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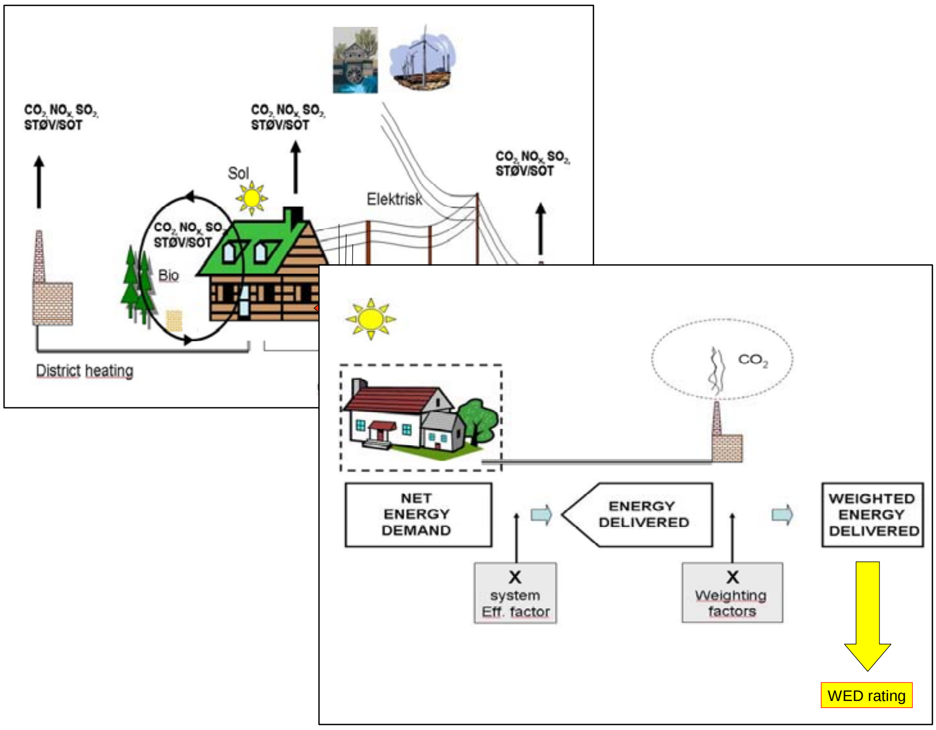

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Analysis of Concerto Energy concepts and guidelines for a whole building approach

Tore Wigenstad, Inger Andresen, Jørn Stene, Owe Wolfgang

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ABSTRACT

This report is a contribution to the EU-project ECO-City – Joint Eco City developments in Scandinavia and Spain. The objectives of the "ECO-City development project" are to establish a technological basis for and to demonstrate innovative integrated energy concepts in the supply and demand side in three successful Communities in Denmark/Sweden, Spain and Norway. The demonstration activities, which are coordinated with the Communities on-going activities, are based on both the demand (ECO-buildings / RUE) and the supply side (RES). All demonstrations will be designed using a "Whole Community Design Approach" in order to ensure the largest energy saving potential possible, and to ensure coherence in all the activities.

The aim of the report is to establish a theoretical and practical platform (guidelines) for further work in the demonstration projects. The platform should be a support in analysing alternative total energy concepts for eco-building projects, both new buildings and renovation projects, applying an integrated approach focusing on energy, emissions, life-cycle costs as a whole building approach.

Starting with the demand side the report is giving examples of building designs and technologies that are suitable for *rational use of energy* – RUE (Chapter 2). Continuing with the supply side, energy systems are analyzed in order to give an overview of the most relevant systems (in Norway), but were *renewable energy supply* - RES systems is emphasised (Chapter 3/4). Different optimizing methods (in general) are presented in chapter 5, before some guidelines on how to combine RUE with RES are introduced in chapter 7. The result is expressed via a *weighted energy delivered* – WED index . The method is then tested on the demonstration project in Trondheim (Chapter 8).

KEYWORDS	ENGLISH	NORWEGIAN
GROUP 1	Energy	Energi
GROUP 2	Environment	Miljø
SELECTED BY AUTHOR	Concerto	Concerto

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INTRODUCTION

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For Trondheim, suitable energy concepts for buildings will be analysed, integrating the supply side and demand side in a symbiotic way. The analysis will be performed for 2 sites (Granås and Svartlamoen) and 16 municipal schools and 3 nursing homes. The analysis shall found a basis for identifying the optimal solutions and technologies, which will satisfy the energy goals (RES for heating and 25%-40% improvement in energy efficiency compared with the present strict national building regulations and targets). The findings shall be documented in a set of guidelines for a *Whole Building Approach*.

The results form the basis for the demonstrations related to new buildings and renovation projects. In addition, they can trigger rational energy policies in local businesses and found a basis for municipal legislative actions in future development projects in the community. The results will also be shared with the consortium and external parties through dissemination and training activities.

The aim of this report is to establish a theoretical and practical platform (guidelines) for further work in the demonstration projects. The platform should be a support in analysing alternative total energy concepts for eco-building projects, both new buildings and renovation projects, applying an integrated approach focusing on energy, emissions, and life-cycle costs.

Starting with the demand side the report gives examples of building designs and technologies that are suitable for *rational use of energy* – RUE (Chapter 2). Continuing with the supply side, energy systems are analyzed in order to give an overview of the most relevant systems (in Norway), with an emphasis on *renewable energy supply* - RES (Chapter 3/4). Different optimizing methods (in general) are presented in chapter 5, before some guidelines on how to combine RUE with RES are introduced in chapter 7. The result is expressed by a *weighted energy delivered* – WED index. The method is then tested on the demonstration project in Trondheim (Chapter 8).

1. ENERGY, ENVIRONMENTAL IMPACTS, LIFE CYCLE COSTS – A WHOLE BUILDING DESIGN APPROACH

1.1 Introduction

In order to find the most effective strategies towards sustainable built environments, it is not sufficient to take the traditional energy-economic optimization approach. Measures that may seem effective by themselves may be quite ineffective in a larger perspective. There may even be direct conflicts between different measures that separately may appear to be very good. Thus, to find the most effective strategies and technologies for zero emissions built environments, a-multi-criteria approach is called for. The solutions will be dependent on a number of factors such as:

- Technological solutions and strategies for energy-efficient building components and energy supply systems
- The knowledge and means to design and implement the energy-efficient technologies and strategies (marketing, education, guidelines/tools, codes, standards, regulations, economics, etc.)
- The knowledge and means to operate and use the energy-efficient technologies (guidelines, education, user-friendliness, service, design, etc.)

Furthermore, different stakeholders may have different preferences:

- Economics
  - Maximize profit (Corporate economic)
  - Minimize total costs (Socio-economic)
- Environmental impact
  - Quantitative: emissions, noise
  - Qualitative: aesthetical/visual
- Quality of supply
  - Reliability/Security
  - Technical attributes: voltage quality, temperature, pressure etc
  - User aspects: comfort, controllability etc
- Reputation
  - Public opinion
  - Level of service
- etc...

Thus, the optimum solution will have to be based on a trade-off between different criteria and values. Traditionally, energy planning has been dominated by the application of energy-efficient technologies and the use of renewable energy technologies, e.g. the introduction of heat pumps, thermal insulation, and biomass systems. The systems have been optimized one-by-one by calculating the life cycle cost (or pay back time) of each system and choosing the ones with the lowest life cycle cost. In the recent years, however, one has realised that in order to achieve significant improvements in overall energy performance of the built environment, it is necessary to take a “whole building approach”. This means that one has to consider both demand and supply side *in connection.* In this way, one will avoid sub-optimizing of a single system, but instead focusing on optimizing the entire system. For example, it is of little use to have a very efficient heat pump system, if the house itself is so leaky that it requires a large amount of energy. In short, the energy system should be chosen and designed to fit the (low) demand. As a general rule, one should start out with reducing the energy demand much as possible, simply because reducing energy demand in general requires less resources than introducing efficient energy supply systems.

Thus, the new energy planning design paradigm is based on the “trias energetica” principle, first formalised by Novem in the Netherlands (Lysen 1996). Trias Energetica is a three step approach that contains the following steps:

1. Reduce the energy demand, by applying energy reducing measures (thermal insulation, air tightness, heat recovery)
2. Use as much renewable energy sources as possible for the generation of energy (solar, wind and biomass)
3. Apply fossil fuels in the cleanest possible way (high efficient gas boilers)

Chapters 2 and 3 give an overview of strategies and technologies that may be used for the demand side and supply side, respectively.

Chapter 4 then gives an overview of emissions associated with different energy sources, while chapters 5 and 6 provide short introductions to life cycle assessment and economic analysis.

Chapter 7 includes guidelines on how to integrate the demand and supply sides and a method for assessing the related environmental emissions, while chapter 8 gives an example of how to apply this method in the Eco-City of Trondheim.

2. DEMAND SIDE. BUILDING DESIGN AND TECHNOLOGIES

This chapter gives a brief overview of strategies and technologies that may be used to reduce the demand side energy consumption.

2.1 Location and orientation

Dwellings with high heating energy loads should have ample solar exposure in the wintertime to take advantage of passive solar gains. For school buildings, it is more important to avoid excessive solar gains and glare, while at the same time provide good daylight conditions. Vegetation and water may be used to improve the microclimate around the building and reduce the cooling load.

In order to take advantage of natural or hybrid ventilation (see section below), particular emphasis should be put on analysing the wind conditions, as well as to consider noise and pollution from traffic and other activities in the neighbourhood.

Fig 2.1 Apartment building in Oslo (Klosterenga) where cold zones (sleeping rooms) are oriented towards the north, warm zones (bathrooms) in the middle, and living room to the south). GASA Architects.

2.2 Shape and floor plan

The shape of the building should be as compact and simple and possible in order to minimise the heat loss through the envelope and facilitate good air-tightness and minimisation of thermal bridges.

The floor plan should be zoned with respect to temperature levels and solar access/daylight access. Also, when designing the floor plan, efficient pathways for ducts and pipes should be sought in order to minimize pressure drops.

2.3 Envelope technologies

Envelope technologies encompass thermal insulation and air-tightness to minimize heat loss, shading devices to avoid overheating and glare, and windows to provide daylight, view, and ventilation.

The current building practice in Norway encompass15-20 cm of mineral wool in exterior walls and 20-30 cm in roofs and floors. Low energy buildings employ 20-25 cm in exterior walls and 30-40 cm in roofs and floors. Standard windows used are double glazed gas filled LE-windows with a U-value of 1.5 W/m^{2}K. Low energy buildings employ triple glazing with 2 LE-coatings, argon gas and insulating spacer and frame, with a total U-value between 0.8-1.1 W/m^{2}K.

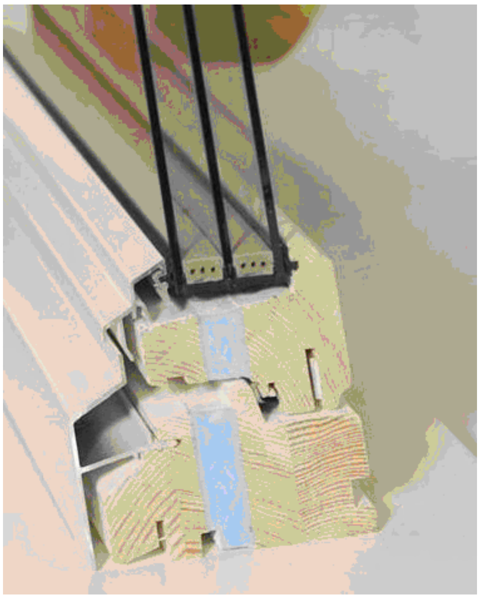


Fig. 2.2 A super-insulated window from NorDan.

Using well insulated windows is an effective energy measure in cold climates, and provides additional benefits with respect to thermal comfort and reduced size of heating equipment. Better air-tightness is a simple and effective energy saving measure. It mainly involves careful workmanship and careful design of construction details around windows and doors, and in joining of floors/roofs and exterior walls.

