DANISH LOW ENERGY AND RENEWABLE TECHNOLOGIES – PROGRESS TOWARDS SUSTAINABILITY

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Introduction and Summary

From the early 1900s Denmark relied almost entirely on imported fuel supplies, and was accustomed to using all fuel sparingly. From the late 1940s, after World War Two ended, energy use rose steeply, particularly oil. However, the 1970s Middle East oil supply crises forced the Danish government to intervene to preserve Danish energy supply security.

Resulting from government intervention, production of Danish offshore oil and gas was accelerated. District Heating was expanded. Wind power, solar power, and various forms of energy from biomass were developed. Various building energy efficiency and energy conservation measures were introduced, including improved building construction and more efficient electrical appliances.

By the mid 1980s the growth of Danish energy usage had been brought under control and some future reduction of total energy use could be planned for. By 2020 it is projected that Danish primary energy consumption will be reduced by about 10% compared with present consumption, and that of Denmark's total consumption about a third will be from renewable sources (4). Complete energy sustainability is some way off, but Danish progress is significant, and well worth studying in the UK.

With UK North Sea oil and gas supplies fast dwindling, the UK's energy supply security is becoming increasingly precarious and the Danish energy policies and technology described in this paper are becoming increasingly relevant for the UK too. A number of technical and policy measures appropriate for the UK are described in outline, together with some of the reasons why DH systems fell from favour in the UK.

Danish Energy Policy Development

Most of Denmark has a maritime climate. There are strong winds for much of the year, and winters are cold. Danish houses have long been relatively well insulated and weather tight. Annual degree days in Copenhagen are 3030 compared with 2390 in London (1). Denmark has about one fifth of the UK land area and one tenth of the UK population..

From the early 1900s Denmark had relied heavily on imported fuel supplies, mainly coal. From the late 1940s, after World War Two ended, Danish energy use rose rapidly, particularly oil usage. Denmark was used to using fuel sparingly, and when in the 1940s Denmark needed new power stations, they were designed for Combined Heat & Power (CHP) operation, and were sited near major cities to provide both electricity and District Heating (DH).

To supply the steeply rising energy demand Denmark had continued to rely entirely on fuel imports. The 1970s oil supply crises revealed that energy supply security had become precarious, and Government intervention was essential. Danish Energy Plan DE-76 (1976) focussed on improving energy supply security, on energy efficiency and on reducing oil consumption. Later, EP-81 (1981) focussed on exploiting domestic fuels and on further expansion of CHP/DH systems. Later energy plans have introduced the concept of sustainability and reduction of carbon emissions (2)

- DH systems have been expanded using heat from the existing CHP power stations, industrial waste heat, and heat from various forms of biomass and municipal waste.
- The electric power utilities already owned and operate the large CHP plants built in the 1940s. In 1986 the Government and power utilities agreed that a number of small-scale CHP plants would be built by 1995 (2). This plan was further extended and DH system boiler plant was required to convert to CHP operation or biomass.
- The power utilities buy the electricity output from all CHP plant and wind generators.

- Energy research and development has been intensified, much of it by commercial companies and Danish consulting engineers.
- Wind power has been developed and its use expanded.
- Building construction standards have continued to be improved, and electrical appliance performance standards have been developed and introduced.

Production and distribution of North Sea oil and gas began in the early 1980s and has since expanded considerably. The national heat planning system adopted in 1979 divided the country into areas according to heating density, the areas to be served by district heating and those to continue to be served by individual boilers. Extended heat transmission networks have been installed to connect urban DH schemes to remote large-scale CHP and other waste heat sources. By 1997, 50% of the electricity market and 80% of DH systems were supplied from CHP systems.

Various taxes and subsidies have been introduced to help implement official energy policy (3). For example, oil use has been taxed to discourage consumption, and the prices of other fuels have been adjusted to make DH systems relatively attractive. Subsidies for heat transmission networks between CHP plant and for other measures have been provided. Taxes and subsidies have been adjusted from time to time depending on progress with implementing national energy policies.

Future energy policy plans include progressive development and expansion of renewable energy sources to enable coal and oil fired electricity production to be phased out. By 2030 it is planned that electricity generation and DH systems will rely almost entirely on renewable sources and natural gas (4). Oil will be used mainly for transport and industrial processes. By 2020 it is projected that Danish primary energy consumption will be reduced by about 10% compared with present consumption, and that about a third of total energy consumption will be from renewable sources (4).

