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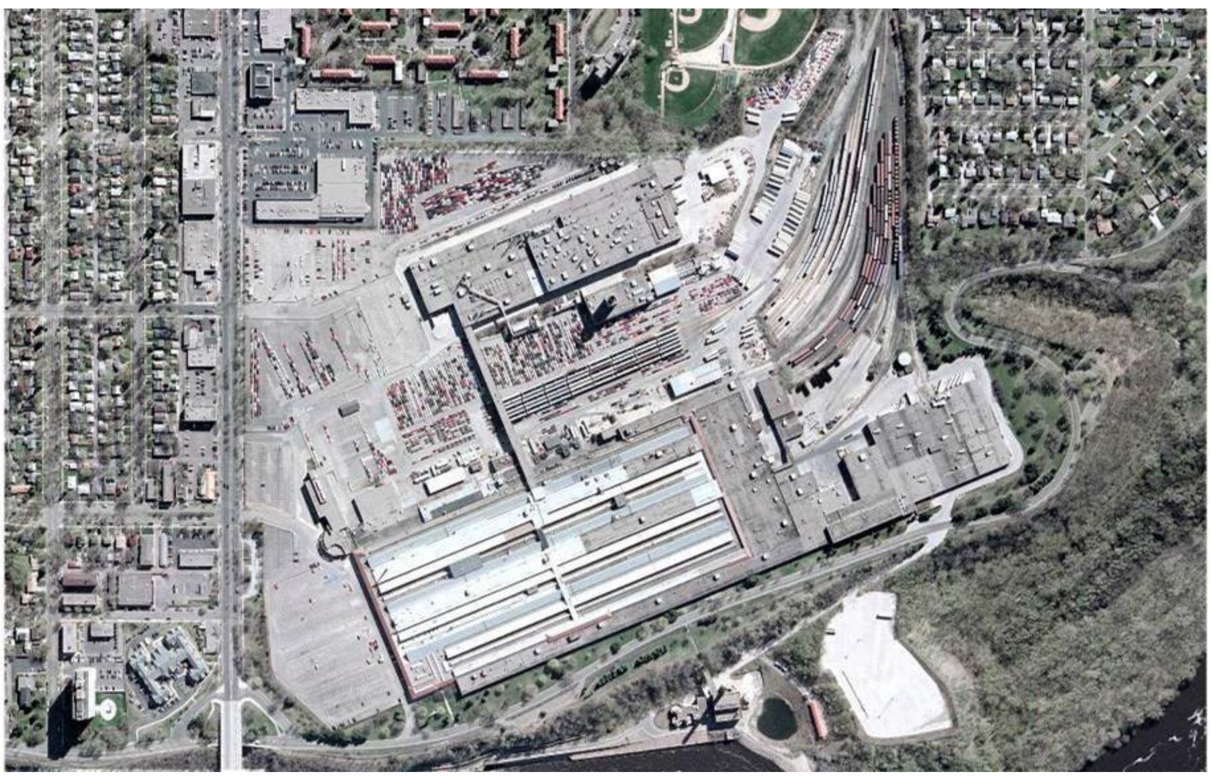
ST PAUL FORD SITE
ENERGY STUDY REPORT



ST PAUL FORD SITE
ENERGY STUDY REPORT

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1. ACKNOWLEDGEMENT

We would like to acknowledge the support of the Technical Advisory Group (TAG) Committee and extend our gratitude for the hours they spent attending meeting and commenting on reports.

The TAG committee consisted of:

1. George Andraos, Director of Energy, Ford Motor Company
2. John Carmody, Senior Fellow, University of Minnesota
3. Eric Engh, Senior Vice President, Ryan Companies
4. Bill Grant, Deputy Commissioner, Minnesota Department of Commerce
5. Richard Graves, Director, U of M Center for Sustainable Building Research
6. Zack Hansen, Environmental Health Director, Ramsey County
7. Alexandra Klass, Professor of Law, University of Minnesota Law School
8. Matt Kramer, President, Saint Paul Area Chamber of Commerce
9. Laura McCarten, Regional Vice President, Xcel Energy
10. Michael Noble, Executive Director, Fresh Energy
11. Matt Schuerger, Energy Systems Consulting Services and Ford Task Force Representative
12. Ken Smith, President & CEO, District Energy St. Paul
13. Sheldon Strom, President, Center for Energy and Environment
14. David Thorton, Assistant Commissioner, Minnesota Pollution Control Agency

The main consultant team consisted of professionals from Ramboll and Krifcon Engineering:

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The main Client team consisted of:

- Merritt Clapp-Smith, Principal City Planner, Planning and Economic Development
- Anne Hunt, Environmental Policy Director, Office of Mayor Chris Coleman
- Jim Giebel, Energy Coordinator, LEED AP, Office of Financial Services

2. EXECUTIVE SUMMARY

The City of Saint Paul hired Ramboll with Krifcon Engineering to undertake an energy master plan study for the redevelopment of the Ford Site.

The intent of the study was to focus on the opportunity to provide the site with a sustainable energy supply, while utilizing local resources.

The work of the consultants has been carried out in close collaboration with the Ford Site Technical Advisory Group, which consists of scholars, utilities, regulators, city representatives, and Saint Paul business representatives. The consultants would like to thank everyone involved for their many inputs.

The Study consisted of distinct activities as outlined below:

Activity 1.1: Conditions, constraints and opportunities
Activity 1.2: Best practice in car use alternatives
Activity 1.3: Best practice building design to reduce energy demand
Activity 1.4: Implementing sustainable site-wide energy system
Activity 1.5: Energy technologies and district energy designs
Activity 1.6: Energy mix, storage and pricing
Activity 1.7: Design concepts and Financial Analysis

This report summarizes the key findings and recommendations of each activity.

The ambition for the site is to be an economic, social, and environmentally sustainable place that provides good jobs, services, community amenities and living spaces and serves as a lighthouse project for future developments. More specifically for the energy part, it was agreed at the launch of the study that the ambition for a Ford Site energy system was to address five guiding objectives:

- **Resilience:** Security of energy supply
- **Innovation:** Rethinking energy supply and energy systems not being limited by current practices
- **'Net Zero':** Limiting the energy consumption and CO_2 emissions to a minimum while maximizing the share of renewable energy
- **Energy efficiency**: Making best use of the energy with low conversion and distribution losses and efficient building stock
- **Cost-effectiveness:** Ensuring affordable energy for the site

Dozens of energy technologies were evaluated and distilled into three energy system concepts for the site. Each concept was analyzed for technical and financial viability, and its ability to meet the five guiding objectives. The analyses identified two technical concepts that best meet the objectives for the site, which are likely to need the City of Saint Paul in a proactive leadership role, since each represents a new approach to energy delivery for sites of this type in the Twin Cities region.

Actions that the City could take to ensure a low carbon solution for the Ford site is to continue its well-established stakeholder engagement, to instigate planning related recommendations, and to safeguard technical issues that will enable the implementation of the best solution for the City, the site, and the community at large.

3. INTRODUCTION

Ramboll with Krifcon Engineering were hired by the City of Saint Paul to work on an energy master plan concept for the redevelopment of the Ford Site into a 21st Century Community. Ramboll has a vision of contributing to developing sustainable cities that are attractive for residents, businesses, and visitors. Our experiences are drawn from projects in all parts of the world, with roots in Scandinavia and Copenhagen in particular.

The intent of the study is to focus on the opportunity to provide the site with a sustainable energy supply, while utilizing local resources.

The work of the consultants has been carried out in close collaboration with the Ford Site Technical Advisory Group, which consists of scholars, utilities, regulators, city representatives, and St Paul business representatives. The consultants would like to thank everyone involved for their many inputs.

An impressive amount of preparation and consideration has already been put into the redevelopment work for the site and provided a solid foundation to build on.

In particular, the Phase 1 Summary report[1] has served as the basis for expected redevelopment scenarios used in this study.

3.1 The vision, goals and priorities for the site

Building upon the earlier work, the ambition for the site is to be an economic, social, and environmentally sustainable place that provides good living spaces and serves as a lighthouse project for future developments. More specifically for the energy part, it was agreed at the launch of the study that the ambition for the Ford Site was to work with five guiding objectives:

- Resilience: Security of energy supply
- Innovation: Rethinking energy supply and energy systems not being limited by current practices
- 'Net Zero': Limiting the energy consumption and CO_2 emissions to a minimum while maximizing the share of renewable energy
- Energy efficient: Making best use of the energy with low conversion and distribution losses and efficient building stock
- Cost-effectiveness: Ensuring affordable energy for the site

Note: Biomass was not seriously evaluated as a potential energy source in this study because the City of St Paul said it would not be a good fit for the site location due to site constraints. In Ramboll's experience, biomass is a common district heating solution, even in urban areas, to decarbonize in the most cost effective way.

There are environmental challenges with biomass but the experiences to meet these challenges are many. In Ramboll's opinion, not utilizing biomass as an option limits the viable opportunities for introducing a low or net zero carbon energy solution to the Ford site.

3.2 Preceding and preparatory works and studies

Prior to the energy study, many preparatory activities for site planning have been carried out. These have provided background information and served as guidelines to assure coherence between energy supply solutions and other aspects.

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[1] Redevelopment of the Saint Paul Ford Site - Phase 1 Summary Report, found on the City of Saint Paul Ford webpages at http://stpaul.gov/21stcenturycommunity.

3.2.1 Phase 1 summary Report

The Phase 1 Summary report outlines five potential development scenarios. From those scenarios, it was decided to use No. 2 and No. 5 to simulate potential site energy use intensity (EUI) and demand that the proposed solutions are based on.