For solar exposed glazing, hading is necessary in order to prevent overheating and glare. The main challenge is to find systems that effectively block solar gains and prevent glare, but still allows some daylight penetration and view. Exterior shading is most effective for reducing solar gains, but shading in-between the exterior glazing is also quite effective, and is more protected against weather strains. Fixed overhangs will to a certain degree reduce solar gains for south facing windows, but will reduce daylight entry throughout the year.

Fig. 2.3 Example of a Venetian blind with two parts that may be controlled individually: Solar shading in the lower part and daylight blinds in the upper part. (Photo: Vental).

2.4 Utilisation of building thermal mass

Heavy construction materials like concrete, masonry or natural stone may be used to shift the excessive thermal energy from day to night, and thereby increase comfort and reduce cooling loads. Effective thermal mass activation requires that the heavy constructions are exposed to the room air. The mass may be activated through night flushing with cold air or via embedded water pipes.

Thermal mass activation, in combination with effective ventilation and solar shading, may significantly reduce or even eliminate the need for mechanical cooling.

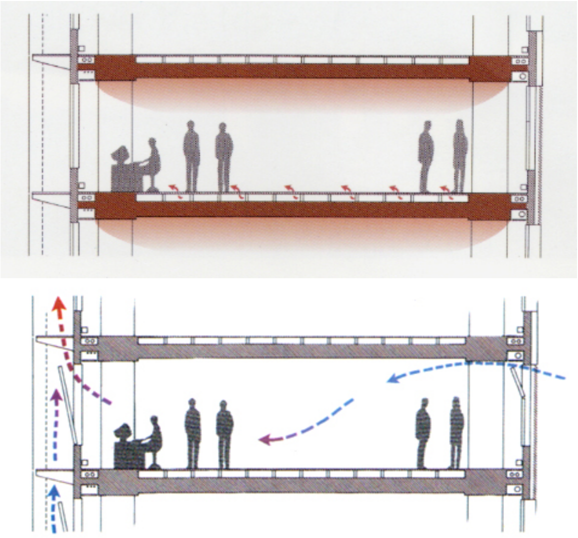


Fig. 2.4 Thermal mass activation in the GSW Headquarters in Berlin. Excess heat is accumulated by the concrete ceiling during daytime (top), and the heat is flushed out through ventilation during night (bottom). Sauerbruch-Hutton Architects.

2.5 Ventilation

The first step in energy-efficient ventilation is to minimize the required ventilation rate by avoiding emissions of pollutants and high temperatures in the occupied space. This may be achieved by selecting low-emitting building materials and avoiding high room temperatures through passive measures.

The second step is to select and design a ventilation system that effectively removes the pollutants from the breathing zone with the least amount of energy use. The ducts must be designed to minimize pressure drops and fan energy use.

Fig 2.5 Rotary wheel heat exchanger from Villavent.

If a mechanical ventilation system is chosen, a high degree of heat recovery may be achieved by choosing an efficient heat exchanger and ensuring an air-tight building envelope. Heat exchangers with efficiencies above 80% are readily available at the market at competitive prices.

Natural or hybrid ventilation may be used to avoid overheating in warm periods, and thereby significantly reduce the cooling energy. Natural ventilation strategies includes taking into consideration the orientation and the layout of the building, the design of façade openings, the utilization of atriums or double facades, and designing and implementing an efficient control system.

2.6 Daylight utilisation

The energy use for electric lighting may be reduced by designing the space and lighting system to utilize natural daylight. This involves designing the window openings and room surfaces to optimize daylight distribution into the room (while avoiding glare and overheating), and controlling the electric lights accordingly. In this way, lighting energy needs may be reduced by at least 50%. In addition, cooling energy needs will be reduced.

Fig. 2.6 Room with specially designed window niches to maximize daylight.
Photo: Ø. Aschehoug

As a rule of thumb, daylighting within a building will only be significant within about twice the room height of the facade. Thus, shallow-plan buildings provide better opportunities for daylighting than deep-plan buildings. The provision of a significant amount of glazing near the ceiling is beneficial from a daylight point of view.

2.7 Energy-efficient lights and appliances

To install energy-efficient lights and appliances is usually a very cost-effective and simple measure. This may result in a significant reduction in electricity use, and may also lead to lower cooling energy needs due to reduced internal loads. A-labelled appliances may be bought at prices that are competitive with other products of comparable quality.

2.8 Control Systems

Control systems to reduce the energy for heating, cooling, lighting and ventilation, may be integrated into a Building Energy Management System (BEMS). In addition to energy savings related to the individual control systems, such a system can yield additional benefits like more sophisticated control procedures, give user feed-back, displaying opportunities for energy savings, and flagging maintenance requirements and equipment failures.

2.9 Behavioural and occupancy factors

Residents can influence the energy use to a large extent through simple actions: Dressing according to the prevailing weather conditions, adjusting the levels of physical activity, moving to cooler spaces in the building, adjusting thermal controls (opening and shutting windows), use of blinds and curtains for shading etc. Strategies to encourage energy-efficient users are feedback on use and management, information, training/education, participation, and social activities/networks

Fig. 2.7 Future residents taking part in planning of a new housing complex at Svartlamon, Norway Photo from the participant Architects MNALs

3 SUPPLY SIDE. ENERGY SYSTEMS

This chapter provides a brief presentation of heating systems and selected systems for local production of renewable electricity. Co-generation systems may also be a viable option for local energy supply, but such systems are not included in this overview.

3.1 Direct electric heating systems

In Norway about 30 TWh/year or 60% of the total heating demand in buildings is covered by direct electric heating systems, mainly due to the low electricity prices during the last decades. The main advantages of direct electric heating systems include the relatively low investment and maintenance costs as well as easy and flexible installation. On the other hand these system are totally dependent on electricity as energy carrier, and they also suffer from a relatively low exergy efficiency, which in turn leads to high associated CO_2 emissions (kg CO_2 per kWh delivered heat) when the electricity is generated by fossil-fuelled power plants. For stand-alone space heating systems located in occupied zones, the relatively high surface temperature may lead to burning of dust and aggravated air quality.

Direct electric heating systems in Norway include (Stene, 2006):

Stand-alone systems – space heating	**Heating capacity**
Electric baseboard heaters (different types)	250–2,000 W/unit
Electric, oil-immersed radiators	400– 2,000 W/unit
Electric fan heater	1,000–2,000 W/unit
Electric floor and ceiling heating systems	Foils – 40 to 150 W/m^2 Cables – 8 to 20 W/m
Stand-alone systems – heating of ventilation air	
Electric heater batteries	1 to several hundred kW/unit
Stand-alone systems – hot water heating	
Single-shell tanks with immersion heaters	40 – 1,000 litres/unit 1–30 kW/unit
Central systems – space heating, hot water heating, heating of ventilation air	
Electric/electrode heaters and boilers	5–6,000 kW
Double-shell tanks (with immersion heaters)	E.g. 200/120 or 300/120 litres

Table 3.1 Direct electric heating systems in Norway.

3.1.1 Electric baseboard heaters.

These systems are used for space heating in both homes and non-residential buildings, are designed as open or closed units with and without air circulation through the units. The heaters can be equipped with advanced programmable thermostats in combination with central control systems. Electric baseboard heaters have traditionally been mounted under the windows in order to prevent draft, but this is not required in low-energy buildings equipped with high-quality windows.

Fig. 3.1 Examples of electric baseboard heaters – closed type (left, middle), open type (right).

3.1.2 Electric floor heating systems

Systems including heating foils, heater cables and heater cable mats which can be installed in both wooden and concrete floors. Electric foils are also applicable as ceiling heating systems, but these systems are only recommended in homes with low space heating demands.

Fig. 3.2 Electric floor heating system with cables for wooden floor

3.1.3 Electric heaters, electric boilers and electrode boilers

These systems are connected to a hydronic heat distribution system (central heating system), and provide space heating, hot water heating and possibly reheating of ventilation air.

In single-shell hot water tanks, the hot water is normally heated by *electric immersion heaters*. In buildings equipped with a hydronic heat distribution system, the hot water system normally comprise one or several double-shell storage tanks, each constructed from a primary vessel for storage/heating of hot water and a secondary vessel connected to the hydronic system. The hot water in the primary vessel is preheated by the water in the heat distribution system, and reheated by electric immersion heaters.

Fig. 3.3 Examples of a small capacity electric heater for residential applications (left) – electric boiler for non-residential buildings (middle) – single-shell hot water tank with electric immersion heater (right).

3.2 Gas-fired systems

In Norway both propane and natural gas are of current interest in gas-fired heating systems. Systems utilizing propane require an underground pressurized tank (16 bar) which may be rented from the local gas supplier. Gas pipe grids for natural gas (4 bar) are already available in parts of Haugesund and Stavanger, and may also be installed in parts of other Norwegian cities, e.g. Bergen and Trondheim.

Gas-fired heating systems in Norway include (Stene, 2006):

Stand alone systems – space heating	**Capacity**	**Efficiency [1)]**
Mobile gas-fired stoves	4–6 kW	Approx. 100%
Gas-fired stoves for wall installation	2–6 kW	Approx. 95%
Gas-fired fireplaces	5–10 kW	Less than 80%
Central systems – space heating, hot water heating, heating of ventilation air		
Gas-fired boilers	>5 kW	94 – 98%

Table 3.2 Gas-fired heating systems in Norway

1) Efficiency related to the upper heating value (UHV)

The specific CO_2 emissions from gas-fired boilers are typically 15 to 30% lower than that of oil-fired boilers due to lower carbon content in the fuel and higher combustion efficiency – typically 0.22 to 0.29 kg CO_2 per kWh.

3.2.1 Gas-fired stoves

Systems with an open flame in a combustion chamber are mounted on the outer wall, and connected to a double-shell duct for air supply and removal of the exhaust gases. Low-capacity gas-fired stoves with a catalytic burner do not need an exhaust pipe, and they can be placed on inner walls or on the floor (mobile type). In these systems the exhaust gases (CO_2, water vapour, particles) are released directly to the room. Some gas-fired stoves are equipped with fans for enhanced air distribution.

Fig. 3.4 Example of gas-fired fireplace.

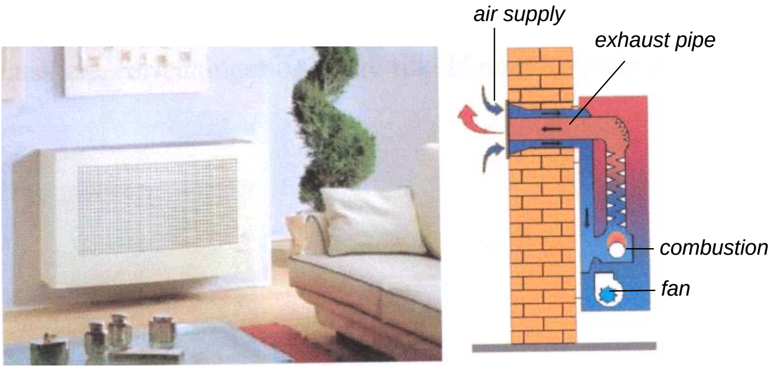


Fig. 3.5 Example of a wall-mounted gas stove as well as principle sketch that illustrates the function of a gas-fired stove.

3.2.2 Gas-fired condensing boilers

Fig. 3.6 Example of a residential condensing gas boiler.

These boilers are connected to a hydronic heat distribution system, and provide space heating, hot water heating and possibly reheating of ventilation air. Since the boilers utilize most of the heat in the exhaust gas, they can achieve high energy efficiency. Recent field tests from Germany have, however, documented that the annual efficiency can be as much as 10%-points lower than the efficiency at optimum operating conditions, typically 85-90% of the UHV (Wolff et al., 2004). In order to achieve the highest efficiency it is crucial that the exhaust gas is sufficiently cooled, and this require a low return temperature in the heat distribution system.