The changes in Danish energy demand and in the energy supply mix are illustrated in outline in the table below:

Danish Energy Consumption by Fuel (MTOE) (20)

	1950	1960	1970	1980	1990	2000
Coal	4.8	3.6	0.8	6.0	7.9	4.7
Oil	1.9	5.5	16.8	12.9	8.6	9.3
Gas	-	-	-	-	2.0	4.7
Renewables	-	-	-	-	1.2	2.2
Total	6.9	9.4	17.9	19.3	19.8	20.3

Danish District Heating (DH)

District Heating (DH) has long history in Denmark as it has in many other countries. The long established need to use imported energy supplies sparingly has made DH systems specially important.. In the past 20 years, DH has doubled its share of the whole Danish heat market from 30% to 60% (6) By 1994 DH output from all sources reached 87 PJ/annum and by 2020 is planned to reach 98 PJ/annum (7).

Danish DH systems schemes are owned and operated by municipalities, DH associations or housing associations. The schemes were originally required to be self-financing with the government providing technical support. Later, the government began providing part of the costs of extending existing DH schemes. With these and other measures, DH in Denmark has proved attractive to consumers, and has been continuously developed and extended.

Danish District Heating Technology

Most of the cost of DH systems lies in the distribution pipe work. Danish DH systems use relatively low temperature hot water with wide differences between flow and return temperatures to minimise water flow volumes and central pumping energy required. Denmark's special contribution to DH technology has been the development of increasingly cheap and efficient Low Temperature heat distribution networks and building heating systems.

Heat distribution from local CHP/DH plants uses flow temperatures generally limited to 95 deg C. Main distribution pipe work is commonly of pre-insulated steel. Heat distribution from local heating sub stations again uses mainly pre-insulated steel pipe work, but with final distribution based on all plastic pipe work and insulation, often operated at no more than 80 deg C, with static pressures no more than 6 bar. Leak detection is provided using wires embedded in the plastic foam insulation. With the temperature regime employed, pipe work can be installed with minimal allowance for expansion. Movement, if any, takes place between the outer casing and the surrounding sand. Total heat distribution losses are reported to be typically 20% (8).

Heat Transmission networks extending to many tens of kilometres connect local DH sub stations to distant power stations and other major waste heat sources. Steel pipework is used, pre-insulated with polyurethane foam (PUR) and mostly cased with polyethylene (PEH). Steel casings used where PEH would provide inadequate protection. Temperatures up to 130 deg C are allowable with the latest materials, but 120 deg C is rarely exceeded, and temperatures of no more than 95 deg C are used in many cases. Transmission pipeline static pressures may be up to 25 bar (8).

The technical success of present Danish CHP/DH technology has resulted in a large measure from well directed government funded research and development. The Planning methods, the insulated steel and plastic pipe work, the jointing and pipe laying methods, the methods of accommodating heat expansion, leak detection, heat metering and operating conditions have all been subject to continuing research and development (9). As well as government research, research and development is also carried out by commercial companies producing pipe systems, consumer installations, controls and heat metering, etc. There are several large firms of consulting engineers in Denmark who have made a substantial contribution to DH technology in Denmark and abroad. The Danish Board of District Heating is an active professional and trade association and publishes an informative quarterly journal.

Technical success has also depended on well trained engineers and technicians, on careful installation and efficient operation, including proper attention to water treatment and the repairs to any leaks which might occur. Most importantly, the European Institute of Environmental Energy in Herning provides training in District Heating, not only for Danish technicians, engineers and administrators, but also for staff from energy utilities in Germany, Eastern Europe and the Far East.

Modern Danish District Heating distribution pipe work, when properly specified, installed and operated, now has an expected life of more than 50 years. It has however taken some years of well directed development to achieve this standard of performance.

Danish District Heating Consumer Installations

Most earlier systems are Direct Systems. This means that internal building heating system radiators are directly connected to the DH system without interposing heat exchangers. Domestic hot water is heated by heat exchangers or by heating coils in storage tanks. Where secondary distribution mains static pressures are less than 6 bar, direct systems are relatively cheap and simple. In modern form they are reported to be reasonably free from problems with leakage, and are still widely used in cities such as Odense.

More recent systems are often Indirect Systems. This means that internal building heating systems are connected to the DH system via interposing heat exchangers. Indirect systems are more expensive than direct systems, but they provide a reduced static pressure downstream of the heat exchanger, and they limit the consequences of any water leak within the building. For the DH companies, indirect systems mean that less heated water has to be circulated and kept properly treated.

Domestic heating systems are normally fitted with controls to prevent DH water from being returned to the DH system until its temperature has been reduced to below about 40 deg C. This is achieved by measures such as fitting thermostatic radiator valves with adjustable flow restrictors, and by controlling the differential pressure between heating flow and return mains. By these means radiator heat outputs and return temperatures can be accurately controlled.

The heat consumed in each dwelling is required to be accurately metered. Modern installations use ultrasonic heat meters which measure water flow and temperature difference. The latest heat meters are centrally monitored, and by measuring the differential flow between building supply and return pipes they can detect any water leakage within a building.