3.3 Contents of the study – delimitation

The Study has set out to evaluate possible energy supply setups that match the needs and ambitions for the Ford Site redevelopment. The exercise is mainly intended to be a high-level technical evaluation, with a focus on thermal energy and the potential for a local energy network (district heating and district cooling).

The case for district energy solution has been evaluated in comparison with current practices -- Business as Usual (BAU) (natural gas network and individual Heating, ventilation and air conditioning (HVAC)) -- and with an option focused on renewable energy at the individual building level.

In addition to the core evaluation of energy system setup, the following activities have been included to support and validate the results:

15. Evaluation of the potential re-use of tunnels and the steam plant building on the Ford Site
16. Best Practices in Car Use Alternatives
17. Best Practices in Building design and energy demand

The study does not deal with the structural setup between utilities and developers, and ownership of production units, networks, and installations. Also, no socio-economic analysis has been carried out to determine the most favorable solution for the greater St Paul and Minneapolis area.

3.4 The study and review process

The Study consists of distinct activities as outlined below:

Activity 1.1: Conditions, constraints and opportunities
Activity 1.2: Best practice in car use alternatives
Activity 1.3: Best practice building design to reduce energy demand
Activity 1.4: Implementing sustainable site-wide energy system
Activity 1.5: Energy technologies and district energy designs
Activity 1.6: Energy mix, storage and pricing
Activity 1.7: Design concepts and Financial Analysis

The Study was initiated in summer 2014 and launched with a site-visit and kick-off meetings in September 2014. The site-visit served as a fact-finding mission for the consultants and allowed for in-depth discussion with many stakeholders. The first objective for the consultants was to clarify the specific ambitions and objectives for the site in terms of energy and environmental performance.

During a meeting with the Ford Energy Study Technical Advisory Group (TAG) in early September 2014, the five priorities for a site energy system -- Resilience, Net Zero, Energy Efficiency, Innovation and Cost-effectiveness -- were agreed to. No prioritization or weighting of the priorities was identified.

In mid-November 2014, the consultants met again with the TAG and presented interim results on the evaluation of 1) Re-use of site tunnels and steam plant buildings; 2) Best

Practices in Car Use Alternatives; 3) Best Practices in buildings design and energy demand; and 4) Initial screening of potential energy technologies and system setup to apply.
The main discussion with the TAG centered around how to balance the five priorities and in particular the relative importance of environmental performance versus cost competitiveness.

The energy concept for the site is constrained by a number of important factors:

- the relatively small size of the system due to the good energy performance of buildings and size of the site, which limits economies of scale
- limited possibilities for accessing the site with biofuels or other transportation based sources
- the Mississippi River as the only inherent local resource available for the site

Following the TAG meeting in November, the consultants prepared more in-depth evaluations of the most likely energy concepts optimizing on the five priorities. The results were presented at a TAG meeting in January 2015, when it was agreed to focus on a solution with district heating and cooling based on solar thermal panels, heat pumps/chillers (for heating and cooling) run on river water, thermal storages and gas boilers for back-up and peak-load production. In the run up to the meeting, a sub-group of the TAG proposed to focus the priorities to 1) energy efficiency, 2) Net Zero and 3) Cost-effectiveness, without losing sight of 4) Resilience and 5) Innovation. To evaluate the district energy concept, it was to be compared to a business as usual scenario and an individual supply scenario.

In parallel, it was agreed to expand the scope of the study to include a high-level financial feasibility assessment of the three energy concepts.

During the visit in January 2015, the consultant team presented the study process at a public meeting held by the City, and met with a number of developers who might have an interest in a large redevelopment site like the Ford Site.

4. CONSTRAINTS AND ASSUMPTIONS

This section outlines the constraints and assumptions that the energy concepts are based upon.

4.1 Localization

The 135-acre (≈55 ha)[2] Ford Site is located between St Paul and Minneapolis, Minnesota, adjacent to the Mississippi River on one side and residential neighborhoods on the other, as the city has grown to surround the site. The location's limited transportation access complicates the ability to supply large quantities of fuels e.g. biomass or bio-oils, as part of an energy solution.
In proximity of the site there a number of large energy consumers that in time could be integrated into a district energy network, such as St Catherine University and the Minnesota Veterans Home, but given the uncertainty regarding the Ford Site itself, as well as energy requirements of the neighbors, these potential consumers are not considered in this study.

A hydroelectric plant is located just next to the site. This plant was historically part of the site but has been sold off and now supplies electricity to the grid.

[2] Including 13 acres of Canadian Pacific Rail property.

4.2 Ford Site infrastructure

The main area of the Ford Site is being prepared for redevelopment with no remaining infrastructure or buildings. The only buildings to remain are the former steam plant and wastewater treatment plant on the riverbank. The steam plant is worthy of preservation due to its architectonical value. The buildings may serve as a future energy center as applicable.

Picture courtesy of Ramboll taken during site visit

The Site is equipped with an extensive underground tunnel system utilized in the past for silica sand mining and transportation of vehicles. A duct has been used to distribute steam from the former steam plant on the riverbank throughout the site. Traffic tunnels have been used to move finished vehicles from the production facility to the riverbank for further off-shipping. A number of sand tunnels have been used for mining sand and cover large parts of the site.

The other remaining infrastructure is a natural gas branch close to the steam plant building and electric utilities on the north side of the site.

4.3 Urban development and energy demand

To evaluate potential energy concepts for the site, two development scenarios for the build out have been used. The two scenarios are picked from the Phase 1 Summary Report, Scenarios 2 and 5. Both scenarios envisage a mixed use of the site with different profiles, Scenario 2 has more light industrial whereas Scenario 5 has a dense urban-village profile with a large residential share.

Based on the scenarios, the energy demand and profiles for the site have been developed, which lays the basis for the energy concepts. The energy concepts have been optimized for a phased build out of the site over 10-15 years.

For the financial viability analysis, the City of St Paul and their advisors have chosen to proceed with using Scenario 5 with a high residential density as the baseline for building stock area and type distribution.

Based on the distribution of energy, annual heating and cooling demands for Scenario 5 can be summarized as follows:

Annual Total Heat demand	Annual Total Cooling demand
47,503 MMBtu/yr	25,616 MMBtu/yr
13,922 MWh/yr	7,507 MWh/yr

Site Energy Utilization Intensity (EUI) for different building types have been used according to climate zone 6A (St. Paul) and the Minnesota Sustainable Building (SB) 2030 code.

5. BEST PRACTICE INPUT

This section introduces the inspiration gathered in activity 1.2, 1.3 and 1.5 regarding best practices in car use alternatives, building design and district energy systems.

5.1 On site transport

The transport sector and the energy sector are often highlighted as the main obstacles to a green and sustainable urban development and a key bottleneck in modern urban environments. Minimizing individual car use will thus contribute to a more sustainable site and less congestion in the surrounding areas.

Experiences from all over the world show that significant reductions in car use are hard to come by and where reductions are seen they are often a result of holistic planning exercises. Such planning includes not only traffic infrastructure but also building densities with more dense areas around transit nodes that combine various types of public and private transport modes.

The Ford Site presents a very good opportunity to demonstrate a (near) zero car environment in the United States. Saint Paul hosts a well-functioning bike-sharing program in Nice Ride[3], the site is bordered by a strong bus transit corridor, and if a study currently underway identifies the Ford site as the route for a new light rail line, then the Ford Site will significantly bring down the need for individual cars.

Shared space in Brighton, UK

[3] https://www.niceridemn.org/

The on-site transportation could give priority to walking and cycling, and work on a shared space principle where signs and markings are removed and it is up to the users to agree on the right of way, where to park, etc. Shared transportation spaces around the world have been very successful with little conflicts and accidents and allow for multiple modes in the traffic areas.

As the highest aspiration, a car free Ford Site would provide better air quality and significantly reduce the carbon and energy footprint of the site.

5.2 Concept for sustainable building design

Building design and energy intensity have developed quickly in recent years. In many parts of the world, examples of zero-energy or Passivhaus buildings have been built pushing the boundaries for what is possible. The performance of the buildings varies and the installation cost is often high, and it raises the question of what is the right level of ambition.

If we are to partly or fully decarbonize the energy system, how do we then find the balance between improving energy performance of the buildings and the energy system. Almost all low energy houses have energy generation attached to the building often as solar energy, which essentially shifts the generation from a central point to the end consumers.

The energy standards for the State of Minnesota in general are less ambitious than at the federal level (ASHRAE 90.1/IECC or International Residential Code) according to the Department of Energy (DOE). One of the initiatives to improve energy standards is the Minnesota SB 2030 Energy Standard that requires a gradual reduction in carbon emission starting in 2010 with 60% less than a 2003 code legal building of same location, type, and use, and ending with net-zero carbon emission in 2030.

SB 2030 is a localized version of Architecture 2030's 2030 Challenge.

Other examples of systems that promote green or energy efficient buildings are Energy Star, LEED (Leadership in Energy and Environmental Design), Green Globes, Advanced Energy Design Guides, 2030 Challenge, Living Building Challenge, and Passive House.

Looking from an international perspective, the European Union has a goal of having all new construction being nearly zero by 2021 as mandated by the Energy Performance of Buildings Directive, EPBD.[4]

To decide the level of ambition, the Danish Building Research Institute has studied the cost-optimal levels of minimum performance requirements and concludes that somewhere between the Danish Energy Class 2010 and 2015 makes sense. Translating that to Minnesota conditions and e.g. SB2030 is not easy[5], but the climate zones are comparable and therefore minimum requirements similar to the SB2030 targets for 2020, corresponding to 80% below 2003 legal code, with a small amendment, have been recommended and used for further analysis.