Since gas-fired boilers achieve high energy efficiency even at part-load operation, they are also suitable as peak load units in bivalent heating systems with e.g. thermal solar collectors or air-to-water, brine-to-water or water-to-water heat pumps.

Gas-fired boilers use a much simpler chimney design than oil-fired system, and they have lower maintenance costs and longer lifetime. However, since the pressurized tank, tubing, control system and safety equipment are more complex than the atmospheric storage tank and supply systems in oil-fired systems, the investment costs are more or less the same (Shell, 2005).

3.3 Biomass-fired Systems

In Norway wood (birch, alder, spruce, pine etc.) as well as briquettes and pellets processed under high pressure from wood and waste wood, are the main “fuels” in wood-fired heating systems. The heat value of wooden briquettes and pellets is about 4.8 kWh/kg, and the energy density (kWh/m^3) is in the order of 30 to 40% lower than that of oil and propane, respectively, when the combustion efficiency is excluded.

Fig. 3.7 Examples of wooden briquettes (left – diameter 50 to 75 mm, moisture content 5-20%) and wooden pellet (right – diameter , 8 and 12 mm, moisture content 6-10%).

Wood-fired heating systems in Norway include (Stene, 2006):

Stand alone systems – space heating	**Capacity**	**Efficiency [1)]**
Wood-fired stoves	3–15 kW	70–80%
Pellet-fired stoves without water jacket	1.5–10 kW	80–90%
Central system – space heating and hot water heating		
Pellets-fired stoves with water jacket	2–10 kW	80–90%
Wood-fired boilers	15–50 kW	70–80%
Pellet-fired boilers	10–80 kW	80–90%
Energy cabins (pellet boiler + solar system)	15–450 kW	80–90%

Table 3.3 Wood-fired heating systems in Norway.

1) Range of measured efficiencies at full and part load. However, the seasonal/annual efficiency may be lower.

High-efficiency *wood-fired stoves* for residences have a primary and a secondary combustion chamber which ensures complete combustion and low emissions at both full and part load conditions. The stoves are either designed for high surface temperature and radiative heat rejection or moderate surface temperature and convective heat rejection (air heating).

3.3.1 Pellet-fired stoves.

The stoves are designed as complete combustion systems including an integral storage tank, an automatic feeding system for pellet and controlled combustion. Units without water jacket are for space heating only, whereas units designed with a water jacket provide both space heating (20%) and hot water heating (80%).

Fig. 3.8 Examples of wood-fired stove (left) and pellet-fired stove with and without water jacket (middle/right).

3.3.2 Pellet-fired boilers.

The boilers are in principle identical to oil- and gas-fired boilers, but the burner is especially designed for pellet. The boiler is normally installed in a separate boiler room and connected to a hydronic heat distribution system. There exist also so-called *energy cabins* which are self-contained systems that combine a wood pellet burner with a solar thermal system for central heating of all kinds of buildings. The units comprise a boiler, pellet storage container, chimney, thermal solar collectors and control system as well as a buffer storage tank and an expansion tank for the hydronic heat distribution system.

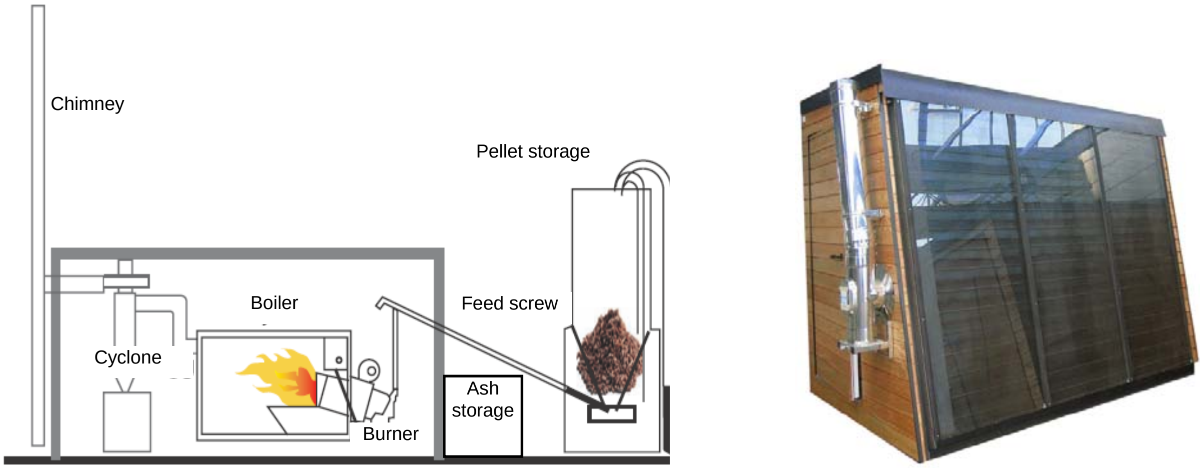


Fig. 3.9 Principle sketch of a medium capacity pellet-fired boiler system (left) – 15 kW energy cabin (right).

3.4 Solar thermal collectors

Solar thermal collector systems commercially available in Norway include flat-plate water based collectors and vacuum tube collectors. Flat-plate collectors are comprised of a rectangular box with a transparent cover. Fluid is circulated in tubes which are attached to an absorber, normally with a surface painted black or having a selective coating. The hot water or liquid goes from the collector to a storage tank. The collectors may be used for DHW heating and space heating. These systems achieve an average yield between 300 and 700 kWh/m^2 per year, depending on the location and the system quality. Vacuum tube collectors consist of rows of parallel transparent glass tubes with vacuum inside, each containing an absorber covered with a selective coating. Fluid temperatures may reach 75-180°C. Their performance is high; exceeding flat-plate collectors by 30-40%, but the cost is also correspondingly higher. Solar collector systems in Norway are designed to meet around 50% of the DHW load and 30% of the space heating load.

Fig. 3.10 Norwegian dwelling with flat-plate solar collectors on the façade. Source: www.systemhus.no

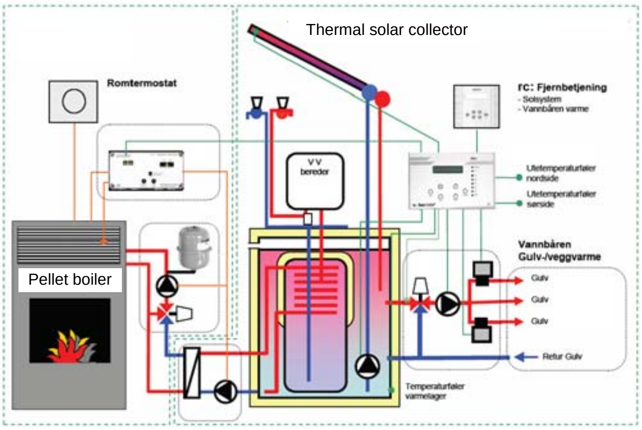


Fig. 3.11 Principle example of a combined solar collector system in combination with a pellet-fired boiler

A typical DHW system for a single-family house consists of 5 m^2 of flat plate collectors mounted on the south facing part of the roof, and a 300 litre storage tank. Equivalent energy prices for heat delivered by solar collector systems in Norway range from 0.30-1.0 NOK/kWh depending on type of system and location.

3.5 Heat pump systems

Heat pump systems for heating/cooling of buildings in Norway include (Stene, 2006):

Heat pump type	SH	SC	WH	VH	Comment
Air-to-air	x	x			Single or multi split units/systems
Air-to-water			x		Heat pump water heaters (HPWH)
	x		x		Combined systems (mainly for homes)
Exhaust air-to-air	x	x			Balanced ventilation systems
Exhaust air-to-water	x		x	x	Exhaust air vent. syst., mainly HPWHs
	x		x	x	Balanced ventilation systems
Brine-to-air	x	x			Mainly for homes – free cooling
Brine-to-water	x	x	x	x	All kinds of buildings – free cooling
Water-to-water	x		x	x	Mainly non-res. bldgs. – free cooling

Table 3.4 Heat pump systems for heating/cooling of buildings in Norway.

SH = space heating, SC = space cooling, WH = hot water heating, VH = heating of ventilation air

3.5.1 Air-to-air heat pumps

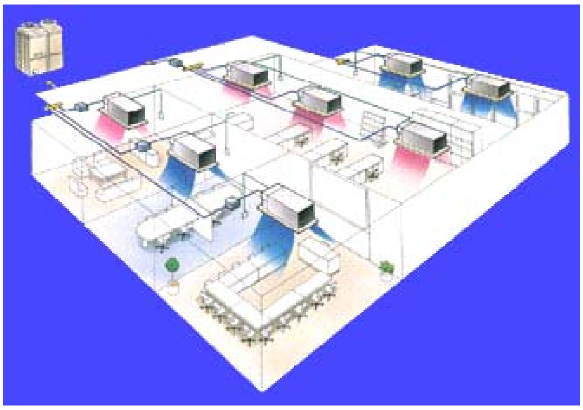


Fig. 3.12 Principle example of a multi-split air-to-air heat pump system for a non-residential building.

These systems utilize ambient air as heat source/sink and provide space heating or cooling by circulating and heating/cooling the indoor air by means of one or several indoor units. Air-to-air heat pumps for homes have normally one indoor unit, whereas systems for larger buildings are designed as multi-split systems with maximum 40 indoor units for each outdoor unit. The latter systems can be used for simultaneous heating and cooling. Since air-to-air heat pumps don't require a separate heat distribution system, they are also suitable for installation in existing buildings. The heating capacity of air-to-air heat pumps diminish when the ambient air temperature drops. (e.g. -15% at +2ºC and -40% at -15ºC for the best units (ref. +7ºC air temp.)). With the exception of low energy houses, heat from a supplementary heating system is therefore required during parts of the heating season. In Norway the Seasonal Performance Factor (SPF) of air-to-air heat pumps for homes typically range from 2.0 to 2.5.

3.5.2 Air-to-water heat pumps

Systems that utilize ambient air as heat source, and provide hot water heating only or combined space heating and hot water heating by means of a hydronic heat distribution system. State-of-the-art air-to-water heat pumps for combined space heating and hot water heating may achieve a slightly higher SPF than air-to-air heat pumps, and their total energy saving is also larger since they cover the hot water heating. Japanese air-to-water heat pumps using carbon dioxide (CO_2) as working fluid are likely to be introduced in the European/Norwegian market in 2007/2008.

The main types of ventilation systems in Norwegian buildings in include exhaust air ventilation (homes, blocks of flats) and balanced ventilation with heat recovery (non-residential buildings, new homes). *Exhaust air heat pumps* are designed for: 1) Hot water heating only or 2) Combined hot water heating and space heating. The latter system requires a hydronic heat distribution system and a supplementary heating system, e.g. electric immersion heaters or a condensing gas boiler.

3.5.3 Exhaust air heat pumps

These heat pumps are installed in balanced ventilation systems, and are used for, and
1) Reheating and cooling of ventilation air,
2) Reheating of ventilation air and space heating or
3) Reheating of ventilation air, space heating and hot water heating.
Space heating is provided by distributing hot air through the ventilation system or by means of a hydronic heat distribution system. Some heat pump systems use both ventilation air and ambient air as heat sources in order to increase the heating capacity. Compact heating and ventilation devices with integrated exhaust air heat pumps (*CVHD*) have recently been developed for low-energy and passive houses. The units comprise an earth collector for preheating of ambient air (optional, homes only), fans, high-efficiency heat recovery unit, exhaust air heat pump, solar thermal collector (optional), hot water storage tank and electric reheater. The heat pumps achieve high energy efficiency due to the relatively high average heat source temperature.

Fig. 3.13 Example of a CVHD.

