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Environmental assessment of rebuilding and possible performance improvements effect on a national scale

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Abstract

The paper deals with improvements on environmental significant activities related to the life supporting function "building and housing", using life cycle assessment (LCA). In the calculation, back-casting technique is utilised and implies to a future scenario, based on known technology. Besides heating, waste water treatment is a significant issue, according to the definition of building and housing function practised. The main conclusions from the assessment are that rebuilding is an environmentally better choice than the construction of a new building, if the same essential environmentally related functional performance is reached. Furthermore, the case study and the national estimates performed prove that the potential environmental impact can be reduced by about 70% for the heating service and 75% for the waste water system, if the suggested measures are performed.

Keywords: Ecological sustainable building; Life cycle assessment (LCA); Back-casting; Rebuilding; Multi-dwelling; Energy conservation; Waste water conservation

1. Introduction

In the life cycle of a building, the following major activities can be identified where environmental performance can be assessed: construction of a new building, rebuilding, extension, operation, maintenance, and demolition. It is obvious that most options in the design process to reach best available environmental performance appear for new buildings. However, also the rebuilding of existing buildings has opportunities to improve building environmental performance. It is noticed that rebuilding including maintenance activities represent almost half of the environmental impact in the residential and services sector, see Fig. 1. Since most people live and work etc. in "old" buildings it is of great concern to evaluate what can be done by rebuilding in order to improve the environmental performance, if major market changes shall be carried out. At least on a national perspective, it is therefore more of interest to assess possibilities and limitations associated with the existing building stock, rather than new buildings if a more sustainable building sector shall be established. In Sweden, there is a large amount of apartments from the so called "Million homes program" that were built during the 1960s and 1970s and now are in great need of refurbishment. An ongoing EU project called SUREURO has aimed at rebuilding multi-dwelling houses from this generation since it represents a significant part of the building stock in all Europe and is generally a subject for rebuilding [1].

The aim of this paper is to determine the importance and rebuilding improvement possibilities for multi-dwelling houses in an environmental perspective. Calculations are performed to compare the previous environmental performance of an existing multi-family house with the performance after the rebuilding has

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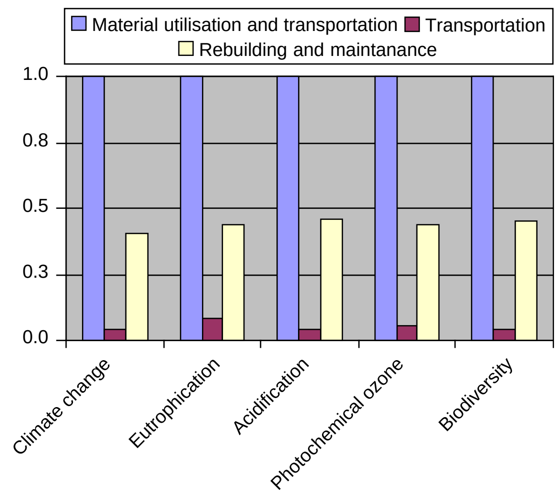

Fig. 1. The environmental contribution from rebuilding and transportation in the residential and services sector in Sweden (1998–1999) [2].

occurred, and to determine the importance of rebuilding activities in general on a national scale, and its potential positive long-term effects if some rebuilding activities will be performed. An existing building located in Stockholm was chosen as it represents a generation of multi-dwelling houses that are frequent objects for rebuilding today. A number of economical realistic possible rebuilding measures, that not only increase the comfort or aesthetic values, without also improving the building (both technical and environmental) performance are defined and evaluated.

The selected rebuilding activities for the single building object will then be enlarged by calculating a scenario where these improvements will be performed on the entire existing multi-dwelling building stock. Esthetical concerns are made in that sense that for older generations of buildings, no major changes of facades are found convenient. In a life cycle perceptive the improvements effect external technical system such as local heating plants, fertilisation of agriculture land and waste handling. All these systems and connected activities will change in the future why different scenarios describing both today's situation and future potential improvements has to be accounted for. Based on statistical information from the Swedish Statistical Central Bureau/SCB [2] the time span for rebuilding has increased from 30 in the 80s to 40 years today, why a rebuilding activity and its overall pay-back was determined to 35 years in this study.

In the present paper, a life cycle assessment (LCA) concept is offered that makes it possible to evaluate different possibilities addressed in rebuilding in general, or more precise in this paper, in order to improve the environmental impact during the utilisation of the building. Traditionally LCA concepts adopted on buildings e.g. [3–7] and case studies [8–11] have applied a *linear building perspective* typically described as

The building are constructed, utilised for its intended purpose for a defined number of years and then finally demolished.

Hence rebuilding and extension is not included in this kind of linear assessment of buildings an alternative approach has to be worked out. The alternative LCA concept offered, introduce a so called *functional unit* that takes a *building and housing service life cycle perspective* oriented approach into account instead. In this approach each included building and housing service accounted for in the building functional units start- and endpoints have to be defined, as described below:

The service life cycle will start to account for all activities that have to be performed so that all materials in necessary amounts and qualities shall be available as required for the specified service. The service will then account for all activities related to the predicted service life.

The service life approach allows analysis of rebuilding or extension as well as a traditional linear scenario that is adequate for new buildings representing the linear building perspective defined above. Focussing on a free number of building services it also apply to a generic LCA framework applicable for buildings and constructions. This framework including a menu of building services and further development will be published in a separate paper.

2. LCA concept for environmental assessment of building and housing services

The word *service* corresponds in this concept to the system that provides something which is needed or asked for e.g. different building facilities, compared to the facilities itself that are optional equipment etc. that then are provided for a particular activity. The function of the system (i.e. functional unit) describes the purpose for which it is used. When analysing buildings it has been found convenient to define a *primary system* that covers the subsystem equal to the *physical building* and secondly the utilisation of and facilities related to it referred to as the subsystem *housing*, Fig. 2. The physical building can be divided in different activities such as construction, maintenance, rebuilding, extension and demolition, while housing can more or less be compared to a continuous process including related activities to both the building and its utilisation such as heating, ventilation, water supply etc. A consequence of this definition of housing is that e.g. tenants transport from the building and other facilities is not included in the housing service, since it is not related to the utilisation of different construction alternative or housing. In other concepts as in the REGENER project this is assumed to be a part of a building service and will then give a