[4] http://ec.europa.eu/energy/efficiency/buildings/buildings_en.htm

[5] Comparing various rating and standards is not a simple task though that the methodology differs depending on the focus areas, one typical example is that the electricity plug loads are included in some schemes.

kBtu/ft²/yr

Code / Building Type	Prototype Floor Area (ft²)	ASHRAE 90.1-2004	2012 IECC / ASHRAE 90.1-2010	SB 2030 Suggested Ford Site Requirements	Percent below 2003 baseline
Small office	5,502	53.7	41.8	32.0	80
Medium office	53,628	62.2	46.2	30.0	80
Large office	498,588	99.7	84.8	30.0	80
Stand-alone retail	24,692	107.2	71.9	29.3	80
Strip mall retail	22,500	118.3	85.4	30.0	80
Supermarket	n/a	208.0	145.0	27.3	80
Primary school	73,959	100.1	75.1	34.0	80
Secondary school	210,887	98.4	64.7	29.3	80
Hospital	241,501	179.9	138.5	79.3	80
Outpatient health care	40,946	161.5	123.3	58.7	80
Full-service restaurant	5,502	570.2	470.9	48.0	80
Quick-service restaurant	2,501	781.9	723.0	52.7	80
Small hotel	43,202	87.4	75.8	42.0	80
Large hotel	122,120	151.8	119.1	44.0	80
Warehouse	52,045	35.3	25.2	20.0	80
Mid-rise apartment	33,741	68.0	60.4	38.0	85
High-rise apartment	84,360	72.1	65.8	39.5	85

In addition, we recommend that some elements of control of process and plug loads are included in the Ford site development requirements. It could be a strengthened requirement for plug load control and/or only Energy Star certified or better appliances to be installed.

5.3 Energy system best practice

District energy offers the opportunity to implement the most efficient, clean and future proof energy supply but it is important to ensure that the solution chosen is optimized in terms of its production, distribution, and usage.

A district energy system offers added value to individual systems in respect to the resilience and fuel changing flexibility that it offers.

The City of St. Paul already has a well-functioning district energy system, District Energy St. Paul that provides highly efficient hot water service to almost 200 buildings in downtown.

Although the Ford site is somewhat remote from the downtown, it makes good sense that a potential new energy system in the town aims to be compatible and/or aims to be capable of connecting to the existing system should such an opportunity arise in the future.

Illustration of potential outline of network on the Ford Site

A district energy system is a great foundation for low-carbon energy supply of buildings. By having both district heating and district cooling, certain synergies can be achieved, which can increase the energy efficiency and reduce the price of both heating and cooling for the end consumers.

The design recommendations are inspired by know-how and experience from European countries like Denmark where the district energy concept is well established.

A low temperature heating and high temperature cooling system would be offering the Ford site an opportunity to utilize renewable energy sources.

In a historical perspective, a low temperature district heating can be categorized as the 4th generation of the technology development, following the steam-based systems (1st generation), the superheated water systems (2nd generation), and the hot water systems (3rd generation).

Conventionally, the heat demand in a district energy system is met by waste heat from power stations (co-generation) and/or Energy from Waste (EfW) utilizing a heat generation which would otherwise be wasted and subsequently it comes at a very low cost. In smaller schemes such as for the Ford Site, it is common to look at installing the heat production, which often unfortunately adds cost to the scheme.

Traditionally, co-generation plants are fueled on natural gas (or coal for large systems) but gas Combined Heat and Power (CHP) also known as co-generation will meet a potential renewables target. The next obvious step would be to turn to biomass as a fuel. However, biomass fueled technologies add other complexities with fuel transportation and flue gas emissions and the surrounding air quality. There is no doubt that local air quality would be affected by the installation of a biomass plant. However, for larger plants there are a number of possible gas cleaning technologies available that may be employed in order to meet regulatory requirements

Alternative technologies such as solar (both for generating electricity and heat), wind or heat pumps could come into play, especially if low temperature systems are employed.

Once a district energy network is in place it opens up for utilizing a variety of heating and cooling sources. The potential phasing of the Ford development and its network may open up possibilities for changing technologies over time.
A practical solution – although not an energy saving solution – is to utilize the district heating system to heat up exterior / outdoor construction surfaces in order to remove snow and ice.
Snowmelt technology can reduce or eliminate conventional snow removal, reduce wear and tear on walking and driving surfaces, and provide clean, safe, ice-free traffic areas. Walkways that are snow, ice, and salt-free will increase the comfort and confidence of users and building owners.

Whether this is an option to consider for the Ford site will depend on the cost of conventional snow removal, against the cost of the produced heat.

Having a district heating system in place will enable household domestic appliances such as dishwashers to be connected. Instead of using electrical power for heating water, the appliances would use domestic hot water heated by district heating. For households, this would convert power consumption into an increased district heating consumption.

6. ENERGY SUPPLY DESIGN CONCEPTS

Based on the building design and energy system best practice, the consultants have developed a set of design concepts that could be appropriate for the Ford Site.
The work has been carried out in a 4-step process:

1. Creation of a gross list with all potential technologies
2. Initial screening of technologies filtering out clearly incompatible or non-viable technologies
3. Evaluation of technologies based on priorities
4. Creation and evaluation of production system scenarios

An initial gross list of 35 technologies was identified, consisting of the most relevant and promising production and energy storage technologies for the Ford site. Some technologies are basic technologies that can be applied almost anywhere such as boilers and regular heat pumps, whereas other technologies are very specific in their requirements for input or conditions, such as industrial waste heat recovery or deep geothermal.

6.1 Technology screening

A total of 35 energy production technologies were identified as potentially suitable for the site.

All of the technologies could in principle be attractive solutions - given the right circumstances/context. Therefore, the evaluation focused on the technology and the conditions under which they could be utilized (price structures, consumer demands, laws, regulations, space available, impact on the local environment (smoke, noise, waste), synergy with other infrastructure, etc.).

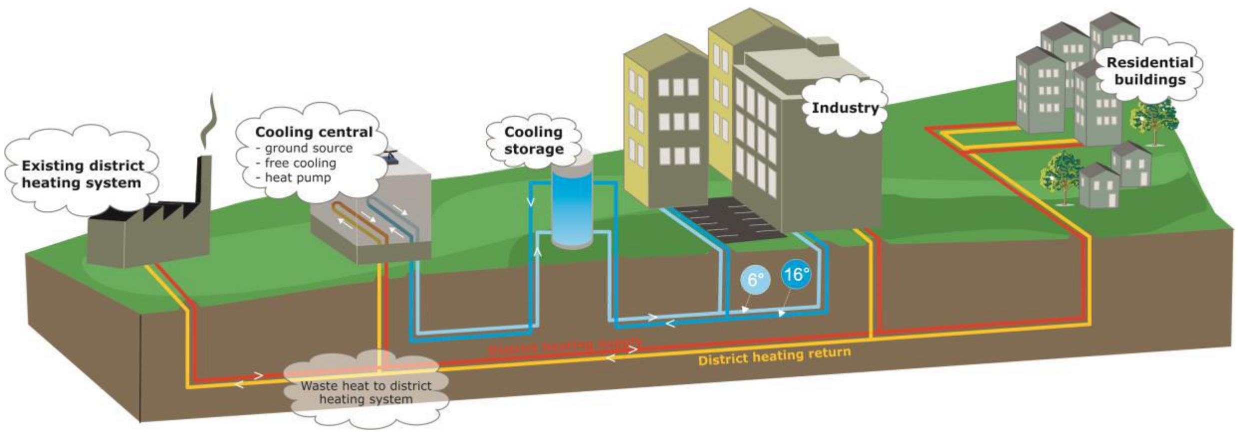
The technologies were divided into four categories (Combustion, Heat Pumps, Solar Energy, and Other) and scored on the five priorities (Net Zero, Resilience, Innovation, Energy Efficient, Cost Efficient).

6.2 Energy system concepts

Following the screening and scoring of the technologies individually, a number of system designs were put together and evaluated using the 5 priorities. The evaluation identified system designs with natural gas boilers, solar thermal energy, and heat pumps as likely to fit the site.

In the discussions with the TAG it was agreed that the five priorities were not satisfactory to evaluate the economic viability. The group agreed to boil the five priorities down to three by excluding the innovation and resilience parameters. Innovation was hard to measure and not an ambition in itself if the solution did not have a positive impact on the other criteria. Resilience had earlier been voiced as an important parameter for competitiveness but given the very high levels of security of supply already in place there was only very limited room for improvement.

Furthermore, it was agreed to expand the scope of the study to carry out a financial viability analysis of the proposed energy concepts. The primary aim was to identify the competitiveness of a district energy solution compared to a business as usual scenario and a concept with individual building solutions for renewable energy production. Secondly, system performance in terms of share of renewable energy and carbon footprint was also to be assessed.



Supply concept for district heating and cooling

7. FINANCIAL ANALYSIS OF ENERGY CONCEPTS

During the work with screening energy options for the site, it became clear from the discussions with the TAG that a more thorough viability assessment would be needed to enable a decision around direction.

Based on development Scenario 5, estimations were made of the likely build out phasing of the site, and the likely energy demand and its duration throughout the year.

