energy-efficiency improvements. The implication of tenants only being occasionally involved is that added value to indoor environment is invisible to the property owners.

Stakeholder participation can create synergies. By participating with a greater commitment to implementing energy-efficiency strategies in the residential building sector, energy utilities can work with their customers to avoid the burden of measures that will have a significant negative impact on district heating system efficiency. Energy utilities can participate in different ways, e.g. by providing their customers with knowledge on the relationships between energy efficiency, indoor environments, and energy demand, or by restructuring company operations to include the implementation of energy-efficiency measures (and thus become true energy service companies, known as ESCO). Another strategy could be to revise the pricing model for district heating to reflect how it affects the profitability today and in the future. The incentives for property owners include lower energy bills and environmentally adapted heating, while the benefits for the utilities are lower costs, reduced greenhouse gas emissions and more satisfied customers, and the residents in general would benefit from e.g. a better indoor environment quality and better health.

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