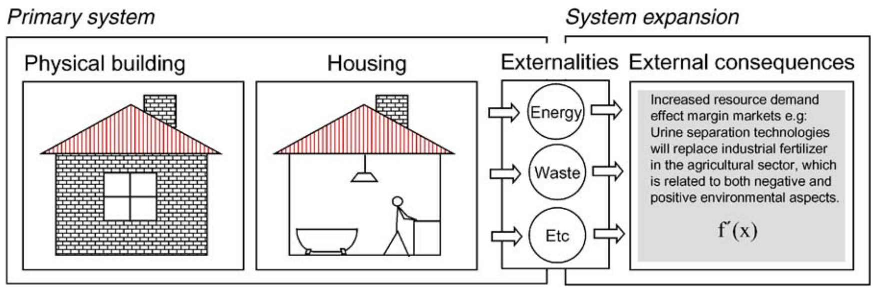

Fig. 2. The conceptual approach utilised to describe the building and housing function, divided in a primary system and an optional system expansion.

significant contribution to the overall impact [4,12]. However, this kind of environmental assessment is preferably considered in urban planning. For both physical building and housing it is possible to define different services that shall be covered in the study. Since different case studies cover different services they are usually not directly comparable. The services all together will then in each case study correspond to the system boundary setting valid for the here called *primary system.* The primary system partly corresponds to the LCA terminology on "foreground system" [13–15], in that sense that the influence of the building design, tenants behaviour and externalities facilities is very central for the overall studied building and housing function. Therefore, as an optional choice for a service related to the primary system, it is always possible to work with the concept of *system expansion* in order to assess external consequences caused by a changed behaviour in the building sector on other systems such as energy or waste water handling. System expansion—in this purpose—is an interesting tool to apply to services that affect the margin market [16]. Also working with system expansion will in this case give additional information on "what will happen if ..." a material or energy flow increases or decreases on the market. Therefore the functional unit for building and housing primarily is divided in primary system and system expansion. Then, included services in these systems also have to be defined in the functional unit.

In this article the physical building address two services/systems, covering the following questions:

1. What is the environmental impact of building construction?
2. What is the environmental impact related to rebuilding in order to also improve energy and water conservation performance during the operation phase?
3. What is the environmental impact related to maintenance?

The housing service in this case study covers the following systems:

1. Heating and ventilation, including electricity need for apartment and household equipment.
2. Water supply and waste water treatment.

Finally, system expansion is utilised for waste water treatment in order to assess what consequences different strategies and technical solutions have when human nutrients (urine and faeces) are used as fertiliser in the agriculture sector.

3. Time dependence

3.1. Energy sector

The Swedish building sector (including housing) represents over 40% of the total energy consumption [17]. When estimating the future energy mix representing the year of 2035, the entire energy sector has to be considered. The outstanding feature valid for electricity and the heat production is the change to more renewable energy sources. Further on, since all renewable energy sources are constrained the future scenario has to begin with estimating the resources available and the final market share. For instance the forestry, the wood resource has to be divided in different end users such as sawn timber, paper production, energy production that lead to the conclusion that wood cannot be used as the only energy source. Instead, the economical and environmental constrains combined with the technically available potential are crucial when the future energy mix shall be estimated. In this paper a number of official future scenarios are utilised as background material when the future energy mix is estimated. The present energy mix and the future scenarios are given in Tables 1 and 2.

3.2. Environmental performance for background processes

When the environmental life cycle inventory (LCI) data for historical environmental impact from the production of the existing building—e.g. in the case study from the 1960s—current LCI data is used instead. This estimation is also valid for data for building material and processes happening in future, e.g.

Table 1
Current Swedish electricity mix and the case scenario valid for 2035 based on three future scenarios from other projects (in TWh)

Electricity production Scenario etc. Notes	Today [18] Mix	Elforsk [19]		CTH [20]		SAME [21]	Future scenario mix
		Technical potential	Utilised potential	Post mat. sc.	Materialistic scenario		
Hydropower	65[a]	130	80	65	65	66	80
Combined district heat and power	5,1	40	30	15	25	14	25
Industrial back pressure power	4,5	8	5	10	15	12	12
Wind power	0,3	25	10	20	25	13	15
Solar cells or thermal solar power	0	—	5	6	6	0	5
Coal condensing power	0,3						
Gas turbines	0,0						
Nuclear power	70[b]						
Sum	*145*	*203*	*130*	*116*	*136*	*105*	*137*
Distribution losses	9,3						8,8
Import (+), export (–)	+7–17	–10 to –14					+10–15
Sum	*145*						*141*

[a]Represent production during the period 1993–98.
[b]Figure represent gross energy. The primary energy use according to UN/ECE is 206 TWh.

Table 2
Current Swedish energy mix and supply of energy sources for heat production 2035 based on three future scenarios from other projects

	Today mix [18](1999)	CTH [20]		SAME [21]	Future scenario mix
		Post mat. Sc.	Materialistic sc.		
Local plants					
Oil	5	—	—	—	0
Wood	4,3	—	—	—	1,7
Sun panels		—	—	—	1,0
Free heat, heat pump		—	—	—	—
(electricity to heat pump)		—	—	—	—
Direct heating	2,0	—	—	—	—
Conversion and distribution losses	1,4	—	—	—	0,3
Sum	*12,7*	—	—	—	*2,0*
District heating					
Wood fuels	14,7	8	14	8,6	11
Black liquor and tall oil	1,6			—	—
Peat	3,1			—	—
Refuse from biological material	6,1			—	5
Refuse from fossil material	—	—	—	—	1
Hydro gas	—	—	2	—	—
Oil	5,5	—	—	6	—
Coal, incl. blast furnace gas	3,4	—	—	—	—
Natural gas	3,3	8	3	30	—
Free heat, heat pump	7,4	19	19	—	7,4
(electricity to heat pump)	(2,3)	(5,9)	(5,9)	—	(2,3)
Electricity for boilers	1,8	—	—	—	—
Sun panels	—	3	3	—	—
Waste heat	3,6	4	8	4	2
Sum	*50,5*	*42,0*	*49,0*	*48,6*	*26,4*
Utilisation of district heat delivery					
Conversion losses	2,7	2,6	3,0	2,8	1,4
Distribution losses	3,9	3,7	4,4	4,1	2,0
Multi family houses	20,9	35,7	41,6	39,1	26,4
Single family houses	4,2				
Other buildings	14				
Industries	4,9				
Sum	50,5	42,0	49,0	46,0	29,8

maintenance. However, for these processes or activities that, to a great extent, are significant for the result, improved LCI data has been used instead, such as for;

- energy production,
- transportation,
- future forestry,
- waste water handling (including the agricultural sector).