Building heating terminals are now generally supplied as packaged units complete with valves, heat exchangers, pumps and controls. The equipment needed for building installations has been subject to many decades of well directed development, and is available from many Scandinavian suppliers and their UK agents.

Danish Combined Heat & Power (CHP) Development

Denmark has long been aware that using the waste heat from large-scale thermal electricity generation for heating buildings via district heating systems made maximum use of the energy in the fuel consumed. When in the 1940s Denmark needed new power stations, they were designed for Combined Heat & Power (CHP) operation, and were sited near major cities to provide both electricity and district heating (DH). The six new municipal CHP power stations built in the 1940s were by 1977 delivering about 7 TWh of heat/annum in addition to about 21 TWh of electricity (5).

`From the late 1980s a number of small-scale CHP plants were built to serve district heating schemes in urban areas not already served by CHP schemes. The latest CHP power stations are typically gas-fired Combined Cycle systems with a refuse and biomass incineration plants in addition. Such CHP power stations produce almost as much electricity for sale as electricity-only power stations, with substantial heat sales in addition.

For example, the Viborg CHP plant has one 42 MWe gas turbine and one 16 MWe steam turbine to serve the eleven local district heating schemes and 10,000 households via a 12 km heat transmission network. The electrical and heat outputs are 58 MWe and 58 MWth respectively. The plant's overall energy efficiency is 88%. Viborg's 1998 heat sales were 40% of total sales, and contributed substantially to the plant's overall viability, as well as reducing the need to use even more gas, oil or electricity to heat the houses served by Viborg's district heating network (2).

To achieve maximum operational flexibility and economy, Danish CHP power stations generally have large hot water heat storage accumulators. The heat stores normally operate at atmospheric pressure, and at temperatures typically 95 deg C. Typically, a steam cushion at the top of the store is used to exclude oxygen from the system (9).

As in the UK, Denmark has a number of industrial CHP schemes, but their total power capacity amounts to only about 5% of Denmark's total installed CHP capacity (2).

Danish Renewable Energy Schemes

Denmark has played a leading role in developing renewable energy sources with the objects of reducing both CO2 emissions and fossil fuel consumption. If development continues along present lines, by 2005 it is expected that up to a third of electricity consumption will come from renewable energy sources, and by 2030 it is projected that up to a third of all primary energy will come from renewable energy sources (4).

Wind Power

The Danes regard wind power as one of the cheapest methods for reducing CO2 emissions from electricity production (10). By 1996 3,800 wind turbines with a total capacity of 600 MW and an annual output of 1,200 GWh had been installed, with installations becoming progressively bigger and more efficient. In 2001 wind turbines produced 4,300 GWh (12)

The new Danish Government has abolished the administrative instructions to generating companies building off-shore wind farms, and some observers have assumed that no more would be built. However, it is understood that the Danish Government intends to encourage the further expansion of off-shore wind farms by other means (11), and the generating companies are understood to be continuing to build new off-shore wind farms (12). In addition to expanding off shore wind energy production, the generating companies have offered incentives to owners of 2,000 old wind turbines of below 100 kW capacity to scrap their existing turbines and to replace them with larger machines (12).

Energy from Biomass

The economics of burning, gassifying or digesting all available forms of biomass have been explored, and are now being rapidly developed. It is projected that by 2030 Biomass will provide over 20% of all Danish primary energy requirements (13).

Significant numbers of relatively small scale biomass plants are already in commercial operation, and larger plants are being built (13). Existing plants include:

- 120 new straw or wood chip fired DH systems plants are now in operation. Wood chips are apparently the preferred fuel for new plants.
- 35 relatively old coal-fired DH systems plants have been converted to burn wood pellets. These are more expensive than wood chips, but only relatively minor alterations to the boilers were required. The change from coal to biomass has meant that combustion emissions have become CO2 neutral.

More than 60% of all municipal waste is incinerated and it provides about 5% of the fuel needed for electricity and DH systems production. The environment is protected by intercepting the ash in the flue gases using electrostatic precipitators. Lime reactors are used to reduce hydrogen chloride, hydrogen fluoride and sulphur oxide emissions (14). It is understood that Danish public opinion is more concerned about the use of landfill than about refuse incineration.

Should the UK now begin to learn from Denmark ?

UK Industry statistics suggest that UK Continental Shelf oil and gas supplies will all be used up within less than ten years (15). Before ten years are up the UK will increasingly have to rely on gas and oil supplies from abroad, much of them imported via long distance pipelines (17). UK energy supply security is becoming increasingly precarious, our balance of payments seems likely to be affected, and fuel prices seem bound to rise. These reasons alone are sufficient to justify the recent Energy White Paper's call for economies in UK energy use.

Despite the UK's precarious energy future, we still use energy wastefully when compared with Denmark and others of our neighbours. For example, UK central power stations are not designed for CHP operation, and they waste much of the energy in the fuel they consume in conversion and distribution losses. Further, in the absence of large scale DH systems, UK buildings consume even more gas than our power stations (16). Again, much of it is wasted in boiler and other losses. Also, UK power stations consume about a half of UK extracted water supplies, a matter of increasing importance (19).