3.5.4 Brine-to-water heat pumps

Systems that extracts heat from rock/groundwater, sea water, lake water or soil (indirect systems with brine collector), while *water-to-water heat pumps* utilize groundwater or seawater as heat sources. The heat pumps are designed as heat pump water heaters or as combined systems providing space heating, hot water heating and possibly reheating of ventilation air by means of a hydronic heat distribution system. The heating capacity range from about 4 kW for residential systems to several MW for large capacity systems in non-residential buildings. Heat pumps in non-residential buildings utilizing groundwater, seawater or energy wells in bedrock as heat source, can also cover the entire or a large share of the total cooling demand by rejecting heat directly to the heat source – so-called free cooling. Brine/water-to-water heat pump systems are more expensive than air-to-water heat pumps due to the extra investment costs for the heat

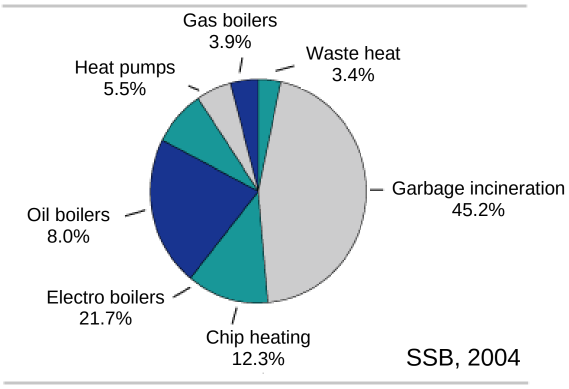
Fig. 3.14 Example of a residential brine-to-water heat pump system. Heat pump unit (1).

source system. However, since the average source temperature is higher, they typically achieve 30-40% higher SPF.

3.6 District heating (and cooling) systems

District heating systems are large-scale central heating systems which provide heating for housing estates, groups of larger buildings or parts of cities. The systems comprise one or several heating plants, a buried pipeline system for distribution of 60 to 120ºC water as well as heat exchanger centrals and hydronic heat distribution systems in the individual buildings. The heating is provided by garbage incineration plants, electro boilers, oil-fired boilers, gas-fired boilers, biomass-fired boilers, heat pumps, solar thermal collectors or a combination of heating plants. High-temperature waste heat from industry can also be used.

For combined district heating and cooling systems heat pumps are normally used in the energy central, and a large share of the cooling load can normally be covered by rejecting heat to the heat source (free cooling), e.g. to seawater, ground-water or a thermal energy storage in bedrock. In district heating systems with garbage incineration plants, heat driven absorption chillers can be installed to produce chilled water.



SSB, 2004

Fig. 3.15 Relative heat production from different heating centrals in Norwegian district heating systems.

In Trondheim (Norway) the energy utility TEV Fjernvarme AS has built a 110 km district heating grid supplying heat to about 5.000 homes and 400 corporate customers. The district heating system covers about 25% of the total heating demand in Trondheim, and about 50% of the delivered heat is produced in a garbage incineration plant, Heimdal Varmesentral (TEV, 2005).

The capacity of the district heating system is now being extended, and about 12 km with pipelines and a new garbage incineration plant will be completed by June 2007. This will increase the annual heat production by about 200 GWh, which equals the heat demand in about 15.000 homes.

A new system for seasonal storage of garbage is now being established in Trondheim in order to utilize the garbage which is delivered during Spring, Summer and Autumn, when there is a limited heating demand in the district heating system. The excess garbage will be wrapped with plastic and stored as bales of a suitable size.

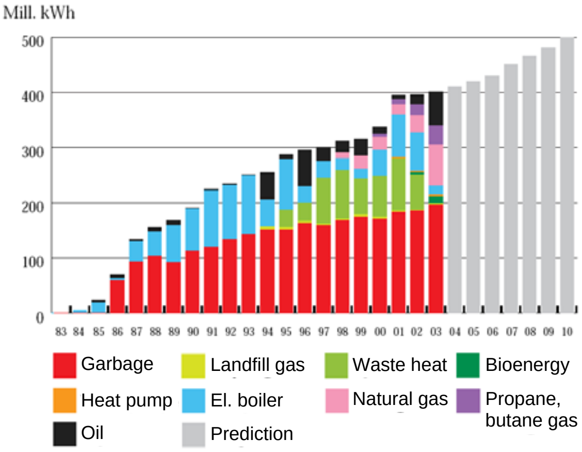


Fig. 3.16 Heat production from different sources in the district heating system in Trondheim (TEV, 2005).

During the winter the garbage bales will be used to increase the heating capacity of the incineration plant, thus reducing the need for supplementary heating from oil, gas and electricity from about 50% in 2006 to 20-25% in 2007.

The town council of Trondheim has decided that all buildings which are constructed within the concessionary area of TEV Fjernvarme AS, i.e. near the district heating grid, can be directed to connect to the grid. Consequently, it is very difficult to implement or employ other kinds of heating systems in buildings located within this area.

In summertime, there is surplus heat in the district heating system. Some of this excess heat is now being used as drive energy for absorption chillers installed in two district cooling plants in Trondheim. Most of the cooling demand is, however, covered by “free cooling “ from river water. The current district cooling plants cools about 170.000 m^2 floor area, and the total cooling production in 2005 was about 6 GWh. A new absorption chiller is expected to be installed in 2007/2008 (Eggen, 2006).

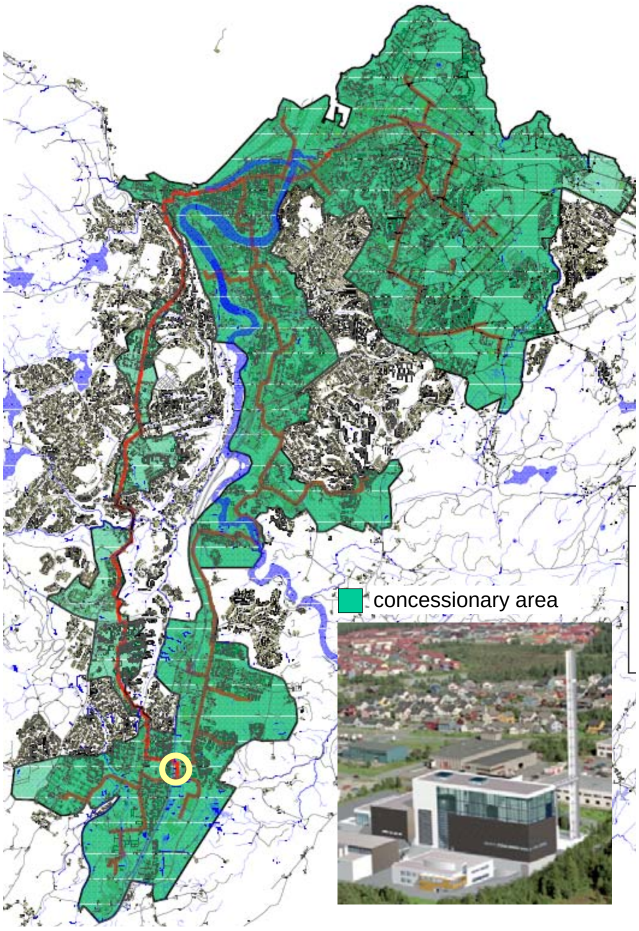


Fig. 3.17 The concessionary area for Trondheim Energiverk Fjernvarme, and the new garbage incineration plant (TEV, 2006)

3.7 Heat distribution systems

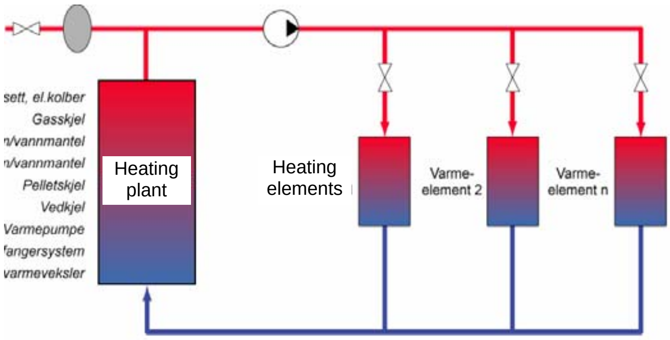


Fig. 3.18 Principle sketch of a hydronic heat distribution system.

As pointed out in the previous chapter, heating systems can be categorized as stand-alone heating systems and central heating systems. The latter type requires a distribution system for space heating, either a hydronic system or an air (ventilation) system. Space heating by means of ventilation air (e.g. CVHD) is, however, only regarded a viable option in low-energy homes and passive houses, since high air-temperatures may lead to thermal discomfort and low ventilation efficiency. Hydronic heat distribution systems are normally designed as a two pipe system, where the different heating elements are connected in parallel. Hydronic heating elements for space heating in different types of buildings include:

- Radiators
- Skirting heating boards
- Convectors with or without fan
- Floor, wall and ceiling heating systems

For *radiators* the heat transfer surface at the water and air side are relatively equal. Radiators are designed for a supply/-return water temperature of typically 80/60ºC, 70/50ºC or 60/40ºC. Each radiator is equipped with a thermostatic control valve, and some systems have temperature-time programming. Radiators have traditionally been installed below the windows in order to eliminate draft, but this is not required in low-energy buildings and passive houses.

Fig. 3.20 Example of a

Hydronic *skirting board heating systems* are made from 18 to 35 mm copper tubes which are installed along the walls and covered by a skirting board box. At a distribution temperature of 30 to 50ºC and 5ºC temperature difference between the supply and return line, the heat output per meter range from about 45 to 130 W. Due to the simple construction the systems are suitable for installation (retrofitting) in existing buildings.

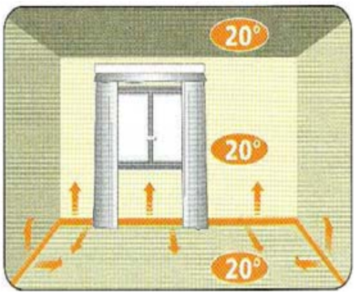


Fig. 3 20 Principle function of a hydronic skirting board heating system.

Convectors have much larger air side area than radiators, and they can be equipped with a fan for forced convection. *Fan convectors* have a heating capacity of 1 to 15 kW at 50/45ºC supply/return water temperature, and the capacity (fan speed) is controlled by a thermostat. The noise level typically ranges from 28-40 dBA at minimum capacity to 48-54 dBA at maximum capacity. Some fan convectors are designed for both heating and cooling, and in cooling mode the air is cooled by the cold brine from e.g. a brine-to-water heat pump system.

Fig. 3.21 Example of a residential fan convector.

Hydronic floor heating systems utilize the floor as the heating surface, and the systems provides good thermal comfort and high indoor air quality since most of the heat is transferred as low-temperature radiant heat. ID 15-22 mm plastic tubes are either founded in 50 to 100 mm concrete or installed in light thermal constructions in wooden floors or on top of concrete floors. The light constructions have a much better controllability and temperature response than constructions in concrete. In order to achieve optimum thermal comfort, the surface temperature of the floor should be within about 22 to 28ºC, which corresponds to a maximum heating effect of approximately 20 to 60 W/m^2. The water supply temperature should be as low as possible since this reduces the heat loss against the ground for basement installations, and leads to the highest possible efficiency for heat pump pumps, solar thermal collectors and condensing gas boilers. If the floor heating system is correctly designed, the maximum water supply temperature at 20 to 30 W/m^2 heating load will typically range from about 28 to 33ºC (Gundersen, 1998). In 2005, hydronic floor heating systems were installed in about 40% of all new single-family homes in Norway (Varmeinfo).