Process related figures for the energy sector representing the future have been estimated by the SAME project [21] and best available technology by IVL [22]. These references are then combined with upstream LCI data. In the future scenario diesel is assumed by $\frac{2}{3}$ to be replaced by ethanol. This LCI data, based on background information mainly from a modern plant [23,24], is also used as upstream LCI data in the future forestry. The relation, however, between emission figures from the energy production combined with upstream data valid for the energy carrier is not crucial.

4. Environmental weighting method

Since the purpose of this work is to identify what is small and big, a weighting method is used to aggregate the environmental profile from the LCA and give an internal relation between different impact categories [25]. The weighting method is based on the Swedish quality norms, which is a national instrument in order to reach the sustainable society within a generation. The Swedish Building Eco-Cycle Council (BYKR) in an environmental investigation to identify significant environmental impacts 14001 [26] has adopted the weighting method. The investigation was performed as an environmental investigation according to ISO 14001, partly using LCA. In the work it was noticed that no consensus was reached to use any characterisation factors valid for the impact category resource depletion, human and ecological toxicity. For this matter these impact categories are not implemented in here as well.

The weighting method is based on the same method as utilised by EDIP [27], which in is derived from "distance to target" concept by BUWAL [28]. Compared to the EDIP model using a distance to target approach, the utilised weighting method is based on a political and scientific established belief of what can be regarded as a sustainable acceptable damage for each impact category. Then, as in the EDIP method a normalisation is done which implies to a unit expressed as; *weighted personal equivalents*. The Swedish quality norm is so constituted that all requirements must be fulfilled if the sustainable society shall be reached. In other words this means that a numerical equal value (given in weighted personal equivalents) of increased sulphur emission cannot compensate an emission affecting climate change as long as the quality norms are fulfilled (which is the case). This fact should be in the reader's mind when reading dimension weighting figures. More information about the weighting method and the utilised categorisation factors is found in reference [25].

5. Result from the studied multi-dwelling house—a case study

During the Swedish so-called "Million Homes" programme that took place in the 1960s and 1970s, many similar houses were built, because the focus was on production methods rather than design and adaptation to the landscape. The chosen three-storey house was built in 1966 and includes 24 apartments (average size 81 m^2) and two staircases. The heated floor area of the house is 2112 m^2 above ground and 295 m^2 in the basement.

The house has a typical flat roof design and a partial basement. Access to the apartments is from long balconies on the long North face of the building. It has one of the common designs from the "Million Homes" programme. It is situated in an area with 49 almost identical houses called Östberga, a suburban area of Stockholm.

The concrete load-bearing frame has external insulation of lightweight concrete that holds the stucco facade. One face of the building is shown in Fig. 3.

5.1. Energy use

The community housing authority Svenska Bostäder owns and operates the buildings. The energy use in the buildings is monitored by monthly meter readings of district heating, cold water and electricity to operate the buildings. Examples of energy use for these houses are shown in Table 3.

Fig. 3. Facade of the studied multi-dwelling house.

Table 3
Measured yearly energy use according to Svenska Bostäder's meter readings. The numbers are adjusted to a meteorological reference year (Average for three identical houses including thermal distribution losses between them)

Year	District heating (kWh/m^2)	Electricity for the building (kWh/m^2)
1995	178	
1996	189	
1997	184	
1998	192	14

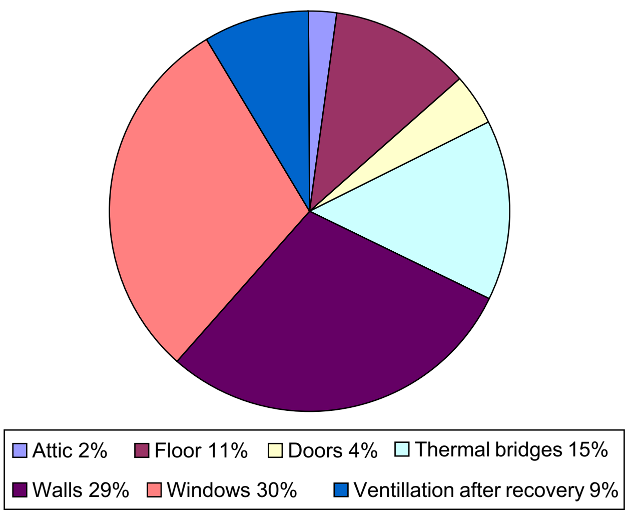

Fig. 4. Conduction and ventilation losses for the examined building, highlighting the relative importance of the two suggested rebuilding measures walls and windows, together with the already performed improvement of the ventilation in Östberga.

The domestic electricity use in the apartments was not available. Svenska Bostäder's, target for the district heating energy use for these houses is 160 kWh/m^2year.

Energy use calculations using the ENORM 1000 computer programme (ver. 1.10) was performed to establish a platform from where saving potentials could be estimated, see Fig. 4. First, the calculations were calibrated to a level corresponding to meter readings of heating energy use. From this level, the saving potentials for different measures were calculated.

5.2. Energy conservation measures

The first wave of energy conservation measures was performed in the 1980s, when additional insulation in attics and heat recovery of the ventilation air was installed. Some of the double-pane windows in bathrooms have been changed in the examined building to triple-pane because of moisture damage to the old windows that were placed too close to the shower. The performed measures limit the alternatives and profitability of the new measures. Measures and savings were calculated as shown in Table 4.

The domestic hot water and electricity uses were entered as default values from ENORM 1000. The thermal bridges disappeared after external insulation was added. The positive effect of reduced air leakage was not considered in these calculations.

5.3. Waste water conservation measures

The rebuilding includes an installation of a urine separation WC in the apartments and local tanks located both in the basement and outdoors. The outdoor tank will keep the urine cool. The tank system is dimensioned for the yearly production of urine and flush water from the building. This means that after the recommended storing time of the urine, it is distributed directly to the farmer. The distance between the building and the agriculture land used in the calculations is 400 km. Faeces and domestic waste water run to a traditional waste water treatment plant.

The nutrients in the urine will be used as fertiliser. Compared to mineral fertilisers, bio availability and emissions vary. Assumptions used in the calculations are given in Table 5.