Analysis of three (3) technical concepts for financial viability was conducted:

- **Concept 0:** Business as usual Concept, **BAU** (Grid electricity, natural gas individual heating, and cooling with air conditioning)
- **Concept 1:** District energy Concept, **DHC** (ATES based heat pump/chiller energy production, Solar Thermal, River free cooling, thermal storage (day-to-day) and gas boiler as back-up)

- **Concept 2:** Individual generation Concept, **IND** (Solar PV on roof tops, central (ground source) heat pumps for heating and chillers for cooling, hot water storage (day-to-day))

The three concept designs are based on previous knowledge attained from the two review memos produced for this study:

1. "*Energy Technologies and System Report*" and
2. "*Best Practices in Building Design*"

The district energy concept changed during the design concept work. It now includes Aquifer Thermal Energy Storage (ATES) instead of the river source heat pump scheme. This change was implemented as a result of poor technical feasibility on the heat pumps since the temperature of the Mississippi drops to below freezing point for approximately 4 months of the year.

A TAG subcommittee has provided input on the financial analysis, especially regarding the financial assumptions, pricing of installations and pipes, and the expected build out of the site.

Concept 0 - BAU was chosen as the reference scenario, to represent a business as usual approach with regards to energy supply. Estimating the average price for energy that a customer will pay in a BAU scenario, it is possible to compare the three concepts. The assumption is that costumers should pay the same price for energy in all three concepts, with the added value of a greener, less carbon intensive energy supply via concepts 1 or 2.

It is evident from the results of the study that the BAU concept has the highest CO_2 emission during the project evaluation period. Emissions from the district energy (DHC) and the individual renewable (IND) concepts are very close and there is no clear conclusion about the lowest emissions of the two. However, both the district energy solution and the individual renewable energy solution is highly capital cost intensive, with cost recovery and future energy savings accrued over the long-term. For such investments to be made instead of business as usual, cab funding or value added strategies are required.

The economic analysis carried out is particularly sensitive to:

- Prices – capital and operational
- Assumptions on annual demand
- Design consideration and the associated capital investment in related equipment for both the District Heating and Cooling option and the individual renewable energy option.

A conclusion on the preferred concept is dependent on a couple of key decisions:

- The priority and weighting of the energy system objectives.
- Who will deliver the energy services on the site, - Xcel Energy; District Energy St Paul; a site developer; or some combination of parties.

8. CONCLUSIONS AND RECOMMENDATIONS

The redevelopment of the former Ford assembly plant site offers a rare opportunity for the City of Saint Paul to be involved in creating a new 21st Century Community. The City has a vision to develop a sustainable and livable community that is attractive for residents and business alike.

Creating a sustainable and livable community requires looking at the bigger picture, creating livable space, supporting sustainable energy design, building energy efficient structures, and revisiting conventional water infrastructure and transportation. As such, business as usual in redevelopment practices and energy delivery will not do.

Thinking outside the box and picking best lessons learned from other communities around the globe will be the way forward for the City of Saint Paul and the Ford Site redevelopment, envisioning a long-term plan and accepting a long-term investment.

Ramboll's view is that there are a number of energy models that can be identified for the site, if it is understood that these systems are likely to be more capital intensive at the front end, and larger investment returns over the long-run, Each of the models has been driven by a public leadership, influenced by local priorities, and constrained by policies governing the apportionment of risk and public sector borrowing.

The variations between the models are largely the result of factors such as public sector borrowing, exposure to risk, expansion and replication, and social and environmental goals. The City of Saint Paul's priorities looking ahead should focus on:

- Building internal political support and commitment, overseeing the development of strategies and policies to develop the project opportunities and to obtain budget commitments to advance the project through detailed feasibility, business planning, and procurement.

- Continuing to establish the appetite among major stakeholders to engage in the project. Establish a stakeholder engagement plan and work with stakeholders to establish a project delivery group to take forward the recommendations of this report.

- Establish commercial options for delivery of the Energy Concept and the City's appetite for involvement. This should include an assessment of key drivers and motivations for advancing the project forward, as well as acceptable risk and the internal commitment and resources it can allocate for delivering the project. The outcome of this should be to establish the City's role in the identified project opportunity and the commercial basis on which the future strategic opportunity could be delivered.

- Commission a detailed feasibility study that looks at both a technical concept and at a delivery plan and business model to further evaluate Concept 1 (DHC) and 2 (IND), and the issues that the financial analysis has identified as critical and to which a preferred concept is sensitive. Important parameters that warrant further investigation are:

  Identify delivery vehicle for the energy on site.

  The scenarios should be revisited in more technical detail including:

- ATES is included in Concept 1. There are however many parameters which should be thoroughly examined to achieve a higher probability that ATES is actually possible and viable. Very important are the local hydrogeological conditions.
- Investments in piping network – more detailed work will be required to further develop the network design and assess investments costs and opportunities for lowering capital costs.
- Getting closer to the actual investments in small and large scale chillers.
- Explore funding options and investigate the possible sale of renewable energy credits or other grants.

The main key message for the future work is that the development of the Ford site should capture the spirit of the local community and balance economic and environmental interests even if it requires advancing new ideas and solutions.

APPENDIX 1 - CONDITIONS, CONSTRAINTS AND OPPORTUNITIES
AC 1.1 REUSE OF TUNNELS AND STEAM PLANT BUILDINGS

Activity description:
Identify site-specific physical, locational and geological conditions, constraints and opportunities that will set parameters for site energy demand and utility infrastructure.

ENERGY

MEMO

Job	**City of St. Paul – Ford site redevelopment – zoning framework district energy study**
Customer	**City of Saint Paul**
Memo no.	**1**
Date	**11-05-2014**
To	**St Paul - Merritt Clapp-Smith**
From	**Ramboll, Pernille M Overbye**
Copy to	**Ramboll - Jakob Bjerregaard** **Krifcon – Flemming J Kristensen** **St Paul – Anne Hunt**

Reuse of existing tunnels and steam plant buildings

Date 11-05-2014

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Ref 1100012867
Doc-ID 3434-13
Doc-Name: Reuse of concrete ducts
Version 3

Made by JO/PMO
Checked by JAKB/MHCCSP
Approved by PMO

1. Introduction

Ramboll Energy (RE) and Krifcon have been hired by the City of St Paul (the City) as engineering consultants to study the potential for creating an integrated, district energy system for the Ford site redevelopment.

It is the project's aim to deliver a concept that will focus around local conditions, available technologies and anticipated development that is economically viable. The team was asked to evaluate the potential reuse of the existing steam plant building (steam plant) and steam tunnel to the main site.

The project will focus around establishing a distribution of heat through a piping network to a number of buildings, normally referred to as district heating. A district heating network can be scaled to supply heat to an urban development area, a university campus, or to an entire town or city.

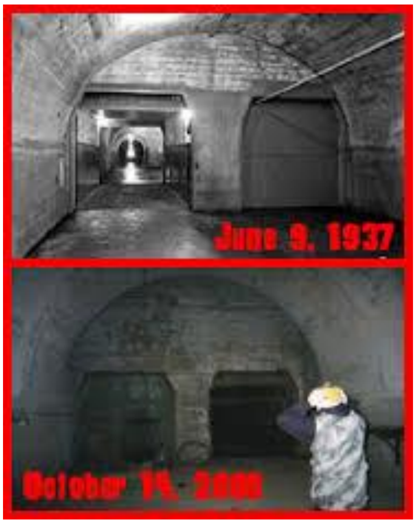
District heating in the United States has traditionally been based on steam distribution, where the vast majority of European district heating systems today are based on hot water. Steam or medium/high temperature hot water networks were more frequent in Europe in the early days of district heating, but hot water systems have been the preferred option for 50 years or more. All new networks are based on hot water with a maximum temperature of 230°F (110°C).

Rambøll Danmark A/S
DK reg.no. 35128417

2. Ford Site - steam concrete tunnel, vehicle tunnel and sand tunnels

The Ford site has an old steam pipe that runs through a bridge structure from the steam plant building to the bluff face and then runs through a tunnel about fifteen feet below the surface to the center of the former assembly site.

Further below the surface, at a depth of about eighty feet, is an old vehicle tunnel used until around 1959 for getting cars from the assembly plant to the river. In addition, there is an extensive network of sand mining tunnels, created from 1926 to 1959, when the plant produced glass for vehicle windows with silica mined from underground sandstone on site. When Ford stopped making glass on site, the mining tunnels were shut down and the entries closed, but the tunnels remain.



Picture courtesy of Action Squad website www.actionsquad.org/ford

The lengths of the tunnels vary:

- the vehicle tunnels are around 750 feet each
- the mined sand tunnels are in total around 12,500 feet
- the utility tunnels (steam, sewer and electricity) are around 4,000 feet

Ford Motor Company hired geo-technical consultants to evaluate the tunnels in 2008. The analysis concluded that the tunnels were stable, but additional analysis will be required if any of the tunnels are contemplated for reuse.

With entirely new infrastructure planned for the redeveloped site, including a potential new hot water district heating network, Re finds it difficult to justify the reuse of the existing tunnels on the main site for district energy pipes.

From a planning perspective it would give some unnecessary – and costly – restrictions on the pipe routing for the district energy network. The reuse of the tunnels combined with pre-insulated pipes would be a technical challenge during design and installation, and the overall costs of the network are therefore likely to be significantly higher than they would be otherwise.

However, if the former steam plant is repurposed for a new energy use, then the old steam pipe bridge and tunnel would be useful in getting the new pipes from the plant, under Mississippi River Boulevard to the site boundary. It should be noted that once all equipment is cleared from the tunnel, a thorough condition and structural report should be conducted of the steam tunnel structure and bridge.