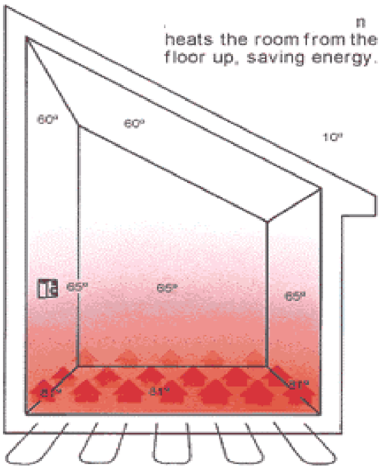


Fig. 3.22 The principle of a radiant floor heating system.

Hydronic *ceiling heating systems* utilize the ceiling as the heating surface. In order to maintain acceptable thermal comfort, the temperature difference between the ceiling surface and the air should be maximum 5ºC, which means that the systems are only applicable in low-energy buildings with low space heating demands. Low-temperature ceiling heating systems with low thermal mass are constructed in the same way as light floor heating systems installed in wooden floors, but the installation is easier and cheaper (Gundersen og Schild, 2005). Ceiling heating systems can also be used for reheating of ventilation air in balanced ventilation system as well as for space cooling. For the latter system the water in the pipeline system is cooled by means e.g. of the cold brine from a brine-to-water heat pump system (free cooling).

Fig. 3.23 Example of a low-temperature ceiling heating

3.8 Building Integrated Photovoltaics

Building integrated photovoltaic (BIPV) systems are not very common in Norway, but markets for these systems are rapidly increasing in countries like Germany and Japan. There are many products available that are easy to fit into building facades, roofs, glazing and shading systems. Most systems do not require any specialized skill to install, and BIPV have demonstrated reliable electric output. In Norway, these systems may produce 100 to 150 kWh/m^2 of module area per year. The investment cost is still quite high, ranging from 500 to 1500 EURO/m^2.

Fig. 3.24 Photovoltaic cells laminated into glass modules in the façade of a building at the University of Trondheim.

3.9 Building Integrated Wind Turbines

Wind turbines integrated into the built environment have so far not been realised in Norway, but a few examples exist in some European countries, the US and Japan. Commercial products include small vertical and horizontal axis wind turbines ranging from 2-10 kW. Costs are in the range of 3-4000 EURO/kW.

Fig 3.25 6 kW wind generator at Cumbernauld Primary School, Scotland.

4 EMISSIONS

This chapter gives an overview of emissions associated with different energy sources. It introduces two different models for weighting the environmental impacts of different energy sources; one is based on the related emissions of CO_2, the other is based on environmental costs associated with all emissions from the different energy sources.

4.1 Emissions based on CO_2

If a CO_2-based weighting model is chosen, the point of departure will be the production of CO_2 by combustion of fuel, usually related to units of produced kWh.

4.1.1 Petroleum products

It is easy to calculate the combustion of fossil fuels like oil/paraffin products where the combustion energy is transferred to heat or water, because the base data are known:

	CO_2 (kg/kWh fuel value)	
Oil	0.273	Values used by SFT[1]/SSB[2] in their calculations
LNG[3]	0.202	Values used by SFT[1]/SSB[2] in their calculations

Table 4.1 CO_2-emissions (kg/kWh) from petroleum products.

4.1.2 Biomass products

Combustion of biomass products, like wood/pellets, straw, bio-diesel/oils, etc., also produce CO_2, but a corresponding amount is bound during the growing season. Due to the short life cycle, the net production is most often used as a reference, and the CO_2 load is set to 0.

	CO2 (kg/kWh fuel value)	
Biopellets	0	The value is usually set to 0 because the amount of CO_2 that is embodied in the organic material is released either through combustion or through decomposition.
Wood, residue	0	
Straw	0	

Table 4.2 CO_2-emissions (kg/kWh) from biomass products.

Even if 0g CO_2 /kWh is an accepted and widely used value, the use of bio fuels do have other environmental impacts. In particular, dust (soot) will constitute a local pollution problem, especially if the use of bio fuels is considerable in a certain neighborhood. Other polluting substances that are released through combustion of biomass products include SO_2, NOx, CO (with incomplete combustion) and VOC.

4.1.3 Electrical energy

In Norway, electrical energy has until recently been regarded as a clean and renewable source of energy, due to the fact that all domestic use have been based on hydro power. Today, however, the situation has somewhat changed, because a certain percentage of the Norwegian electrical use is imported, and this imported energy stem mainly from European coal power. Thus currently, a certain amount of CO_2 is assigned to the production of electrical energy:

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[1] SFT = Statens Forurensningstilsyn (Norwegian Pollution Control Authority)
[2] SSB = Statistisk Sentralbyrå (Statistics Norway)
[3] Liquefied Natural Gas

	CO2 (kg/kWh el)	
Electricity from natural gas	0.348	Electricity produced from natural gas without CO_2 capture Fuel-value : 202 kg/kWh Efficiency : 60 %

Table 4.3 CO2-emissions (kg/kWh) for electrical energy.

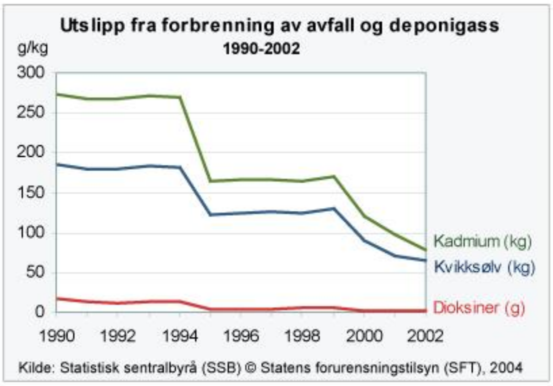
Marginal analysis

In practice, the entire production capacity of the Norwegian hydro power stations is being fully utilized. This means that the increase in the energy use has to be supplied by import. Thus, a marginal analysis of the new electricity is justified, which means that also the saved energy may be considered in this way.

It should be noted that the CO_2-emissions from production of electrical energy may vary within wide ranges, depending on the fuel source, the technology, etc. There is an ongoing debate about whether to use a marginal analysis, what energy sources should be considered (coal, oil, gas), and about what conversion efficiencies to enter into the equation.

4.1.4 District heating

A district heating plant may be based on several different energy sources. In Norway, the main energy source for such plants is solid waste (from households). The emission value for combustion of waste is set to 100 g CO_2/kWh. However, the most significant environmental impacts from combustion of solid waste are airborne emissions of cadmium, lead and poisonous organic compounds like PAH and dioxins. The total environmental emissions are dependent on whether or not toxic waste is included, how efficient the combustion process is, and how well the effluent gas is cleaned.



Utslipp fra forbrenning av avfall og deponigass 1990-2002

Kilde: Statistisk sentralbyrå (SSB) © Statens forurensningstilsyn (SFT), 2004

Figure 4.1 Emissions of Cadmium, Mercury and dioxins. Source: SSB/SFT

Energy source in DH Plant	2002 [GWh/year]	2003 [GWh/year]	mean [GWh/year]	g CO_2/kWh fuel value	Weighted g O_2/kWh fuel value
Solid waste combustion	824	1022	923	100 $^{5)}$	41.5
Oil boilers	357	560	459	285 $^{1)}$	58.8
Wood chips boilers	213	240	227	0 $^{4)}$	0.0
Electric boilers	421	188	305	348 $^{2)}$	47.6
Heat pump systems	126	139	133	116 $^{3)}$	6.9
Natural gas	57	115	86	209 $^{1)}$	8.1
Waste heat	123	63	93	0	0.0
Net production, total	2121	2327	2224		163

Table 4.4 Total energy production and CO_2-emissions from all district heating plants in Norway [GWh/år]
Source: SSB. Statistical area 10-08-10.

1) *Data taken from Table 4.1*
2) *Data taken from deduction of marginal analysis of electricity from natural gas (table 4.3)*
3) *COP for heat pump = 3*
4) *Presumes cleaning*
5) *SFT = Statens Forurensningstilsyn (Norwegian Pollution Control Authority)*

Weighted mean net CO_2-emissions (based on 2002 and 2003) may be set to 163 g/kWh fuel value. Oil and gas boilers are presumed to be of the condensing type, which give a technical efficiency of 100%. Mean heat loss from the district heating pipes is set to 8 % (same source as above).

4.1.5 Resulting weighting factors based on CO_2-emissions

Based on the previous deductions, the following table of weighting factors based on CO_2-emissions may be established:

Energy source	**g CO_2/kWh delivered**
Bio	0
District heating	176
LNG	209
Electricity	348
Oil	285

Table 4.5 Weighting factors based on net CO_2-emssions.

It should be noted that:

The method does not include the total environmental impacts associated with the use of the different fuels, only the CO_2-emissions. Also, since the method is based on mean values, it does not differentiate between different types of combustion technologies, distribution systems, or effluent cleaning systems.

4.2 A method based on other environmental parameters

An alternative weighting method to the CO_2-baseed model is to include a wider range of environmentally harmful emissions, and to weight these according to a model of societal costs of emissions. This may be done as follows:

	Bio fuels	Natural gas	Oil	Waste
Dust [mg/kWh]	9	0	6	5
NO_x [mg/kWh]	270	80	240	240
SO_2 [mg/kWh]	3	14	85	26
CO_2 [g/kWh]	0	209	285	100

Table 4.6 Emission quantities.
Source: ENERCON AS Samlede miljøkostnader. Biobrensel, naturgass og avfall. 2005

	Environmental costs	Bio fuels [NOK/kWh]	Natural gas [NOK/kWh]	Oil [NOK/kWh]	Solid waste [NOK/kWh]
Dust	590 NOK/kg	0.005310	0	0.003540	0.002950
NO_x	18 NOK/kg	0.004860	0.001440	0.004320	0.004320
SO_2	14 NOK/kg	0.000042	0.000196	0.001190	0.000364
CO_2	80 NOK/ton		0.016080	0.021840	0.007840
SUM		0.0102120	0.017716	0.030890	0.015474

Table 4.7 Estimated environmental costs for the different energy sources.
Source: ENERCON AS Samlede miljøkostnader. Biobrensel, naturgass og avfall. 2005.

The environmental costs of *district heating* may now be calculated based on the same weighting procedure that was used for the CO_2 –method above (dust fractions related to solid waste and bio fuel are set to 0).

The environmental costs of e*lectrical energy* may now be calculated based on the same weighting procedure that was used for CO_2 –method above.

Energy source / carrier	Environmental costs [NOK/kWh]	Weighting factor related to electrical energy
Bio	0.010	0.35
District heat	0.016	0.55
Gas	0.018	0.60
Electrical	0.030	1.00
Oil	0.031	1.00

Table 4.8 Estimated environmental costs and related weighting factors for the different energy sources/carriers.

It should be noted that this method is also based on mean values of emissions, so it does not differentiate between different systems within the main categories.

5. LIFE CYCLE ASSESSMENT

Ideally, a life cycle assessment (LCA) should be carried out to account for all environmental impacts of a system during its life time. In practice, however, it is most often not possible to carry out life cycle assessments of all products and systems during the planning of building projects and community systems. An LCA requires much time and resources, which most often are not available. However, one option could be to check if LCA's have been carried out for the systems and technologies similar to the ones that are being considered in the project.

The following includes a brief introduction to LCA.

According to the ISO 14040 standard, LCA addresses the environmental aspects and potential impacts throughout a product life (i.e. cradle-to grave) from raw material acquisition through production, use and disposal. The general categories of environmental impacts needing consideration include: resource use, human health, and ecological consequences.

LCA allows the environmental aspects and potential impacts associated with a product to be assessed, by:

- compiling an inventory of relevant inputs and outputs of a product system;
- evaluating the potential environmental impacts associated with those inputs and outputs;
- interpreting the results of the inventory analysis and impact assessment phases in relation to the objectives of the study.

LCA is used for:

- comparing two competing systems over their complete, or partial, life cycle.
- comparing the life cycle phases of the same system.
- comparing a system and its alternatives.
- comparing a system to a reference.