5.4. Environmental performance

The environmental impact from different activities for the examined multi-family houses is illustrated in Fig. 4, where the environmental impact from the accumulated energy supply (for 35 years) used for heating, ventilation, domestic and electricity use for the building is the overall dominating environmental impact. In rough figures the construction of the building is only one third

Table 4
Calculated total purchased energy use according to results using the ENORM 1000 computer program

	MWh/year	kWh/m^2year
Base case		
Energy supply	522	217[a]
Measures		
20 cm loose-fill insulation on attic floor ($U = 0.13$–0.08)	518	215
12 cm mineral wool + 1.5 cm stucco on external walls ($U = 0.83$–0.24)	395	164
Window replacement ($U = 2.7$–1.0)	450	187
External wall and window replacement as above	329	137
Ventilation air heat recovery ($\eta = 0.5$–0.9)	466	194
All measures as above and 22–21°C indoor temp.	279	116

[a]1. District heating: 156 kWh/m^2year (heating and dom. hot water), Domestic and for the building electricity use: 60 kWh/m^2year.

Table 5
Bio availability, and emission from different nutrients compared to mineral fertiliser, based on [29–33] given as effect or release (bio available) of amount (emission) of 1 weight unit supplied nutrient

	Bio available	Emission to air		Emission to water		Emission to ground
		N_2O	N_2	NH_3	P-tot	NH_3
Phosphorus	0.93	—	—	—	0.07	
Ammonium nitrogen or nitrate nitrogen	0.85	0.0025	0.048	0.096	—	0.054
Phosphorus from urine applied in the soil	1	—	—	—	—	0
Nitrogen from urine applied in the soil	0.95			0.01		0.04

compared to the environmental impact related to the current energy supply. The accumulated water supply and wastewater treatment is entirely dominated by the remaining emission of nutrients to the wastewater treatment plant's water recipient. If the existing building stock is regarded as sank cost (i.e. the historical impact is not relevant today or in the future since it already has happened), it is quite obvious that a potential improvement that reduce the building energy demand and improve the wastewater infrastructure is one of the main interesting building services to find major improvements to. The problem area is—as already described—twofold since improvements can and must be done both on site as in the interlinked infrastructure if a sustainable building sector shall be reached. For the property owner this means that freedom of action often is limited, and sometimes local society regulations give limitations.

One way to illustrate the potential success of the suggested improvements is to calculate the pay pack time, which is given in Fig. 6. In Fig. 6 each impact category is illustrated separately. For all environmental impact categories, the environmental impact, related to rebuilding, is paid back within a 8-year period except for the impact category for biodiversity. The background LCI data in Fig. 6 is based on the current electricity and district heating production environmental performance. If the very same rebuilding instead was performed with the future energy production figures (all other conditions remaining), following pay back time would instead occur; acidification 30, climate change 27, eutrophication 23, photochemical ozone formation 12 respective 4 years for impact category biodiversity. With other words, if the environmental load for energy production reduces, it will lead to an increased pay back time but will still be environmentally profitable and within the rebuilding period estimated to 35 years.

When the total environmental impact from the rebuilding is combined with the accumulated impact from the building energy supply for the future, the relations in rough figures are 1:5 (see Fig. 5). A very changed attitude of the relation of the impact from the building and maintenance of 35 years combined with the future improved building will come about. The environmental importance between the building activity and the future heating will be of the same order of magnitude. Thus, the improvement based on changed construction solutions and material selection will increase in future. A result from the calculation is also that rebuilding in this case study is much better in an environmental perspective compared to a total demolition and then constructing a new building on the same site.

The pay back time concerning the wastewater conservation measure is almost instant. The urine separation system evaluated is an easy way to improve the emissions from the wastewater treatment plant, as illustrated in Fig. 5, but it is at the same time an applicable and efficient way to optimise the nutrient flows in the society. One advantage with urine separation, when used as a fertiliser, is that urine compared to traditional sewage sludge includes less heavy metals and bring about a higher degree of nitrogen recirculation [32]. In fact, in urine concentrations of heavy metals are comparable to the best mineral fertiliser [31]. The disadvantage with urine separation can partly be found in hygienic aspects and the need for a change in personal routines when using a WC. These aspects can, however, be overcome if an adequate storage routine is practised [31]. Urine separation can be an interesting alternative if sewage sludge is not accepted on agriculture land in the future.

In order to examine consequences in the agriculture sector if urine is used as fertiliser and replace mineral based products, a system expansion is introduced. Four scenarios are introduced and described below:

1. Current wastewater treatment plant where phosphorus purification of 97% and nitrogen 73% is present. The sewage sludge is recalculated to 50% and therefore replacing a certain amount of mineral fertiliser.
2. Urine separation is introduced and used to replace mineral fertiliser. No sewage sludge is used in agriculture.
3. As above but 50% of a "nutrient poorer" sludge is recalculated.
4. As above but 100% of the "nutrient poorer" sludge is recalculated.

The changes in environmental impact caused by change in agricultural fertilising methods are given in Table 5.

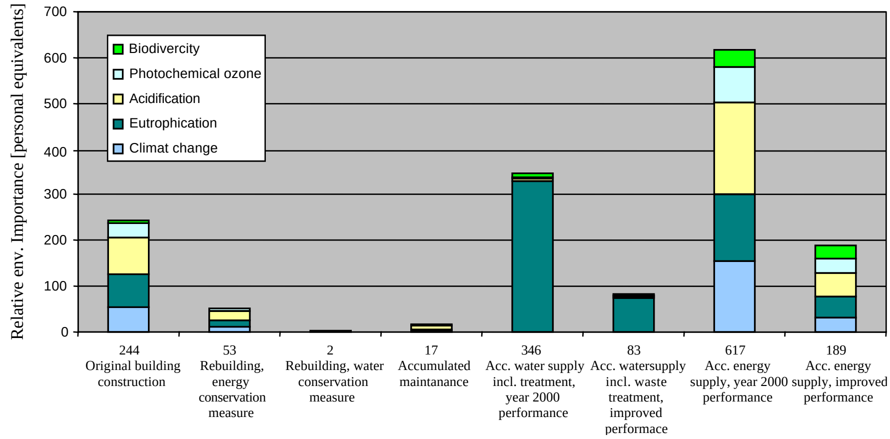

Fig. 5. Environmental impact for the original building construction, rebuilding and different activities from the operation phase including the current performance as well as the improvement valid for the year 2035. The environmental impact is given in the unit, weighted personal equivalents, according to the Swedish environmental quality norm [25].