Pictures courtesy of Ramboll taken during site visit

The other tunnels may be able to be used as a storm water basin, or more easily for cultural/communal activities. As an example it can be mentioned that in Copenhagen an old underground water reservoir is today used as a museum.

Pictures courtesy of the museum "Cisternerne" website www.cisternerne.dk/en/

2.1 Overall steam versus hot water piping

The piping technology used for the distribution networks was more or less the same for steam, medium/high temperature hot water, and hot water systems until the 1970s. Pipes were installed in concrete ducts and were either insulated individually with mineral wool (or a similar material), or the concrete ducts were filled with an insulating compound, often bituminous, after installation of the pipes.

The introduction of pre-insulated pipes in the 1970's was an important step towards cheaper hot water networks. The industry experienced some difficulties with the new technology in the early years but during the 1980's most of the initial problems was solved. Since then, pre-insulated piping systems have been considered the only option when hot water district heating networks are planned and designed. The practical temperature limit for these systems is 250 ^{o}F (121 ^{o}C), since an elevated temperature will damage the insulation and shorten the service life of the pipes considerably.

Concrete ducts are still used for steam and medium/high temperature systems and some operators in Denmark still insist on using them even in lower temperature hot water networks. In particular, when they relocate large dimension pipes in an urban environment with a high density of other services, they see an advantage in the flexibility offered by concrete ducts. Another point to consider is the demand for maintenance - pre-insulated pipes may require excavation (e.g. to replace casing joints), but pipes in modern, high-quality concrete ducts can be left in the ground for 50- 100 years. This could be attractive under certain circumstances to some network operators, despite the higher costs.

Modern pre-insulated piping systems rely on the interaction between the pipes and the surrounding soil to keep stresses and pipe displacements at an acceptable level. When an older network of pipes in concrete ducts is about to be replaced with pre-insulated pipes, it is sometimes suggested to run the new pipes in the old ducts, but this is normally inconsistent with fulfilment of the pipe/soil interaction requirements.

Any issues that may accrue due to increased frost debts will need to be considered during a concept design phase.

3. Existing Steam Plant Buildings

Reuse the former steam plant buildings should be considered when the new energy system is established.

RE has some experience with the reuse of buildings for energy systems and, in general, it cannot be recommended. The technical difficulties encountered when combining new installations with an old building structure are often underestimated and the costs are high. The reuse of buildings should therefore – in RE's view – be generally avoided, unless architecture, planning, or other specific conditions justify it. In this case, RE recognizes that there are other interests in building reuse that go beyond technical considerations.

Architect Albert Kahn designed the main steam plant building, along with hydro plant building and main assembly building at the Saint Paul site. Albert Kahn, the foremost American industrial architect of his day, designed a number of landmark buildings in the United States and for Ford Motor Company. He was sometimes called "the architect of Detroit". Together with his brother, he developed a new style of construction where reinforced concrete replaced wood in factory walls, roofs, and supports. It was this that interested Henry Ford.

Another motivation for retention and reuse of the existing steam plant is the assumed difficulty of getting approvals to construct a new energy production plant next to the Mississippi River.

In this context, reuse of the steam plant buildings should be considered. Once the buildings are cleared of the former equipment, which RE does not suggest to reuse, the buildings condition and structural integrity should be carefully assessed. It is not certain if the existing chimney can be reused, since the environmental and permitting requirements will have changed from when it was originally established.

Picture courtesy of Ramboll taken during site visit

It should be noted that the existing steam plant buildings has far more space than would be needed for a new energy production plant. This opens up part of the buildings to be used for other purposes. The rooms on the upper floor, one of which is shown on the picture above, could be used for an innovation visitors' center, a renewable energy teaching facility, maybe with a café and restaurant available to the public.

4. Summary

In summary, we can highlight the following for consideration by Ford and the City of Saint Paul:

- Depending on its condition, it can be an advantage to the future district energy infrastructure for the site to reuse the portion of the steam tunnel that connects the steam plant building to the boundary of the main Ford property.
- The sand tunnels do not provide a good conduit for new energy infrastructure to and on the main redevelopment site. They may be considered for reuse for other purposes.
- Depending on its condition, the steam plant buildings can be an advantage to use as a new energy center, with remaining space in the buildings available for other uses, such as a teaching facility and/or a restaurant.

5. References

http://en.wikipedia.org/wiki/Twin_Cities_Assembly_Plant
http://www.actionsquad.org/ford.htm
http://en.wikipedia.org/wiki/Albert_Kahn_(architect)

APPENDIX 2 - TRANSPORT
AC 1.2 BEST PRACTICE IN CAR USE ALTERNATIVES

Activity description:
Desktop study to outline best practise from US and Europe.
Best practise in car use alternative projects that the team has been involved in around the World, as well as other significant completed or near complete projects by firms outside the team. Bring forward internally gained experience and best practices. Evaluation of ideas and solutions across different urban transportation approaches with the focus on abandoning the car use.

Intended for
City of St Paul

Document type
Report

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FORD SITE ENERGY STUDY
BEST PRACTICES IN CAR USE ALTERNATIVES

RAMBØLL

Krifcon

FORD SITE ENERGY STUDY
BEST PRACTICES IN CAR USE ALTERNATIVES

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1. INTRODUCTION

The City of St. Paul is in a process of developing the former Ford production facility into a sustainable urban neighborhood which can be a show case for the coming transformation of an old industrial area into an attractive and livable community.

All over the world cities are being haunted by an ever growing number of cars as urbanization continues and populations grow. This has led to rather desperate measures in some cities; Hamburg, Germany is looking to ban all cars in 20 years, but softer measures can also be applied as in Milan, Italy, where the local government rewards citizen with 1,5€/day for leaving their car at home.

This memorandum responds to Activity 1.2 Best practice in car use alternatives with the objective to identify best practices in neighborhood site design to maximize walking, biking and transit as alternatives to car use.

The study brief calls for an outline of best practices from the US and Europe, considering that the Ford site will be a new brownfield development it seems obvious to focus this report around smart planning measures for creating such a site in a sustainable manner with focus on reducing transportation by car and optimizing transportation by other more sustainable means.

Where appropriate reference cases are highlighted to illustrate the planning measure addressed.

Being a Danish consultant our experience from the US market in this particular area is naturally limited. However, Throughout the US and Canada there seem to be mush focus on electrification of the car pool more so than maybe decreasing car us in general and encourage walking, biking and public transport. It should be noted that electrical vehicles are only really low carbon is the electricity is produced by renewables means otherwise it is just a mean to move pollution.

Having said that in the US more and more cities are starting to consider alternatives to cars by implementing free or low costs city bikes, a variation of walking and cycling paths and light rail connecting sub-ups with Downtowns.

In Canada Community Energy Plans are in the process of being mapped throughout the country the work is being led by the Community Energy Association (CEA) The work to date highlights that focus appear to be different in different states. Alberta, Québec and Newfoundland & Labrador having more focus on low carbon transportation. In Alberta GreenTRIP provides $2 billion in community funding for sustainable public transport.

Example 1 Community Energy Plans

2. GENERAL OVERALL CONSIDERATIONS

As cities have been rapidly growing the last decades the once remotely located industrial areas have now been enveloped into new and modern urban developments. The old industrial sites are in many cities barriers for the citizens and children creating networks and relationships in the neighborhood and also form a serious barrier for the accessibility in and through the greater district for example for efficient public transport routes whether they are bus routes or tram lines.

Transformation of these old industrial areas into thriving urban neighborhoods can be a huge contribution to the development of livable city centers. However any transformation of an old abandoned industrial area into a living urban district will generate a demand for transportation, which has to be addressed. This demand can be met in many different ways from the entirely car based solution to the pure public transportation solution. If the choice and development of the transportation solution is handled carefully it can be a huge benefit for the urban development in terms of unit prices, diversity, environmental impact, salability etc. Any redevelopment of these centrally located facilities into a new active function whether it is residents, offices or mixed use will inevitably lead to a higher demand for transportation. This higher demand will of course be concentrated on the site but will also influence the adjacent transport system outside the site.

The impact on-site and on the general traffic network can be influenced significantly with a series of ‘smart’ planning measures. These planning measures can be categorized in the following headlines:

1. Holistic infrastructure concept
2. Land use based on principles of mixed use
3. Balanced physical planning measures - matching density to the transit capacity
4. Increased density around transit nodes
5. Compact community with short commutes
6. Walkability – neighborhoods that promotes walking
7. Cyclable city – direct, safe and fast cycle routes with high connectivity
8. High quality transit supply – Bus Rapid Transit (BRT) and Light Rail Transit (LRT)
9. Mode shift facilities – regulation of parking, P&R incentives
10. Strategic infrastructure design
11. Strategic parking policy
12. Branding and communication measures
13. Economic incentive planning

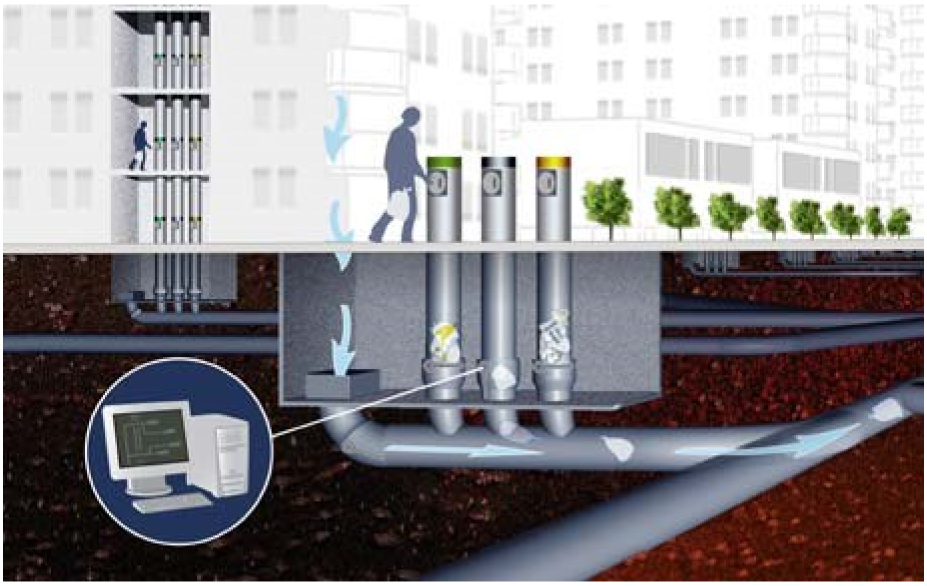
3. PLANNING MEASURES

Each of the above mentioned planning measure will briefly be addressed in the following.