These comparisons are useful in order to assist in:

- identifying opportunities to improve the environmental aspects of products at various points in their life cycle.
- decision-making in industry, governmental or non-governmental organizations (e.g. strategic planning, priority setting, product or process design or redesign).
- selection of relevant indicators of environmental performance, including measurement techniques.
- marketing (e.g. an environmental claim, ecolabelling scheme or environmental product declaration).

6 ECONOMIC ANALYSIS

This chapter gives an introduction to different economic models that may be used to analyze total energy concepts in buildings and communities.

6.1 System boundaries

In analysing different energy concepts, focus has to be set on a detailed modelling of the *Area of Interest* (AoI). The AoI is in this case is the group of buildings to be renovated or constructed, i.e. a neighbourhood. However, important information from, and interaction with, the *Global Area* (GA) have to be accounted for in a proper way. The GA is the area beyond the borders of the AoI, i.e. the "outside world". Depending on the type of analysis that is to be carried out, one can define several different system boundaries:

- *Physical Boundary* (Attributes: Geography, capacity, energy transfer, etc)
- *Impact Boundary* (Attributes: Emissions, economy, cost/price etc)
- *Political Boundary* (Attributes: Laws, permits, concessions, polit. instruments etc)

When defining the system boundaries it is important to use a consistent methodology for all energy carriers in question and to avoid possible double accounting of attributes between the Area of Interest and the Global Area.

In a micro-economic (corporate) perspective, energy is simply traded at the system border at *market price*. In a socio-economic perspective, however, the *cost* of energy imported to the AoI is assumed to reflect long term marginal cost of generation and transmission, and externalities like environmental effects of emissions in the GA. In a perfect market environment, socio-economic cost is equal to market price. In reality, all markets are more or less imperfect due to effects like market power, unaccounted externalities and other constraints. As a first estimate, however, the market price would be a fair indicator of the socio-economic cost at the system boundary.

Within the AoI energy networks are modelled in detail, including local energy sources and total customer load (el, heat etc). All costs and emissions emerging from operations and investments inside system boundary should be included in the optimization and decision process. In the case of a socio-economic optimization, also customer installations and investments should be included.

The System Boundary between AoI and GA must be clearly defined and consistent for all energy carriers, characterized by relevant attributes. Two main approaches are common:

<u>Approach 1:</u>

- Assume that the energy price at the system boundary reflects the long term marginal cost of upstream generation and transmission costs and emissions in GA. This is a recognized principle that has been applied to electricity network planning for many years.

<u>Approach 2:</u>

- Define separate attributes for emissions and reliability at system boundary.
- Standardized and recognized methods for calculating these attributes are then needed. In particular, a method for calculating the mix of energy sources for imported electricity at system boundary is needed.

The latter approach is the most suitable when dealing with the whole building approach

6.2 Optimizing

Optimization is an activity that aims at finding the best way to do something. In mathematics, *optimization is defined as the task of minimizing or maximizing an objective function subject to a set of constraints*. E.g. an optimization can minimize the need for external energy supplied to a building, given that the basic energy needs must be met. A formal optimization requires that the objective (e.g. minimize external energy), the constraints (e.g. that basic energy needs are met) and options (e.g. possible technological solutions) are clearly defined.

In many cases it is not obvious how an optimization problem should be formulated. Stakeholders that engage in planning activities may have different objectives and preferences. An environmentalist may want to minimize the polluting emissions for a given budget at disposal, an economist may want to minimize the costs given that emissions are acceptable and an entrepreneur may want to maximize profits. These are reasonable objectives seen form the perspective of the different individuals, and one cannot use mathematics to select the “best” objective. If a project will be carried out only if several players with different objectives think it is worthwhile, it may be relevant to study the problem with several optimisations.

The goal in this study is to analyse alternative total energy concepts for eco-building projects, taking into account energy, emissions and life cycle costs. Thus, each of these factors should somehow be included (in objective or constraints) in the optimizations carried out within this study. In the following we will emphasize the total effects for the whole society measured in terms of socio-economic surplus and the discussion is based i.a. on NVE (2003), ”Samfunnsøkonomisk analyse av energiprosjekter”, Håndbok 1-2003 (in Norwegian).

There exist many different methodologies for optimisation and assessment of particular projects, and the used mathematical methods can be classified in different ways. *Static* models typically analyses the situation in one period, while *dynamic* models take into account that the analysed system evolves over time and that decisions must be taken in different periods. The uncertain outcome of some factors is taken into account in *stochastic* models, while there are no uncertain factors in *deterministic* models. Table 6.1 gives an overview of the methods that will be discussed, and in the following discussion the methods are divided into the paragraphs “Optimizing by simple calculations” and “Optimizing by complex simulations”.

The methods described in the paragraph “Optimizing by simple calculations” is static in the sense that one analyses if it is optimal or not to take an action (e.g. carry out an investment) in the present period. The timing of investments is not considered. It is however possible to take some uncertainty into account. If these “simple” methods are used the needed calculations are often carried out in Excel spreadsheets. The methods discussed in the paragraph “Optimizing by complex simulations” are usually dynamic and they take into account that decisions must be taken in different periods. When these methods are used it is also possible to make more comprehensive models of the studied system. Such models can be *linear* or *non-linear*, and variables can be *continuous* or *integer*, and the models are usually defined and solved numerically in tools for programming and optimisation, such as AMPL, GAMS, C or Fortran.

Simple calculation:	
Net present value (NPV)	Relatively simple method used in many studies. Appropriate when dynamics, uncertainties and interdependencies are of little importance. Important to calculate NPV for several competing alternatives. Attitude towards risk can be included e.g. by a risk-adjusted interest rate.
Expected net present value	Generalisation of NPV that can be used if uncertainties are important.
Cost-effectiveness	Simplification of NPV that only considers the costs of different projects. Appropriate only if there are small differences in the benefits of different projects.
Limiting factor analysis	If some restrictions (investment budget, total use of external energy) limits the set of investments that can be carried out we can use this method to prioritize between projects.

Complex optimisation:	
Linear programming (LP)	Mathematical model type that can be used to account e.g. for interdependencies between different components or projects. There exist many effective solvers for large numeric problems of this type. Restrictions must be linear and variables must be continuous. Can not be used to analyze discrete investments, but it can be used in combination with the other optimisation methods.
Mixed integer programming (MIP)	A generalization of LP that allows non-continuous variables, e.g. discrete variables for investments in particular projects. MIP problems are easy to formulate but depending on the problem the computational time can be long. A possible solution is to use LP for the system analysis and MIP only for the expansion planning. Exact solution even if there are several continuous state variables.
Deterministic equivalents	A model formulation for i.a. LP and MIP that can be used if uncertainties are important. Depending on the stochastic formulation the computational time can be long.
Dynamic programming (DP)	Divides the optimisation process into several smaller problems. For very large numerical problems with discrete variables this is an important alternative to the MIP formulation. The solution is an approximation if there are continuous state variables in the problem.
Stochastic dynamic programming (SDP)	A generalisation of DP that can be used if uncertainties are important.

Table 6.1 Some optimisation methods

6.2.1 Optimizing by simple calculations

Net present value

If only one singe project is considered and it is impossible to delay the decision of whether to invest or not, the net present value (NPV) of the project is typically considered. The present value is the sum of all discounted incomes and expenses that will occur as a consequence of the project, cf. Eq. (6.1). If the present value is positive it is profitable to make the investment. In this case the "*optimisation*" is simply to decide if the investment should be carried out or not.

$$\mathrm{NPV} = \sum_{t=t_0}^{T} \frac{\mathrm{benefits}_t - \mathrm{costs}_t}{(1+r)^{t-t_0}} \tag{6.1}$$

Symbols

NPV	:	Net present value
t	:	Period, typically a year
t_0	:	First period, e.g. 2006
T	:	Planning horizon, e.g. 2026
$\mathrm{benefits}_t$	:	The benefits of the project at time t, including rest-value in period T
costs_t	:	Costs of the project at time t
r	:	discount rate

If a private investor carries out an NPV analysis he or she will typically only include the private costs and benefits in the calculation. If, however, the socio-economic surplus of the project is calculated, all costs and benefits for the society shall in principle be included. In practice one has to make considerable simplifications e.g. by limiting the assessment to those who are directly affected by the project. Another common simplification is to assume that the socio-economic cost of buying a product from persons or firms not included in the study is given by the market price (adjusted for fiscal taxes). This would be true if markets had worked in accordance with the theoretical model of perfect competition without externalities, but in reality no markets are perfect. Still, this handy assumption is widely used. The alternative would be to use/make models for imperfect markets in any limited study or to somehow estimate the “real” resource costs. It is however common to adjust for obvious externalities.

In many cases an investment comes in response to a particular need in society. If there is too little electric power, investments in new generation will be considered. If there is an increasing need for housing due to population growth then investments in new residential areas will be considered. Thus, if one compares any given project with the hypothetical case of doing nothing to address the considered problem, almost any project would appear socio-economic profitable. It is therefore essential to compare the gains of a particular project with the gains of the *most likely alternatives*. If there are several mutually exclusive alternatives one should select the alternative that gives the highest present value (at least if one tries to maximize socio-economic surplus).

It is well known that investors dislike risk. This is often accounted for by using a larger interest rate if the size of the payoff from a project is very uncertain. It is also possible to account for risk aversion with a utility function that represents the decisions maker’s preferences. In this case one has to take different stochastic outcomes into account in the analysis.

Expected net present value
In order to calculate the NPV in Eq. (6.1) all future costs and benefits from the project must be specified. This will in general not be possible since there are many uncertain factors. The simplest way to deal with this is to guess what the future values will be and to use these guesses in Eq. (6.1). In practice annual costs and benefits are often calculated, implicitly assuming that the benefits and costs are the same each year. In this case the investments costs must be annualized to be comparable with costs and benefits that occur every year. Alternatively, one can specify the probability of different future outcomes and calculate the expected present value of the project as the probability weighted sum of all stochastic outcomes, cf. Eq. (6.2).

$$\mathrm{E}\left[\mathrm{NPV}\right] = \sum_{q=1}^{Q} p_q \sum_{t=t_0}^{T} \frac{\mathrm{benefits}_{qt} - \mathrm{costs}_{qt}}{\left(1+r\right)^{t-t_0}} \qquad (6.2)$$

Symbols
E[NPV] : Expected net present value
$\mathrm{benefits}_{qt}$: Benefits of the project at time t in scenario q.
costs_{qt} : Costs of the project at time t in scenario q.
Q : Number of stochastic scenarios
p_q : Probability for scenario q; $\sum_q p_q = 1$

Cost-effectiveness
In some cases projects are compared only by considering their costs (cost-effectiveness), cf. Eq. (6.3). The advantage with this approach is that one does not have to calculate blurred benefits of projects, and not much information is lost if there are small differences in the benefits of different projects (e.g. because the competing projects have exactly the same function).

$$\text{Discounted costs} = \sum_{t=t_0}^{T} \frac{\text{costs}_t}{\left(1+r\right)^{t-t_0}} \tag{6.3}$$

A disadvantage with this method is that possible differences in benefits (for example a possible comfort-effect of a hydronic heating system compared to direct electrical heating) are neglected. In principle it is however possible to adjust for this separately by reducing the cost of a project if it has larger benefits than other projects. Another disadvantage with this approach is that it rules out the possibility that the best strategy sometimes can be to not invest in *any* of the alternatives.

Limiting factor analysis
An investment decision can be affected by other factors than the present value. The investment budget can for example be limited. In this case it may not be possible to carry out all profitable investments, and one should select those projects that gives largest surplus per € invested.