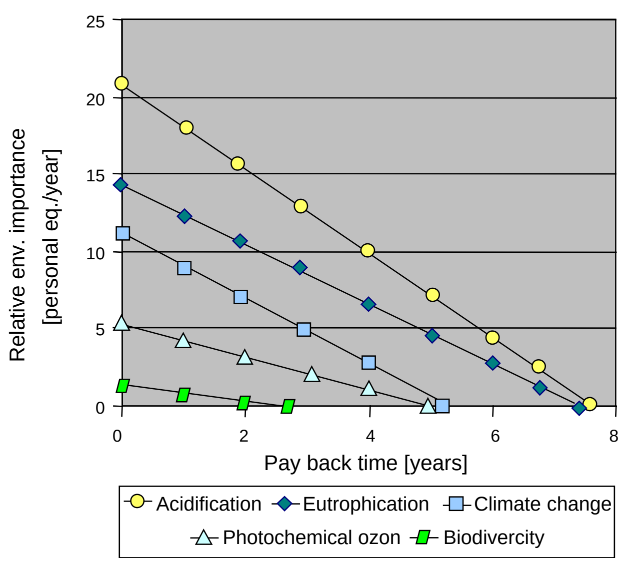

Fig. 6. Pay back time valid for energy conservation measures, given per environmental impact category included in the study. The calculation starts from the current Swedish energy mix and environmental performance. The relative importance of the impact categories is weighted according to the Swedish environmental quality norm [25].

Increased energy need for the tractor is accounted for [34]. Urine is here assumed to be spread with an injection technique, which implies that the urine is given in the soil and therefore minimal emission to air takes place. Emissions to water from the sewage treatment plant that influence eutrophication, is the overall dominating emission and improvement valid for scenarios 2, 3 and 4 above are indicated in Fig. 6. Besides this figure, a delimited overview for the in this study included impact categories are illustrated in Fig. 7.

Generally, the external consequences on the waste water system are not significant to building and housing, and so Fig. 6 in this context is not so interesting. But for the agriculture sector this can be the opposite. The result

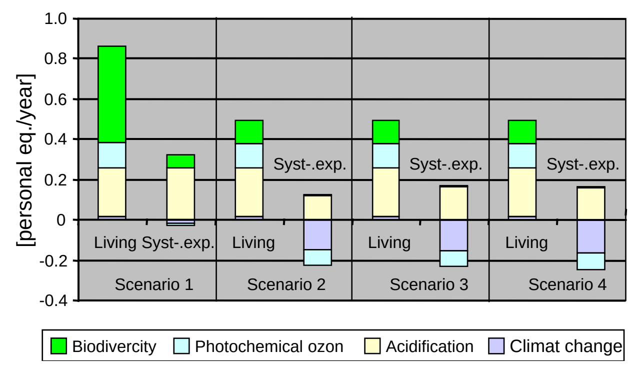

Fig. 7. Environmental impact for housing and system expansion including agricultural effects. Note that eutrophication is the dominating impact category and not included in the figure. Negative figures indicate environmentally positive aspects for the scenario. The impact categories are weighted according to the Swedish environmental quality norm [25].

from the system expansion is that the external effects are a zero balance, see scenarios 2–4, Fig. 7. The major positive effect by system expansion is a saving potential by a reduced need for mineral fertiliser. This resource conservation is, however, not included in Fig. 7, since no categorisation factors for different resource depletion is utilised.

6. Result from the most efficient package of energy conservation measures on a national scale

According to the ELIB investigation [35] the total number of multi-dwelling houses in Sweden was about 126,000 in 1992, with about 2.9 Million people living in them. Dwellings built between 1961–1975 represent more than 30% of the multi-dwelling building stock, and extend over about 29,000 building. Heating energy supply for buildings, divided by year of construction, is given in Fig. 8. The studied building is close in size to the 1961–1975 average building, except that the average apartment size is bigger in the studied house, see Table 6.

If we accept the studied house in a Stockholm location as representative for all Swedish multi-dwelling houses built during this period, see Table 6, a simple way of determining a national savings potential is to multiply the energy savings for the studied house, that could be extracted from Table 6, with the number of houses. The most efficient package of measures corresponds to an energy saving potential in the order of 6.9 TWh for dwellings built between 1961–1975.

According to the ENORM calculation, behind the energy conservation for the most efficient measures in Table 6, heat demand from the heating system only exists in Jan–Feb. This assumes that all the gains are evenly distributed throughout the building. The suggested measures are of the same magnitude as suggested in an earlier report [37]. Furthermore, the measures go further than the so called environmental program for environmental quality and resource efficiency plans for new exploitation in e.g. Margreteborg [38] and Hammarby Sjöstad [39].

Based on the scenario that the entire multi-dwelling stock should be rebuilt on the latest 2035, the total energy demand can be determined based on the goal for energy conservation measures in Table 7. Buildings originally built from 1960 and later, the most efficient measures are assumed for rebuilding as well as for new construction. For this generation of buildings, it is assumed realistic that the energy performance after rebuilding is almost the same. For buildings built before 1960 only minor external rebuilding activities are found

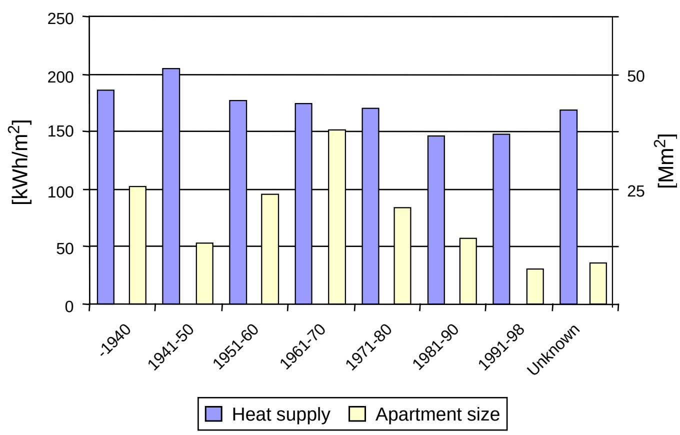

Fig. 8. Present heat supply for the Swedish multi family houses and the apartment size distribution (SCB 1998).