3.1 (1) Holistic infrastructure concept

Studies of cities and community developments that have succeeded in achieving a low car owner ship and low private car transportation share are cities that have taken a holistic view on the whole infrastructure system and not only focused on singular solutions within the sectors. The neighborhood as a whole has to be designed for sustainability, and thus the land use, the energy system, the waste system and the transportation has to be interlinked onto one sustainable system. For example a central suction waste system prevent waste collection cars inside the urban area and the waste can immediately be pre-treated for biogas production for city cars or electricity to be used by then households, for street lighting or for EV's. The suction system can also be used for storm water drainage. And removing the waste trucks from the street network opens for more design opportunities towards walkable streets encouraging citizens to us other transportation means than the car.

Picture 1: Waste suction system



Basically a series of relatively detailed holistic, sustainable and operational objectives have to be developed to be able to design precise and action related policies and design guidelines. The holistic policies have to be able to effectively push the sustainable measures in the direction of the objectives and to choose between the many sustainability measures. Not all measures fit with each other in an overall sustainable system. Selection of measures has to be based on the overall objectives and the sustainable effects including not the least the economic and social sustainability.

3.2 (2) Land use based on principles of mixed use

New neighborhoods should be planned with close consideration for the land uses of the adjacent communities. And the neighborhood itself has to be developed with a strategic mix of uses, which on the one side promotes the business case of the development and on the other supports the sustainable mobility of the neighborhood.

A development in the close proximity of existing residents' areas may have a majority of working places while proximity of working areas may have a majority of residential uses. However there must still be a mix of uses and facilities that allow for diversity and density within the site with the focus on enhancing mobility and minimizing traffic. To achieve this effect the land use plan must carefully design an accessibility relationship between the homes, the working places and the public facilities – the shops, kindergartens, schools, health institutions and leisure facilities.

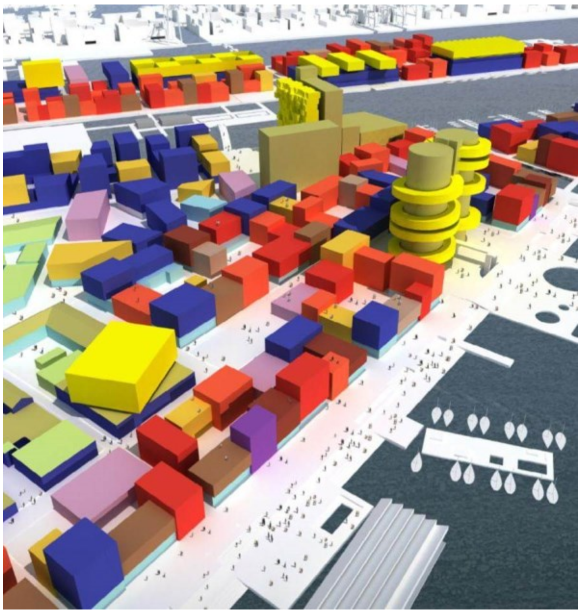
In order to enhance livability, walkability, cyclability and the feeling of security it is important through the land use planning to ensure direct connectivity for the soft road users as well as nice experiences along the travelling or commuting route, such as well-equipped lighting, plantings, parks and entertainment areas where people gather. In the same instance the land use may strategically provide car parking in centralized multi-storeys, still though giving access to every single address for unloading of goods or for disability access.

8-80 Cities is a non-profit organization based in Toronto, Canada. They are dedicated to contributing to the transformation of cities into places where people can walk, bike, access public transit and visit vibrant parks and public places. They approach is to engage people and communities across multiple sectors to inspire the creation of cities that are easily accessible, safe and enjoyable for all. We achieve our mission through grant projects, advocacy work and our innovative services.
The philosophy being that if you create a city that's good for an 8 year old and good for an 80 year old, you will create a successful city for everyone.

http://www.8-80cities.org

Example 2 8-80 Toronto, Canada

The land use plan may even put restrictions on the extent of uses for specified building plots. In Copenhagen's Nordhavn (North Harbor) district Ramboll has developed a concept of a "5-minute-city", where the walking distance from one home to a public facility or to a high speed public transport facility that can lead you to it, is no longer than 5 minutes. This has required detailed planning reserving space for kindergartens, shops etc. inside specific building plots. Thus the developers must accept that they may provide public facilities inside their plot to serve the community even though it was not part of their original business plan.



Picture 2 Mixed use master plan in Nordhavn, Copenhagen

3.3 (3) Balanced physical planning measures - matching density to the transit and infrastructure capacity

The detailed physical planning has to be integrated with the development of the infrastructure system – the energy system, the power system, the waste system and the transportation system. All systems have to be integrated in every development stage of the project. Failure will cause investors to avoid investments. And failure in the mobility system will cause potential residents to choose other areas or existing residents to behave against the intentions and objectives of the site.

The development plan must balance development and infrastructure in a way that demand at all times is matched with sufficient capacity. In many cases it has shown that provision of a rail based transport system – metro or light rail – is hugely stimulating for the ability to attract investors for urban development. At the same time it will attract residents that have intentions to use the public transport and as provision for high quality public transportation, restrictions on car parking should follow.

3.4 (4) Increased density around transit nodes

High density of urban development around transit nodes has evidently great impact on the utilization of the infrastructure system and the travel demand.

In the very big scale there is evidence that the energy consumption in large and dense cities are lower than in dispersed cities, which are applicable also in the lower scale where high density and a compact building structure will have less façade area exposed to the cold or warm climatic environment. Compact low to mid-rise buildings (ground floor plus 5-10 stories) seems to be optimal in many climatic regions, but it has to be calculated carefully in the local climatic and utilization context.

In compact cities the utilization of the infrastructure system, the water supply, the sewage system and the energy system is much higher than in dispersed cities. And the infrastructure cost per household is much lower. This economical factor makes it possible to establish homes and offices in a variety of price levels and types of ownerships, which can leverage the diversity in the community.

On the transportation side, data from the UK shows that urban areas with higher density also have shorter car travel distances and a modal split with lower car share and higher public transportation share.

The impact on the transportation demand and behavior is due to at least three major reasons:

1. High density around a public transit node increases the viability of a rail based system. A rail based public transportation system attracts more passengers and households within a catchment area of a metro or tram station tend to choose to live with a lower car ownership.
2. The walking distance for a large number of potential passengers is within the acceptable distance of 600 meters or 5-10 minutes.
3. People tend to 'follow the leader'. And with a high residents density many will become active daily users of the public transportation system which in itself will attract more users as 'this is what you do' in this neighborhood.

The new urban development plan for Chicago Lakeside – the transformation of the old steel plant south of Chicago – is designed with a multi-purpose transportation system. BRT lines are connecting the Lakeside to the rail line and at the same time are contributing to the connectivity of the Lakeside with the adjacent neighborhoods. The BRT corridors are prepared to be upgraded to LRT once the Metra rail line is upgraded and thus giving short commuting time to downtown Chicago.

http://chicagolakesidedevelopment.com

Example 3 Chicago Lakeside Connectivity

Picture 3 Nordhavn, Copenhagen, Metro and Bike lane illustration

In terms of livability it is important to study the local context carefully. High-rises have the tendency to keep life inside the building, while low to mid-rises to a much larger extent generates city life on the streets outside the building complex. So a sustainable solution is not just to establish high-rises around stations. It is a considerable piece of planning work to estimate the most sustainable balance between functions, livability, modal choice, diversity and economic viability.

It is always a discussion what the appropriate urban density is. And there is no 'correct' answer. An indicative minimum is 25 dwellings per hectare (dph) for bus services and 60 dph for tram service, depending on a number of parameters such as urbanity, length of tram line, car ownership, local culture etc. But in many cases these values are much higher in areas with great success. In Hammerby Sjöstad, Stockholm, which is considered a very successful and sustainable new urban neighborhood, the density is 160 dwellings per hectare (395 dpa) while the planned density of Nordhavn, Copenhagen is 100 dph (247 dpa) but with an additional 100 workplaces per hectare.

3.5 (5) Compact community with short commutes

A compact community built up by a series of high density nodes around the public transport stations and hubs, and with a diversity of mixed use functions will leverage very low car utilization especially if a part of the public transportation system is rail based. The combination of diverse mixed use and the reliability of a rail based transportation system will cause the households to consider whether to acquire the second car and maybe even the first one, because the daily commute can be achieved by public transportation and because the public transportation is the 'smarter' and quicker transportation.

The 5-minute city concept just makes it quicker to walk or go by bicycle. And the daily commute modal choice is not about environmental concern or political beliefs; it is about the smarter and quicker choice that releases time from sitting inactive in jammed car traffic to active personal free time used with the family or by the individual.