For the current project, the amount of externally supplied energy may be a more relevant limiting factor than the investment budget. Suppose that the goal of the optimisation is to maximise the number of inhabitants that can live in a residential area for a given amount of externally supplied energy. This problem formulation can in principle be adequate for the present project, but the solution will in general not maximize socio-economic surplus. Socio-economic surplus deals with costs and benefits for society, and not the number of inhabitants that can live in a residential area. However, if this problem formulation is used, different technological solutions can be assessed by their energy efficiency, cf. (6.4).

$$\text{Energy efficiency} = \frac{\text{Energy supplied to end-users}}{\text{Externally supplied energy}} \tag{6.4}$$

A problem with this particular example is that there are many independencies in the energy system. If a particular technological solution deals with energy conversion, energy storage or energy transport it is not straightforward to calculate Eq. (6.4) for the project without using a more comprehensive mathematical tool. Such tools are discussed in the next section.

6.2.2 Optimizing by complex simulations

In the previous section we discussed some simple and recognized optimisation methods. These methods may be suitable for the intended optimisation within this project. However, many real-life optimisation problems are so complex that more advanced methods are needed. We will first discuss some of the limitation of the simple calculations, and thereafter we will discuss some alternative methods that address these limitations.

An important limitation of the criterion in (1) is that it doesn’t address *when* a profitable investment should be carried out. If, for instance, a new investment must be made to replace an important component in an energy system, the investment can have a positive present value many years before the new component actually is needed. In such cases capital costs can be reduced by delaying investments. This is not accounted for in the static evaluation in Eq. (6.1). The combination of irreversible investments and uncertainty can also make it profitable to postpone investments even though they might have a positive present value. The point is that the *option* to make a particular investment has a value, and that *option value* is eliminated when the investment actually is carried out. The theory of real options can be studied e.g. in Dixit A.K., Pindyck R.S., “Investment under Uncertainty”, Princeton University Press, 1994.

Another problem with the simple criterion in Eq. (6.1) is that it does not take into account that the costs and benefits from a particular investment project in many cases will be affected by other investments. The costs can for instance be reduced if two projects are carried out at the same time. Similarly, the benefits of one project can be reduced due to investment in another project. For instance, the benefits of a district heating system can be reduced if we also make investments that reduce the need for space heating. In such cases we cannot analyze the investments as isolated events. The principal solution to this problem is to find the combination of investment alternatives that gives the highest expected utility. But in many cases this is not an easy task if the yearly costs and benefits of the project are heavily dependent on the dynamic development of a relatively complex system. In such cases there is a need for numerical mathematical models to solve the optimisation problem. In such models one describes the world in mathematical terms, including the interdependencies between different investment alternatives. Usually there are many restrictions and variables in such models even though the models give a very simplified description of the real problem. Still, the objective in the optimisation will in many cases be similar to Eq. (6.1).

For large numerical optimisation models there are several mathematical approaches for the formal model formulation including (but not limited to) linear programming (LP), nonlinear programming (NLP), mixed integer programming (MIP), dynamic programming (DP), stochastic dynamic programming (SDP), stochastic dual dynamic programming (SDDP) and deterministic equivalents. There are also different approaches to describe the world in mathematical terms. A simple example of this is a model of perfect competition versus a model of imperfect competition. In a model of perfect competition it is assumed that each firm is so small compared to the whole market that the price is a parameter in the optimisation. In a model of imperfect competition, however, the price is a variable since the firm must take into account that it has to lower its price to increase the sales.

Since descriptive models, especially models that include human behaviour such as investments, always represent a major simplification compared to real life, it is not relevant to ask if a model is *correct*. The more relevant question is if the model is *adequate for the problem at hand*. If the model is adequate one should in principle use the mathematical optimisation method that fits best for solving such models. In practice, the model formulation continues after one has selected an optimisation method, but it can be worthwhile to consider the model formulation before choosing mathematical tools.

6.2.3 Some recommendations

In any study it is essential to include those factors and mechanisms that are important for the understanding of the problem at hand, while many less important factors must be omitted. The prioritizing of relevant factors is therefore an important step in making a model. For the present case one should try to answer the following questions:

- How will the studied system evolve over time (prices, energy needs, costs etc)? If we have such information: do we expect minor or major changes?
- Is there a lot of uncertainty with respect to the important factors in the studied problem? If there is a lot of uncertainty: do we have any opinion about possible and probable outcomes for the uncertain factors?

- Can each decision (e.g. investment) be studied as an isolated event decoupled from other decisions, or are there many dependencies between the different decisions that must be made?
- What is the object of the optimisation, and which restrictions do we have to take into account?

The answers to these questions are a good starting point for planning a model formulation and a solution method. If it is straightforward to calculate annual costs after an investment has been made and only a few mutually exclusive investments are considered, the simple NPV method is appropriate. This method can also account for some uncertainty, but special considerations must be taken with respect to defining the most important alternatives and the correct timing of profitable investments.

If there are many investment alternatives and important interdependencies either between different system components in the operational phase (after an investment has been made) or between different investment alternatives, it is not appropriate to use the static NPV method. If there are interdependencies in the operational phase a more comprehensive system model, e.g. an LP model, is needed. If there are interdependencies between investment alternatives one can for instance use dynamic programming or a MIP model. Both types of interdependencies can be included in a single model formulation, but in this case it is also possible to simplify the analysis by making separate analyses for the operational phase and for investment decisions. The stochastic methods (deterministic equivalent / SDP) should be used in those cases where uncertainties can have a large influence on optimal decisions.

7. GUIDELINES

This chapter gives some guidelines on how to combine *rational use of energy* (RUE) on the demand side with *renewable energy supply* (RES) from the supply side, in order to give the total solution a quantitative expression.

Traditionally, energy planning has been dominated by the application of energy-efficient technologies and the use of renewable energy technologies, e.g. the introduction of heat pumps, thermal insulation, and biomass systems. The systems has been optimized one-by-one by calculating the life cycle cost (or pay back time) of each system and choosing the one with the lowest life cycle cost. In the recent years, however, one has realised that in order to achieve significant improvements in overall energy performance of the built environment, it is necessary to take a "whole building approach". This means that one has to consider both demand and supply side *in connection.* In this way, one will avoid sub-optimizing of a single system, but instead focusing on optimizing the entire system. For example, it is of little use to have a very efficient heat pump system, if the house itself is so leaky that it requires a large amount of energy. In short, the energy system should be chosen and designed to fit the low demand. This also means that as a general rule, one should start out with reducing the energy demand much as possible, simply because reducing energy demand in general requires less resources than introducing efficient energy supply systems. Thus, the new energy planning design paradigm is based on the "trias energetica" principle, first formalised by Novem in the Netherlands (Lysen 1996). Trias Energetica is a three step approach that contains the following steps:

- Reduce the energy demand, by applying energy reducing measures (thermal insulation, air tightness, heat recovery)
- Use as much renewabel energy sources as possible for the generation of energy (solar, wind and biomass)
- Apply fossil fuels in the cleanest possible way (high efficient gas boilers)

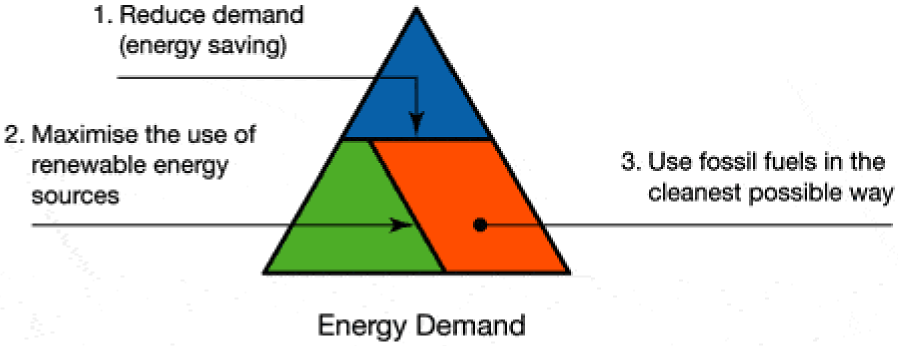


Figure 7.1 The "Trias Energetica" approach, illustration by Ad van der Aa, Cauberg-Huygen, the Netherlands.

7.1 Demand side

The Kyoto pyramid[4] is a Norwegian development of the "trias energetica" approach which has been used in several low-energy dwelling projects in Norway. The approach is organised into 5 steps:

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[4] The "Kyoto Pyramid" was designed by A. Rødsjø, Husbanken, Norway and T.H. Dokka, SINTEF, the name is inspired by the famous meeting in Kyoto, December 1997.

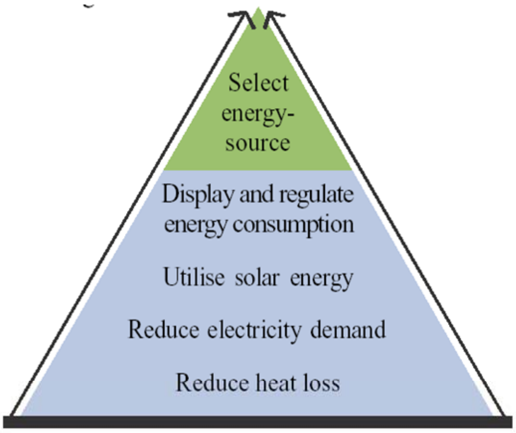

Figure 7.2 The Kyoto pyramid for design of low energy dwellings

1. Reduce heat loss:

- Extra insulated building fabric
- Super insulated windows
- Focus on building solutions that minimize thermal bridges and air leakage
- Exposed thermal mass in floor and ceiling
- Balanced ventilation with heat recovery

2. Reduce electricity demand

- Reduced energy demand for DHW (Domestic Hot Water). By minimize water consumption, better insulated reservoir and pipes.
- Low energy lighting where ”possible”
- Low energy appliances (EU-label)

3. Utilise solar energy

- Passive solar orientation of the building and the windows distribution

4. Display and regulate energy consumption

- A user-friendly information system that gives the inhabitants feedback on energy use and user habits.

7.2 Supply side

The top level of the pyramid is reserved for the energy source:

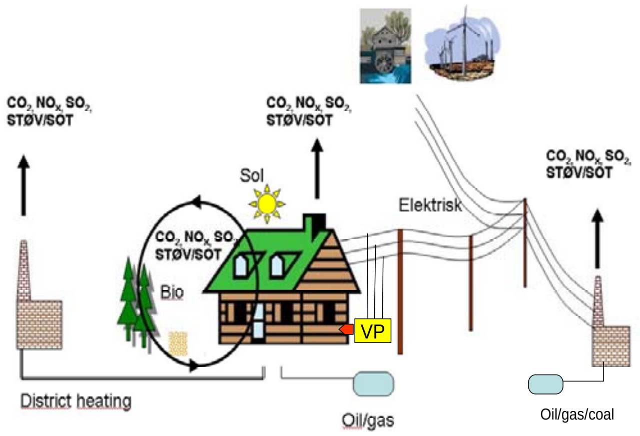

Figure 7.3 Different energy supply system with various environmental impacts

5. Select energy source

Depending on local conditions (possibilities) and the RES-ambition in the project, the type of energy source/carrier can be chosen.

Values from table 4.8 my serve as a guide:

Energy source/carrier	*Weighting factors acc. RES-values*
SUN	0
BIO	0,35
DISTRICT HEATING	0,55
GAS	0,60
ELECTRICAL	1,00
OTHER FOSSILES	1,00

It should be noted that currently there is no official weighting factors for different energy sources in Norway. The weighting factors shown in the table above are similar to the ones that have been suggested for the new Norwegian energy labelling scheme (Wigenstad et al 2005). As explained in chapter 4, these weighting factors are based on an estimation of environmental costs associated with production of one kWh of energy from the different energy sources. Thus, the weighting factors for the different energy sources will vary depending on the production method, technologies used, etc. In particular, the weighting factor for electricity is associated with a considerable uncertainty, since it depends heavily on the import/export situation of electrical energy and the technologies used for producing electricity (i.e. natural gas, coal, etc.). Given the fact that this should be considered over the entire life time of the building (i.e. 50-100 years) during which the energy technologies and import/export situation will probably change considerably, the amount of uncertainty is connected to such factors is obvious. In the table above, the weighting factor for electricity is based on the assumption that the electricity is produced in a natural gas based power plant without CO_2-capture and a conversion efficiency of 60% (as shown in Table 4.3).