Table 6
Comparison of a created average house from 1961–75 and the studied buildings before measures and for the most efficient package of measures [36]

	Average house 61–75	Studied house	
		Before	After measures
Standard			
Apartments per house	24	24	24
Average apartment size	69	81	81
Apartment space per person	—	35 m^2/person	35 m^2/person
Indoor temperature	22°C	22°C	20°C
U-values in W/m^2K:			
Attic	0.23	0.13	0.08
External walls	0.41	0.83	0.15
Floor	—	0.37	0.14
Windows	2.7	2.7	1.0
Doors	—	2.0	1.0
Heating and ventilation			
Ventilation heat recovery, η	—	0.5	0.9
Ventilation rate	—	Building code air flows	Building code air flows
Ventilation system	Exhaust system	supply and exhaust system with heat recovery	supply and exhaust system with heat recovery
Heating supply	District heating	district heating	district heating

Table 7
Goal level for the energy conservation measures scenario for the Swedish multi-dwelling houses after esthetical concern

Construction year	Rebuilding period (year)	Domestic electricity (kWh/m^2)	Building service electricity (kWh/m^2)	Heat supply (kWh/m^2)	Area (Mm^2)
1940	2000–2035	28	10	120	26
1941–50	2000–2035	28	10	110	13
1951–60	2000–2035	28	10	90	24
1961–70	2000–2035	28	18	38	38
1971–80	2010–2035	28	18	38	21
1981–90	2015–2035	28	18	34	14
1991–2000	2025–2035	28	18	32	8
2001–2035	—	28	18	30	42
Unknown	2000–2035	28	18	30	9

adequate, the goal for energy conservation measures in Table 7 is not so ambitious compared to energy performance for newer buildings. In both Fig. 8 and Table 7, a number of buildings with “unknown” construction year are identified. In the applied scenario, these buildings are assumed to facilitate district heating, and the rebuilding period will be between 2000 and 2035. During the same period an additional heating area is considered, that increases the total energy supply. In the scenario, 15,000 apartments of about 80 m^2 in average are assumed to be built yearly, which then represent 22% of the total heated area in 2035.

The lower electricity supply for building services for older buildings takes into account the fact that gravity ventilation systems still will be sufficient or improved with demand-controlled forced ventilation. Only average statistic information on current electricity supply for domestic and building service use was found, representing the total building and building service sector—26 respective 33 kWh/m^2 [17,40]. These average figures compared to supply for domestic and building service electricity, illustrated in Table 7, imply some improvement mainly concerning building service electricity. Improved energy efficiency for domestic equipment is assumed to decrease the electricity demand per unit etc. in the future. But, hence the number of equipments and facilities are supposed to increase, thus no final improvement can be expected (and therefore no benefits accounted for). However, when the energy balance is performed for the multi-dwelling building stock including new buildings the total electricity demand will decrease from 9.3 to 8.5 TWh/year, Fig. 9.

Included in the energy conservation scenario, residential oil boilers are assumed to be replaced by biofuel boilers. Buildings facilitate electric resistance heating are assumed to change energy supply in favour of district heating. The scenario illustrates that it is realistic that by known and established technology drastically reduce the energy use, Fig. 9.

The environmental improvement in Fig. 10 is the result of energy conservation measures for the existing multi-dwelling stock but also changed energy supply. The calculations only account for the existing building stock. This means that the starting energy supply is 36 TWh/year and the end 16.5 TWh/year. Please note that in Fig. 9 also the new buildings are included, that in total contribute to 6.5 TWh/year extra energy supply in 2035. In order to estimate the environmental impact, a building material specification from Mängda AB for actual rebuilding activities was utilised [26]. These material specification figures cover the entire rebuilding activities in multi-family houses actually performed in Sweden in 1998–99, why the figures cannot be used without modifications. To make this ”average rebuilding” figures representative for future rebuilding according to here suggested energy measures, additional

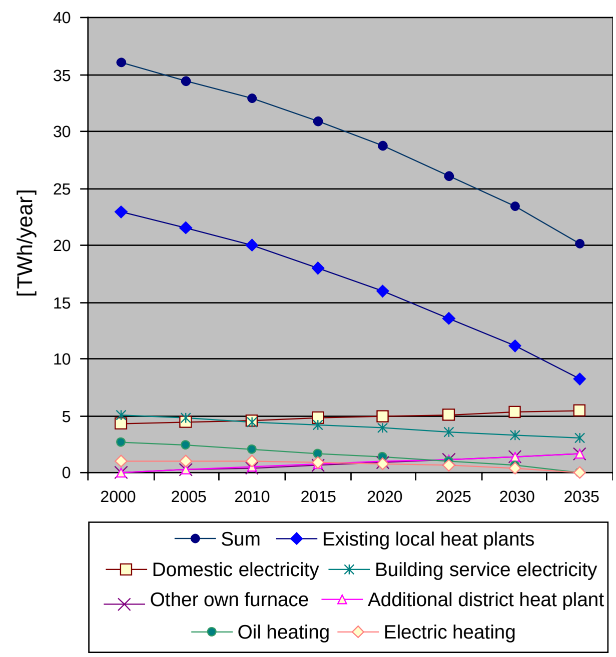

Fig. 9. The development of supply need for heat and electricity from 2000 to 2035, based on an energy conservation measure scenario, valid for the Swedish multi-dwelling building stock including 15,000 yearly produced new buildings [TWh/year].

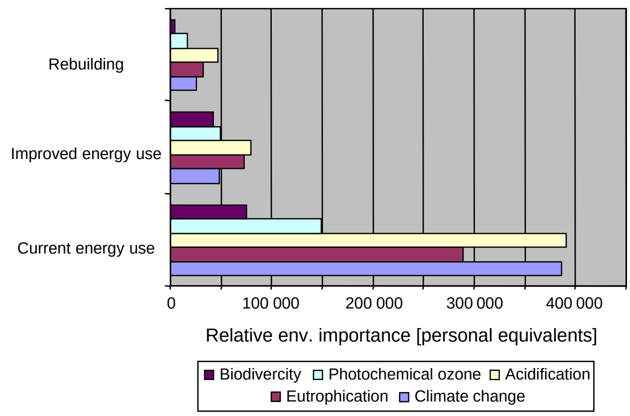

Fig. 10. Environmental impact from the yearly average rebuilding, impact before (2000) and after energy conservation measures (2035), valid for the current Swedish multi-dwelling building stock. The impact categories are weighted according to the Swedish environmental quality norm [25].

building material utilisation was calculated. If this "average rebuilding" scenario is combined with the environmental performance valid for the rebuilding of the studied building in Stockholm, the following difference occurs per surface area; climate change 24%, eutrophication 17%, acidification 16%, photochemical ozone formation 54% and, finally, the impact category biodiversity which is 55%. In other words, in the national calculations the environmental impact is larger per surface area than the rebuilding activities in the case study. The difference is found in the additional materials for the energy measures, but also the fact that the material specification includes more rebuilding activities, especially indoors, that was not included in the case study. From Fig. 10 it is clear that investments in rebuilding will be paid back very fast—only in a few years. Combined with the case study, the current energy supply includes a potentially larger impact that the payback time will be shorter.