3.6 (6) & (7) Walkability and cyclability

Creating an urban development with a high rate of cyclists and walkers automatically causes an ease in the pressure and demand for road capacity. Pedestrians and cyclists demand considerable less urban space both while moving around and while parking. The saved space can be used for more livable environments and design and it can be used to create more compact urbanity for higher public transportation use and viability.

TransForm in California founded in 1997 by Bay Area environmental and social justice groups promotes walkable communities with excellent transportation choices to connect people of all incomes. TransForm's work is focused on four key impact areas:
Reducing greenhouse gas emissions
Reducing the combined cost of housing and transportation
Increasing the rates and safety of walking and bicycling
Increasing access to jobs via public transportation

http://www.transformca.org

Example 4 TransForm California

But creating walkable and cyclable cities is not only done by establishing cycle lanes along the roads. It takes considerable planning to develop exactly the routes and design that give the best mobility for cyclists and pedestrians. The transportation planning methodologies has to be reconsidered as mobility is alpha and omega to create an attractive city for cyclists and pedestrians. Thus the planning challenge is not to establish the right capacity, but to create the right and optimal connectivity. This may include establishing specific facilities for the soft road user for example wide cycle tracks, bridges, air pump stations, litter bins, foot rests etc.

Furthermore the accessibility of cycles for inhabitants and visitors can greatly affect the rate of cycling trips. In Copenhagen electric city bikes are available all over town with built in touch screen computing and GPS. Correspondingly the "Nice Ride" city bikes are accessible all over St. Paul and Minneapolis, and serves as a good opportunity to enhance the cyclability of the Ford Site.

Picture 4 Bicycle bridge in Copenhagen

Bicycle bridge as part of the bicycle motorway in Copenhagen. The design takes into consideration that in a biking city the bicycle is used for many purposes that requires more space.

Picture 5 Footrest and litter bins for cyclists

Urban land use planning policies are highly important to create walkable and cyclable cities. The 5-minutes city as mentioned above will improve the urban life as more people are walking and cycling in the public areas instead of taking the elevator to the parking garage under the building and drive individually along the streets.

3.7 (8) & (9) High quality transit supply – mode shift facilities

Almost all public transport trips consist of one or more transfers between transportation modes. Creation of a high quality transit supply system must be based on the assumption that the users must experience a seamless cohesion between the different modes of transportation. This requires that the different suppliers of transportation have a common focus on the customers. This accounts for the public modes of transport and between the public and private suppliers of transportation.

An important step into a high quality transit supply system is to ensure that the public transportation is an integrated part of the urban planning. Thus the policies for the development must follow the principles of Transit Oriented Development (TOD). In Portland, Oregon an implementation plan has been developed including a funding program for transit-oriented development.

In the Copenhagen region this is implied by the principle of station proximity, which means that within a core area of 600 meters around a train station the utilization rate of the building rights can be double as high as outside the core area.

This has encouraged developers to locate especially office buildings in the proximity of stations again encouraging employees to commute by public transport rather than by car.

Portland, Oregon, was the first US local authority to approve a sustainability plan for addressing the climate change issues. In 1993 a long term plan was adopted resulting in record low carbon dioxide emissions.
This came on top of a community led switch of public money from a motorway to a light rail system. These programs are long and sustaining term by nature and they form stepping stones for continuous adoption of new measures.
Just recently the city has signed up to an Electric Vehicle (EV) project implying initially 36 charging stations in the city, but growing to 500 stations.

http://www.chargeportland .com/

Example 3 Portland, Oregon, sustainability plan

Picture 6 Above ground part of the metro in Copenhagen

Design and planning of the feeder system to BRT or trams must be an integrated part of the regional connectivity and the site master planning. This means that BRT/tram terminals and bicycle facilities and parking must be developed closely related to the public transport system and to train stations to give the best physical integration, the best customer service and convenient transfer conditions. The mode shift facilities may have different service offers such as car wash and cleaning, bicycle service, pumping service, personal shopper service etc.

Once an integrated high quality system is established the viability of the transit system will increase and pay off to the investors in terms of lower demand for car parking which is a costly element in any building complex.

3.8 (10) Strategic infrastructure design

Design of the transportation infrastructure systems has a significant influence on the utilization of the system and the behavior of the users. A streetscape[1] can be designed to:

- Fully regulate the traffic in any case
- send the signal to the users who has the priority
- discard normal regulation and leave it up to the users – the shared space principle

The most ordinary design standard is the total regulation of the traffic. In this case the regulation is marked on the roads, on signs or by signals. And the different user systems, driving lanes, cycle tracks, sidewalks, parking spaces etc. are completely separated by road marking signage and by curbs or similar physical marking. In this case the strongest wins and usually this is the car traffic. They will be given the most space and almost all signage and road marking is directed to their drivers. This generates the impression of a 'machine' and leaves a barrier feeling with the soft road users.

Picture 7 Full regulation of traffic. Lyngby, Denmark

[1] The equivalent to landscape for streets

A streetscape in urban areas can be designed with a use of materials and geometric design that signals low speed, frequent pedestrian crossings etc. In this case it is important to be consistent in the design to ensure the same design standard in the whole stretch or district. In this case signage and road marking can be limited to a minimum and the incentive to stay in the open spaces and squares is more evident.

Picture 8 Lyngby Main Street, Denmark

In designated areas, often commercial districts, the principle of shared space has been tested with positive results. The principle of the shared space is to give back the responsibility to the road users. Normally the road designer takes on the most responsibility by regulating all traffic behavior. With the shared space design all road markings, signage and physical curbs etc. are removed and you leave one space from façade to façade. Then it is up to the road users to agree on the right of way, where to park etc. The results are very positive as the drivers are no more just blind following the signage and standing on their rights, but have to have eye contact with the other road users to negotiate maneuvers. The effect is less conflict, less accidents and increased feeling of security.

Picture 9 Shared space in Brighton, UK

3.9 (11) Strategic parking policy

All car trips are dependent of at least two parking spaces, one at the origin and one at the destination of the trip. This means that in principle all car traffic can be controlled by a parking strategy and regulation - no parking spaces, no cars or the higher the parking rates the lesser cars.

A parking strategy has a huge influence on the car ownership, car utilization, public transportation mode share and the hence the design of the urban spaces. In developing the parking policies for a specific area there are a number of terms to take into account: the residents and other users in the community, the level of the public transport service and capacity, the business case for the development and the aspirations for the urban spaces and the neighborhood.

Given a high standard public transport system and a compact development, restrictions can be put on the parking norms to reduce the number of parking spaces and to increase the parking fees. Even the locations can be moderated and put in a number of specific multi-storey car parks. In this case every car trip includes walking to the parking space raising the attractivity of the public transport system or cycling. Many new developments are designed around this parking regulation, for example Ørestad in Copenhagen.

3.10 (12) Branding and communication measures

Changing an ingrained habit of using the car in almost any part of the transportation chain is not only done by providing new means of transportation. This calls for a profound cultural change management process in which provision of highly efficient alternative solutions to the car of course is a fundamental request. The alternatives must evidently and objectively be the smartest choice. But working with the mind-set of the users and the potential newcomers to the district is equally important. Branding and communication of the alternatives play an important role. In Copenhagen a communication and branding strategy has been developed in recognition of the importance of getting the urban users to take ownership of a transportation mode shift from the car to bicycles.

Picture 10 Copenhagen cycling communication

This strategy builds upon communicating, branding and documenting cycling as the fast way forward in the urban traffic. While cars are queuing, bicycles can move with a higher speed through the Copenhagen road network.
Every second year The City of Copenhagen publishes the "Copenhagen City of Cyclists - Bicycle Account", which is an assessment of the development of the cycle facilities, the development of key figures for cycling and a survey of the cyclists assessment of the level of service and the supply of cyclists facilities. The cycling account's key figures are compared with the goals announced in the cycling strategy. For 2015 the main goals are:

- At least 50% of the commuters or students use bicycle as their mean of transport. In 2010 a percentage of 35 were achieved.
- The number of severely injured cyclists is halved from 2005 to 2015. In 2010 a reduction of 22% was achieved
- At least 80% of the cyclists are feeling secure in the traffic. In 2010 a percentage of 67 were achieved.

The cycling account is a central tool for the planners and the politicians to follow the development and to react on failing performance and new cyclists demands. Further the cycling account is a tool for the public to follow the political decisions and the fulfilment of the goals of the strategy.

Branding and communicating Copenhagen as a city of cyclists have had a huge impact on the attractiveness and livability of the city and is now part of the tourist attractions of Copenhagen. The same could be the case for the Ford development as a showcase for new sustainable urban retrofitting in US.

3.11 (13) Economic incentive planning

Almost any urban development is driven by economic incentives. Ramboll therefore consider it an integral part of urban planning to perceive planning as business development. A beneficial exercise for any public authority before starting an urban development process is to ask the question "What if the municipality was a private company?" This approach will extent the planning process before and after the traditional physical planning process. The pre-planning process will include topics like: Mapping of existing qualities, investigating future trends and potentials, carrying out market analysis, creates partnerships, building of common baselines, creating an operational vision, formulating a business case, branding and communication, investment and financial plan, etc.

Return on investments and profits are the number one trigger for investors whether they are private or public. We have to be very specific and well prepared in our pre-planning to be able to point on exactly the right solutions that are profitable for the investors and the users on the one hand, and that improves urban life and climate adaption efficiency on the other.