It should also be noted that a district heating plant in Trondheim with seasonal storage of waste will have a weighting factor that is lower than the one shown in the table above.

7.3 Integrating demand side and supply side

Following the 4 decision steps from the Kyoto Pyramid, the *net energy demand* can be calculated. Depending on chosen energy supply system, the value must be adjusted according to the system efficiency factor (normally losses during energy transformation/ production inside the building, energy distribution inside the building, and lack of accuracy in the controlling system). This value is defined as *"energy delivered"*. The delivered amount of energy is then given a value through the environmental weighting factors (as explained in chapter 4), which leads to *"weighted energy delivered"*. This last **WED**-value includes both RUE and RES, and the combination is given a quantitative expression.

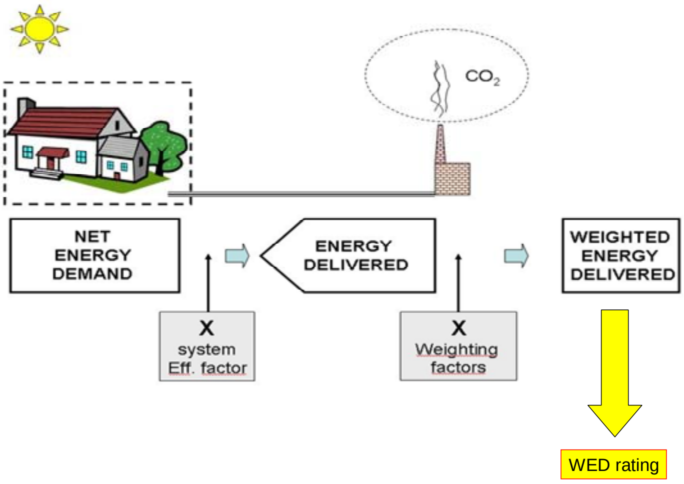

Figure 7.4 Steps from net energy demand to weighted energy delivered.

The WED-value can be treated as a unique value as such. Another possibility is to benchmark it to (i.e.) national regulations, targets in sustainability, or targets during rehabilitation. This benchmark can also be expressed as a *WED-index* by simply divide the target WED-value by the point-of-departure WED-value which could be the value for the existing neighbourhood in case of a renovation, or the normal practice WED-value for the region (in case of new construction). Starting with defining a WED-index, this can then be a leading target in all phases from planning, via construction to commissioning, involving both the RUE in buildings and RES in the energy systems.

Chapter 8 describes one possible ways to establish a WED-index for the demonstration project in Trondheim.

8. GUIDELINES. ECO CITY TRONDHEIM.

This chapter shows how the WED-method described in Chapter 7 may be applied to the demonstration projects within the ECO-City Trondheim.

8.1 Svartlamoen

Building category : Eco-rehab of dwellings in City Ecological Experimental Area, Svartlamoen, Norway

Final energy demand for space heating per m^2 of total used floor area, gross (kWh/m^2.yr):

Source	Measures to be adopted in CONCERTO building	National regulation*	CONCERTO specification	Energy savings %
Transmission through building envelope	Based on values given for building design (above) plus optimisation of window type, insulation, passive solar, intermediate climate zones and comfort metering.	106	75	29
Ventilation	Based on values given for building design (above) plus demand controlled ventilation and through partly controlled natural ventilation and heat recovery.	46	33	28
Pipe loss in building	Design, control, pipe and valve insulation on heating and DHW pipes	18	9	50
Tot. space heat excl. boiler eff.	Total Building Approach average in buildings	**170**	**117** ①	**31**

Other final energy demands per m^2 of total used floor area, gross (kWh/m^{2}yr):

Energy Demand	Measures to be adopted in CONCERTO building	Regulation / normal practice*	CONCERTO specification	Energy savings %
Lighting	Low energy fixtures & controls	25	16	36
Cooling	No cooling	0	0	0
Other appliances	Low energy equipment	5	4	0
Total	Average in buildings	**30**	**20**	**33**
DHW	Water saving fixture, pipe insulation, contr. circ.	35	23 ②	34
Others	Low energy equipment and campaigns	26	20	8
Total	Average in buildings	**91**	**63** ③	**31**

* Norwegian regulations and guidelines: "FOR 1997-01-22 nr. 33: Forskrift om krav til byggverk og produkter til byggverk (TEK)" and "Manual for Enøk normtall", Enova SF 2004.

Target:

Energy Demand	Measures to be adopted in CONCERTO building	Regulation / normal practice* [kWh/m^{2}yr]	CONCERTO specification [kWh/m^{2}yr]	Energy savings [%]
Total Energy	Electricity savings	**261** ④	**180**	**31**

WED-value:

	Energy demand gross (kWh/m^{2}yr)	Primary energy source	Weighted factor	WED [kWhw/m^2 yr]
Termal	140 (① + ②)	District heating	0.5	70
Electricity	40 (③ - ②)	Hydropower	1.0	40
				110 ⑤

WED-index			(④-⑤)/④	(261-110)/261= **0.58**

Building category: Eco-rehab of *Commercial / Cultural building* in City Ecological Experimental Area.

Final energy demand for space heating per m^2 of total used floor area, gross (kWh/m^{2}yr):

Source	Measures to be adopted in CONCERTO building	National regulation*	CONCERTO specification	Energy savings %
Transmission through building envelope	Based on values given for building design (above) plus optimisation of window type, insulation, passive solar, intermediate climate zones and comfort metering.	100	70	30
Ventilation	Based on values given for building design (above) plus demand controlled ventilation and through partly controlled natural ventilation and heat recovery.	38	24	37
Pipe loss in building	Design, control, pipe and valve insulation on heating and DHW pipes	13	7	46
Tot. space heat. excl. boiler eff.	Total Building Approach average in buildings	**151**	**101**①	**33**

Other final energy demands per m^2 of total used floor area, gross (kWh/m^{2}yr):

Energy Demand	Measures to be adopted in CONCERTO building	Regulation/ normal practice*	CONCERTO specification	Energy savings %
Lighting	Low energy fixtures & controls	32	20	38
Cooling		4	-	100
Other appliances	Low energy equipment	17	15	12
Total	Average in buildings	**53**	**35**	**34**
DHW	Water saving fixtures, pipe insul., contr. circ.	10	8②	20
Others	Low energy equipment and campaigns	24	20	17
Extended operation (40%)	**Cultural activities** in building beyond normal hours (4 hrs /day), light, amplifiers etc.	(35)	(25)	29
Total	Average in buildings	**122**	**88**③	**28**

* Norwegian regulations and guidelines: "FOR 1997-01-22 nr. 33: Forskrift om krav til byggverk og produkter til byggverk (TEK)" and "Manual for Enøk normtall", Enova SF 2004.

Target:

Energy Demand	Measures to be adopted in CONCERTO building	Regulation / normal practice* [kWh/m^{2}yr]	CONCERTO specification [kWh/m^{2}yr]	Energy savings [%]
Total Energy	Electricity savings	**273**④	**189**	**31**

WED-value:

	Energy demand gross (kWh/m^{2}yr)	Primary energy source	Weighted factor	WED [kWhw/m^2 yr]
Termal	109 (① + ②)	District heating	0.5	55
Electricity	80 (③ - ②)	Hydropower	1.0	80
				135⑤

WED-index			(④-⑤)/④	(273-135)/273= **0.51**

8.2 Granås

Building category : New dwellings e.g. at Utleira – Building Type 3: "Teppebebyggelse", Norway

Final energy demand for space heating per m^2 of total used floor area, gross (kWh/m^2 yr):

Source	Measures to be adopted in CONCERTO building	National regulation*	CONCERTO specification	Energy savings %
Transmission through building envelope	Based on values given for building design (above) plus optimisation of window type, insulation, passive solar, intermediate climate zones and comfort metering.	46	18	61
Ventilation	Based on values given for building design (above) plus demand contr. vent. and through partly controlled nat. vent. and heat recovery.	24	7	71
Pipe loss in building	Design, control, pipe and valve insulation on heating and DHW pipes	18	9	50
Tot. space heat. excl. boiler eff.	Total Building Approach, average in buildings	**88**	**34**	**61**

Other final energy demands per m^2 of total used floor area, gross (kWh/m^2yr):

Energy Demand	Measures to be adopted in CONCERTO building	Regulation / normal practice*	CONCERTO specification	Energy savings %
Lighting	Low energy fixtures & controls	26	17	35
Cooling	No cooling	0	0	0
Other appliances	Mech. balanced ventilation. Low energy equip.	7	6	0
Total	Average in buildings	**33**	**23**	**30**
DHW	Water saving fixture, pipe insul., contr. circ.	35	31	11
Others	Low energy equipment and campaigns	25	20	20
Total	Average in buildings	**93**	**74**	**20**

* Norwegian regulations and guidelines: "FOR 1997-01-22 nr. 33: Forskrift om krav til byggverk og produkter til byggverk (TEK)"

Target:

Energy Demand	Measures to be adopted in CONCERTO building	Regulation / normal practice* [kWh/m^2yr]	CONCERTO specification [kWh/m^2yr]	Energy savings [%]
Total Energy	Electricity savings	**181**	**108**	**40**

WED-value:

	Energy demand gross (kWh/m^2yr)	Primary energy source	Weighted factor	WED [$kWhw/m^2$ yr]
Termal	65 (34 + 31)	District heating	0.5	33
Electricity	43 (74 - 31)	Hydropower	1.0	43
				76

WED-index				(181-76)/181= **0.58**

8.3 Trondheim community: Public schools

Building category : Eco-rehab in public schools

Final energy demand for space heating per m^2 of total used floor area, gross (kWh/m^2yr):

Source	**Measures to be adopted in CONCERTO building**	**National regulation***	**CONCERTO specification**	**Energy savings %**
Transmission through building envelope	Based on values given for building design (above) plus optimisation of window type, insulation, passive solar, avoiding cold bridges and comfort metering.	90	63	30
Ventilation	Based on values given for building design (above) plus demand controlled ventilation and through partly controlled natural ventilation and heat recovery.	45	29	36
Pipe loss in building	Design, control, pipe and valve insulation on heating and DHW pipes	18	9	50
Total space heating excl. boiler eff.	Total Building Approach, average in buildings	**153**	**101**	**34**

Other final energy demands per m^2 of total used floor area, gross (kWh/m^2yr):

Energy Demand	**Measures to be adopted in CONCERTO building**	**Regulation / normal practice***	**CONCERTO specification**	**Energy savings %**
Lighting	Low energy fixtures & controls	28	22	21
Cooling	No cooling	0	0	0
Oth. appliances	Low energy equipment	15	12	20
Total	Average in buildings	43	**34**	**21**
DHW	Water saving fixtures, pipe insul., contr. circ.	13	10	23
Others	Low energy equipment and campaigns	11	9	18
Total	Average in buildings	**67**	**53**	**21**

* Norwegian regulations and guidelines: "FOR 1997-01-22 nr. 33: Forskrift om krav til byggverk og produkter til byggverk (TEK)" and "Manual for Enøk normtall", Enova SF 2004.

Target:

Energy Demand	**Measures to be adopted in CONCERTO building**	**Regulation / normal practice* [kWh/m^2yr]**	**CONCERTO specification [kWh/m^2yr]**	**Energy savings [%]**
Total Energy	Electricity savings	**220**	**154**	**30**

WED-value:

	Energy demand **gross (kWh/m^2yr)**	Primary energy source	Weighted factor	**WED [kWhw/m^2 yr]**
Termal	111 (101 + 10)	District heating	0.5	56
Electricity	63 (53 - 10)	Hydropower	1.0	63
				119

WED-index		(220-119)/220= **0.46**

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