7. Discussion and conclusion

The studied life supporting function building and housing—as defined here—includes on one side the physical building and on the other hand the utilisation of it referred to as housing. Both housing and the building services included will constitute the actual so-called functional unit in each LCA applied to buildings and housing. The services included can therefore more or less be regarded as a menu, where the interesting parts are determined by what question is asked. A service included in the life supporting function is defined in the method suggested here as: the service must be related to the utilisation of the building or dependent on building design. Compared to other definitions, e.g. in REGENER [4], it should be noted that travelling from and to work etc. is not accounted for, since it is not dependent on how the building actually is designed.

Until now, performed LCA for building is performed as a linear life cycle, in simple terms like construction, operation including maintenance, and finally a demolition phase. This kind of linear thinking is not valid for most buildings in reality and will not be applicable for rebuilding, since this life cycle phase it not included. Therefore, in this paper, the building is described in a sequential life cycle, where the existing building stock can be regarded as sank cost. Furthermore, the suggested LCA method for buildings, system expansion is regarded as an optional choice to study marginal effects on externalities e.g. increased electricity supply. A comparison between system expansion, including a marginal technology regarding an ordinary strict LCA (where all environmental impact is allocated somewhere), is that a system expansion gives additional information in order to put attention to and minimise the potential risk for sub optimisation in the here called primary studied system. Regarding the calculations performed here, it is obvious that system expansion for externalities could be performed. An example where system expansion can give more detailed information on the overall technical system, is an evaluation of the positive gains of introducing heat pumps in a building connected to a combined heat and electricity production plant. In this example and in other detailed system designs, system expansion will be valid and a powerful technique to give additional information. This design procedure is, however, besides the scope of this paper, since the aim here is to identify what is small and what is big and from that identify potential environmental impact conservation measures.

The importance to find cost and environmental effective solutions feasible for rebuilding is crucial in order to decrease the total environmental impact associated with the housing support function building and housing. Furthermore, focusing on rebuilding, as an activity in order to increase the environmental performance compared to new (additional or replacing old) buildings, is essential if we shall reach the sustainable society in a realistic time horizon. Rebuilding activities suggested here are all based on known technical solutions. In that respect, the performed calculations can be further improved if innovations take place. The performed calculations for the case study and the national scale scenario illustrate that:

- Rebuilding is an environmentally better choice than building a new building, if the essential functional performance is the same.
- Besides heating, wastewater treatment is a significant issue, according to the definition of building and housing practised.

- By using a back-casting technique i.e. to describe a realistic future scenario and then take the way from now to the defined future into account, initial investments causing environmental impact can be justified by calculating a pay-back time for different impact categories.
- The case study and the national estimates performed prove that the potential environmental impact can be reduced by about 70% for the heating service and 75% for the wastewater system, if the suggested measures are performed.

The strategy used in the performed calculations, when pay-back time is estimated, is to use the environmental performance of today for the energy and waste water systems to estimate the savings. Different time dependence can be observed in the calculations. For instance, if the very same performed rebuilding activities suggested in the scenario (between 2000 and 2035) facilitates the future energy infrastructure, the pay-back time would then increase. The result—that rebuilding is environmentally profitable—is, however, true also under these (conservative) circumstances. This implies that there will not be any meaning to estimate an environmental profile for the facilitating infrastructure with a yearly resolution. In the performed calculations, the environmental impact to produce building materials is based on today's technology. If the rebuilding takes place in the future, this means that the calculated pay-back time is conservative. This discussion will also be true when comparing the relation between the environmental impact for building a new building and the environmental impact related to housing (heating etc.), see Fig. 5.

In the discussion with different actors in the building sector it has been observed that the way of using back casting as a technique is a successful way to concretise the "diffuse" term environmental sustainability. Applying back-casting in practise, implies to a discussion of functional requirements for products or services, which is a way of thinking that is common in ordinary work with other aspects such as fire resistance etc. It is also an "environmental" vocabulary that can be understood by most parts in the sector and give a direction instead of a problem-oriented attitude. The back-casting technique means that the non-specialist can work with environmental sustainability in general without applying environmental specialist tools like LCA. Even if the knowledge is there and the future scenario's technical solutions are environmentally efficient, other incitement and financial supports have to exist if this progress shall take place in reality. The need for market sound incitement is also addressed in the European green paper "Integrated Product Policy" (IPP) [41]. This article, using back-casting technique combined with LCA and sector knowledge—like building technology—can hopefully be one way to fulfil the aim of IPP in order to reach a more sustainable common future.

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References

[1] SUREURO—Sustainable Refurbishment Europe. Information available at: http://www.sureuro.com.

[2] Erlandsson M. Environmental assessment of demolition materials. In: Hedén S, editor. Residual material from rebuilding: what, where and how much? (in Swedish), Boverket, Karlskrona, October 1998. p. 47–58.

[3] Trusty W, Athena MJ. An LCA decisions support tool application result and issues. Athena Sustainable Materials Institute. In: The Proceedings of the Second International Conference on Building and the Environment, CIB Task Group 8, Environmental assessment of buildings, vol. 1, Paris; June 1997. p. 239–48.

[4] Peuportier B, Kohler N, et. al. REGENER. European methodology for evaluation of environmental impact of buildings—life cycle assessment. REGENER project, summary report, European Commission directorate general XII for science, research and development, Program APAS, January 1997.

[5] Lippiatt B. Building for environment and economical sustainability. Technical Manual and user guide (BEES 2.0). National Institute of Standards and Technology (NIST), report NISTIR 6220, June 2000.

[6] Howard N, Edwards S, Anderson J. Methodology for environmental profiles of construction materials, components and buildings. BRE report BR 370, Watford, 2000.

[7] Dinesen J, Hansen K. Vurdering og deklarering av en bygnings miljömässige egenskaper (in Danish). Statens Byggforskningsinstitut (SBI), Köpenhamn, 1999.

[8] Schuurmans A, Koaji S, editors. LCA in building and construction. A state-of-the-art report from SERTAC-EUROPE. INTRON B.V Report R990096, Sittard, December 1999.