The table below contains relevant statistics from various official sources. It will be seen that delivered energy consumption per capita is much the same. Although Denmark is colder in winter, they keep their houses warmer. Danish building energy use is no more than in the UK mainly because Danish building construction standards are more demanding than UK building construction standards.

The major differences are that Denmark uses much less primary energy per capita than the UK. This is mainly because Denmark's conversion and distribution losses per capita are less than half of the UK's. Denmark also uses about ten times as much renewable energy per capita as the UK.

Selected Danish and UK Statistics

Item	Denmark	UK
Area: Sq km	43,000	243,000
Degree Days:	3030 (Copenhagen)	2390 (London)
Population: millions	5.3	59.1
Primary Energy use: mtoe (2001)	18.7	248.7
Renewables: mtoe (Included in total use)	2.2 (11%)	3.1 (1%)
Conversion and Distribution Losses: mtoe	3.4 (18%)	77.0 (31%)
Delivered Energy: mtoe	15.3	171.7
Transport Energy: mtoe	4.8	54.9
Domestic Energy: mtoe	4.4	48.6
Trade and Services: mtoe	1.9	22.1
Industry: mtoe	4.0	35.1
Non-Energy Use: mtoe	0.3	10.9
GDP: $millions	161.5	1283
GDP/capita: $	33,000	24,000

Danish Energy Efficiency Improvements applicable to the UK

Considerable government intervention and many years work would be needed to convert the UK electricity supply system to CHP/DH operation, and to accelerate the adoption of renewable energy sources. Such intervention is not envisaged in the recent Energy White Paper, but the need for it may be seen with increasing clarity when North Sea oil and gas supplies begin to dwindle and competition for oil and gas supplies from distant shores intensifies.

However, there are measures for improving UK energy use efficiency many of which are within the construction industry's power to implement, given the necessary government support and the necessary will to do so. Where not already available in the UK the equipment needed and the engineering principles to be applied are all available in well developed form from across the North Sea and elsewhere. These measures include:

- Group and community heating schemes served by small-scale CHP systems, with WTD/VV heat distribution. Such CHP systems can in many cases use biomass or refuse fired boilers.

- Wide temperature difference, variable volume (WTD/VV) building heating systems. These need much less electrical energy than is needed for typical UK narrow temperature difference fixed volume heating systems. Also, with WTD/VV heating systems it is easier to make condensing boilers and typical small-scale CHP systems operate as efficiently as generally assumed in official guidance papers. Similar principles can be applied to chilled water systems.

The technical measures described above are generally widely established in neighbouring countries as well as in Denmark, and are not technically complex. However, Government intervention and support is almost certainly needed to provide adequate training for technicians and engineers and to re-establish independent energy related government research and development. These and other things are starting to happen, but we need more people thinking this way before we are forced by circumstances to do so.

Some Reasons for Problems with early UK DH systems

During the 1960s many UK local authorities installed DH systems to serve their new housing schemes. However the concept gradually went out of favour for reasons including the following:

- Many UK schemes were not well enough engineered, installed, operated and maintained. As a result some suffered premature underground mains failures.
- Most schemes depended on commercial fuels whose cost rose substantially in the 1970s. The schemes were not adapted to use cheaper or renewable fuels.

- DH scheme operators generally failed to take effective steps to improve underground mains reliability and to make other technical and other changes needed to keep the schemes attractive to their users.

UK government support in the form of enabling legislation, economic instruments and technical support for District Heating was not adequate to ensure success. In the 1960s, the UK nationalised electricity and gas industries understandably took steps to preserve and to increase their own market shares. In any case, the UK appeared to have ample indigenous fuel supplies and saw no special need for Government intervention.

Conclusions

Impelled to take action by the 1970s oil supply crises, Denmark has since managed to bring her energy consumption under control. Both energy supply and energy use technologies have been substantially improved. As a result, energy consumption in 2001 was no more in 1980 and a reduction of 15% by 2030 is projected. Significant features are as follows:

- The expansion of CHP/DH systems has meant that about 30% of reject heat from all electricity production is now used to heat buildings via CHP/DH systems, and the use of oil and other primary fuels for heating buildings has been substantially reduced.

- Total energy usage includes an increasing proportion of renewable energy.

Until recently the UK had seemingly ample indigenous fuel supplies, and has seen no urgent need to economise. However, with North Sea Oil and Gas supplies fast shrinking, the UK also needs to adopt even more vigorous economy measures than those called for in the recent Energy White paper. It is suggested that many of the policy and technical measures adopted by Denmark are relevant to the UK's situation, and could and should be adopted by the UK in the near future.

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