[9] Vares S, Vanhatalo L, Holt E. Computer aided environmental assessment for building systems. Integrated Life-Cycle design of Materials and Structures. ILCDES 2000. Proceedings of the RILEM/CIB/ISO International Symposium, Proceedings PRO 14. p. 236–40.

[10] Kohler N, Klingele M, Heitz S, et al. Simulation of energy and mass flows of buildings during there life cycle. Inst. für Industrielle Bauprodukten (IFIB), University of Karlsruhe. In: The Proceedings of the Second International Conference Building and the Environment, CIB Task Group 8, Environmental assessment of buildings, vol. 1, Paris; June 1997. p. 41–8.

[11] Jönsson Å, Björklund T, Tillman A-M. LCA of concrete and steel building frames. International Journal of LCA 1998;3(4): 2116–224.
[12] Peuportier B, Kohler N, et al. European methodology for evaluation of environmental impact of buildings—life cycle assessment. REGENER project, report No. 4, Application by target groups, European Commission directorate general XII for science, research and development, Program APAS, January 1997.
[13] Braunschweig A, Müller-Wenk R. Ökobilanzen von Untrerneh-mungen. Eine Wegleitung für die Praxis. Bundesamt für Umwelt, Wald und Landschaft (BUWAL), Bern, 1993.
[14] Clift R, Frischknecht R, Huppes G, et al. Towards a coherent approach to Life Cycle Inventory. Report not yet published from the SETAC working group on the Enhancement of life cycle assessment. Summary published in SETAC-Europe News 1999;10(3):14–20.
[15] Tillman A-M. Significance of decision-making for LCA methodology. Environmental Impact Assessment Review 2000;20: 113–23.
[16] Wiedema B. Margin production technologies in life cycle assessment inventories. International Journal of LCA 1999;4(1).
[17] STEM. Energy in Sweden—facts and figures 1999 (in Swedish). Swedish National energy Administrator, ET 83:1. Eskilstuna, 1999.
[18] STEM. Energy state 1999 (in Swedish). Swedish National energy Administrator, ET 81:1. Eskilstuna, 1999.
[19] Elforsk. A sustainability electricity system for Sweden. A vision for the year 2050 (in Swedish). ELFORSK, Report 96:9, Stockholm, April 1996.
[20] Azar C, Lindgren K. Energy state 2050 (in Swedish). Swedish Environmental Protection Agency, report 4894, Stockholm, July 1998.
[21] SAME. Hållbar energiframtid? Långsiktiga miljömål med system-lösningar för el och värme (in Swedish). Final report from the SAME project, Swedish Environmental Protection Agency; ISBN: 91-620-4965-8, Stockholm, April 1999.
[22] Boström C-Å, Cooper D, Lövblad G. National reports of emissions to air—Recommendation of emission factors for energy production (in Swedish). Swedish Environmental Research Institute, Report L98/78, Gothenburg, December 1998.
[23] Bio-refinery—Energy balances (In Swedish). Siftelsen Svensk Etanolutveckling, Faktablad, Örnsköldsvik, March 1998.
[24] Lindstedt J. Bio Alcoholic Fuel Fondation (BAFF), Personal communication, December 2000.
[25] Erlandsson M. Weighting of different impact categories based on a vision of the sustainable society—the Swedish environmental quality goals (in Swedish). Stockholm, report No. B 1385, Stockholm, July 2000.
[26] BYKR. The significant environmental aspects in building sector (in Swedish). Swedish Building Eco-Cycle Council (BYKR), Stockholm, 2000. Available at: http://www.kretsloppsradet.se.
[27] Wenzel H, Hauschild M, Alting L. Environmental assessment of products. 1st ed. vol. 1—Methodology, tools and case studies in product development. London: Chapman and Hall; 1997.
[28] Abhe S, Braunschweig A, Müller-Wenk R. Methodik für Oekobilanzen auf der Basis ökologischer Optimerung (in German). Bundesamt für Umwelt, Wald und Landschaft (BUWAL), Schriftenreihe Umwelt Nr. 133, Bern, Oktober 1990.
[29] Dalemo M, Björklund A, Oostra H, Sonesson U. System Analysis of Nutrient Recycling from Organic Waste. JTI report Kretslopp och avfall No. 15, Swedish Institute of Agricultural Science Engineering, Uppsala, Sweden, 1998.
[30] Persson K, Kindbom K, Mapping on emissions from working vehicles and tools in Sweden (in Swedish). Swedish Environmental Research Institute, Report B 1342, Gothenburg, July 1999.
[31] Jönsson H, Vinnerås B, Höglund C, et al. Recycling source separated human urine (in Swedish). VA-FORSK, report No. 200:1, 2000.
[32] Nitrogen from land to sea. Main report (in Swedish). Swedish Environmental Protection Agency, SNV 4741, Stockholm, June 1997.
[33] Erlandsson M. Eco-Effect -Miljövärdering av vatten- och avloppsflöden orsakade av boende (in Swedish). Byggd Miljö, KTH Gävle, 9 Mars 1999.
[34] Dalemo M. The ORWARE simulation model Anaerobic digestion and sewage plant sub-models. Swedish University of Agricultural Science, JTI, report No. 213, Uppsala, Sweden, 1996.
[35] Norlén U, editor. För ett samlat grepp på byggnadsbeståndet (in Swedish). ISBN 91-7170-245-8, Gävle, 1998.
[36] Norlén U, Andersson K, editors. Bostadsbeståndets inneklimat ELIB-rapport nr 7 (in Swedish). TN:30 from the Swedish Institute for Building Research, Gävle, 1993.
[37] Elmberg A, Elmroth A, Wannheden C. Hus i Sverige—Perspektiv på energianvändningen (in Swedish). Byggforskningsrådet, Stockholm, 1996.
[38] Keski-Seppälä L, Sollentuna Community, Stadsbyggnadskontoret. Tolkning av Program för miljökvalitet och uthållig resursanvändning i Margreteborg (in Swedish). TJUNR PM 2000-02-07, Sollentuna, 2000.
[39] City of Stockholm, 1999, Miljöprogram för Hammarby Sjöstad (in Swedish). Available at: http://www.hammarbysjostad.stockholm.se/svenska/miljo/HS_Miljoprogram.pdf.
[40] SCB. Energy statistic for multi-dwelling buildings in 1998 (in Swedish). Statistics Sweden, Official Statistic of Sweden No. E 16 SM 9902, Örebro, 1999.
[41] Green book on Integrated Product Policy. Commission of the European Communities, Brussels, KOM(2001) 68 final, 07.02.2001.