In the post-planning process the implementation is the main topic. We have seen many brilliant master plans passively sitting on the shelf, because of an insufficient implementation plan. The implementation plan has to assess the governance structure of the implementing body, the decision process needed, the knowledge capacity of the implementing organization, the legislation etc. The implementing body has to be geared to implement for example a transition of the energy system, the transportation system and the behavior etc.

In the development and planning process economic incentives play an important role for the investor, the developer and the municipality. For the users and the soon to be residents the economic incentive is a major driver too even though the private individuals tend to be slightly more philanthropic than investors. Regarding the car use the parking policy is one of the main denominators for the choice of transportation mode. The location of the parking facilities, the parking norm and the parking rate. These three parameters can determine the car use in the district. But the restrictions imposed on the car use have to be in balance with the alternatives provided. If the alternatives do not match the demand and the expected service quality the district will lose its ability to attract investors and residents.

So working with economic incentive strategies should always be an integrated part of urban planning.

4. CONCLUSION

A number of planning measures and means can be used to lower the dependence on cars and assure good transportation for the future users and inhabitants of the site, without compromising the neighborhood's infrastructure. The development of a transportation concept goes hand-in-hand with the other planning aspects of the site and is crucial in deciding on the building densities with more dense areas around the transit nodes.
The concept of the "5-minute-city" and/or the 8-80 cities concept prove that with the right planning, demand for car transport can be minimized while at the same time allowing a rather high building density and seamless transportation for the inhabitants.

Just as the City of St. Paul already well on its way with a bicycle plan and the twin city bike sharing plan the Ford site could/should be planned around focus of being a non-car development. In due time supported by a connection to the light rail, making it easier to commute to Downtown St. Paul and Minneapolis without having to rely on a car.

APPENDIX 3 - BUILDINGS
AC 1.3: BEST PRACTICE IN BUILDINGS

Activity description:
Desktop study. Identify low-energy and net-zero energy projects that the team has been involved in around the World, as well as other significant completed or near complete low-energy and net-zero energy projects designed by firms outside the team. Bring forward internally gained experience and best practices. Evaluate ideas and solutions across different building uses, urban context, and adaptability to overall net-zero emission targets.

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FORD SITE ENERGY STUDY
BEST PRACTICES IN BUILDING DESIGN

RAMBOLL

Krifcon

ENERGY STUDY
BEST PRACTICES IN BUILDING DESIGN

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1. INTRODUCTION

The purpose of this memorandum is to answer Objective 1, Activity 3: Identify best practices in building design to reduce energy demand and strive for net zero emissions.

Some of the legislative and voluntary frameworks for designing low-energy and net-zero energy building projects in Europe and the U.S. are assessed.
We have provided examples of completed or near complete low-energy and net-zero energy projects to highlight that typical buildings can achieve net zero or low energy usage using currently commercially available methods and technologies.

In compliance with our brief, the team has chosen to look further into Danish and German systems to show different approaches in two countries known for their lofty energy efficiency and reduction ambitions, the mandatory and the voluntary. Though Germany does have rigorous mandatory requirements, they are also the origin of the Passive House system.

For the best practice in the U.S., the team has chosen to visit the typical code basis, the 90.1 standard in several versions including the current Minnesota code. Energy requirements of voluntary systems like LEED (Leadership in Energy and Environmental Design), Minnesota SB 2030 and more are based on the same 90.1 standard in one of its versions.

To give a sense of what the different codes and standards accomplish, the team has assembled and estimated typical total design energy use for a score of different building types. Where plug loads are not included in a given code or standard, other sources have been used to provide estimates hereof, so that comparisons are possible.

We touch upon the compatibility of these energy requirements to District Energy Systems, DES and finally we suggest a level of energy usage for the Ford site. This is used by the team as a basis for determining what kind of DES and technology is the best fit for the Ford Site as this is very dependent on the expected size of the energy demand.

2. MINNESOTA ENERGY CODES AND STANDARDS

Current energy codes for commercial and residential buildings in Minnesota are:

- Commercial: ASHRAE[1] Standard 90.1-2004 with MN Amendments
- Residential: 2006 IRC[2] with MN Amendments

In both cases, the U.S. Department of Energy (DOE) evaluates that the Minnesota specific amendments result in less energy efficient buildings than using either ASHRAE 90.1-2004 or 2006 IRC without the amendments.[3]

---

[1] ASHRAE: American Society of Heating, Refrigeration, and Air-conditioning Engineers
[2] IRC: International Residential Code

Despite urgings from the DOE, the State of Minnesota has not implemented the 2009 IECC (International Energy Conservation Code) / ASHRAE 90.1-2007 or 2012 IECC / ASHRAE 90.1-2010 for commercial buildings yet. The same is the case regarding the 2009 IRC or 2012 IRC for residential buildings[4]. On September 26, 2014 the DOE issued a Determination Notice saying that States are required to certify that they have reviewed the provisions of their commercial building code regarding energy efficiency, and, as necessary, updated their codes to meet or exceed ASHRAE Standard 90.1-2013 /2015 IECC.[5]

The 2012 IECC / ASHRAE 90.1-2010 is expected to become the new energy code in Minnesota sometime in 2015.

For Minnesota State bonded projects, the energy code is augmented with the Sustainable Building 2030 Energy Standards (SB 2030) that requires a gradual reduction in carbon emission (Site Energy Utilization Intensity (EUI) is currently used as a proxy for carbon emission) starting in 2010 with 60% less than a 2003 code legal building of same location, type, and use, and ending with net-zero carbon emission in 2030. SB 2030 is a localized version of Architecture 2030's 2030 Challenge.

SB 2030 is voluntary to use for any other building project.

Table 1: Overview of current energy codes in Minnesota

Current Energy Codes / Standards	Commercial, civic, institutional incl. multi-residential	One and two-family houses and multi-residential 3 stories or less
Privately funded projects	ASHRAE 90.1-2004 incl. Amendments	2006 IRC incl. Amendments
State Bonded projects	SB 2030	N.A.
Federal projects	ASHRAE 90.1-2010	2009 IECC (and 30% better if cost-effective)

[3] https://www.energycodes.gov/adoption/states/minnesota
[4] https://www.energycodes.gov/sites/default/files/documents/MinnesotaDOEDeterminationLetter 05312013.pdf
[5] https://www.energycodes.gov/determinations

3. BEST PRACTICES IN EUROPE

All the European Union's (EU) individual countries have different ways of eventually complying with the EU goal of having all new construction being nearly zero by 2021 as mandated by the Energy Performance of Buildings Directive, EPBD[6].

The national targets for low energy buildings in a group of selected European countries are shown below (Table 2).

Table 2: European Strategies to move towards very low energy buildings. Source: SBI (Danish Building Research Institute) plus other sources.

Country	Low energy target
Austria	Planned: Social housing subsidies only for passive buildings as of 2015 Since 2009, the city of Vienna has required all new single-family homes to be built with a maximum heating demand of 45 $kWh/m^2/yr$ (14.3 $kBtu/ft^2/yr$) without controlled ventilation and maximum 33 $kWh/m^2/yr$ (10.5 $kBtu/ft^2/yr$) with controlled ventilation. Some regions have stricter requirements and offers grants (up to € 28,000) for passive house standards.
Denmark	By 2020, all new buildings shall use 75 % less energy than currently enshrined in code for new buildings. Interim steps: 50 % less by 2015 , 25 % less by 2010 (base year=2006)
Finland	30 – 40 % less by 2010; Passive house standards by 2015.
France	By 2012, all new buildings are low energy buildings (Effinergie standard – average 30 $kWh/m^2/yr$ (9.5 $kBtu/ft^2/yr$) dependent on climate zone); by 2020, new buildings are to be energy-positive.
Germany	By 2020, buildings should be operating without fossil fuel. Some cities in Germany (such as Frankfurt) already require the Passive House Standard for all new buildings constructed on property purchased from the city. In May 2014 the EnEV 2014 provisions was passed which mandate a 25% reduction in primary (source) energy from 2016 compared to the reference building described in EnEV 2009. Among the revised requirements is also a 20% increase in insulation values.
Hungary	New buildings to be zero emission buildings by 2020, for large investments already in 2012
Netherlands	50 % reduction by 2015, 25 % reduction by 2010 both compared to current code plans to build energy-neutral by 2020

[6] http://ec.europa.eu/energy/efficiency/buildings/buildings_en.htm

UK (England and Wales)	All new homes from 2016 to mitigate, through various measures, all the carbon emissions produced on-site as a result of the regulated energy use. This includes energy used to provide space heating and cooling, hot water and fixed lighting. There are three core requirements which must all be met for a home to qualify as zero carbon: 1. The fabric performance must, at a minimum, comply with the defined standard known as the Fabric Energy Efficiency Standard (FEES) and 2. Any CO2 emissions that remain after consideration of heating, cooling, fixed lighting and ventilation, must be less than or equal to the Carbon Compliance limit established for zero carbon homes, and 3. Any remaining CO2 emissions, from regulated energy sources (after requirements 1 and 2 have been met), must be reduced to zero. Requirement 3 may be met by either deliberately 'over performing' on requirements 1 and 2 so that there are no remaining emissions, or by investing in Allowable Solutions. Allowable solutions can include a number of options such as supplying low carbon heat to neighboring sites through heat networks. In London, the London Plan requires all major new developments to plan for decentralized energy measures through a hierarchy of solutions involving connection to district heating networks.
Sweden	Total energy use / heated square meter in dwellings and non-residential buildings should decrease. The decrease should amount to 20 percent until 2020 and 50 percent until 2050, compared to the corresponding use of energy in 1995.

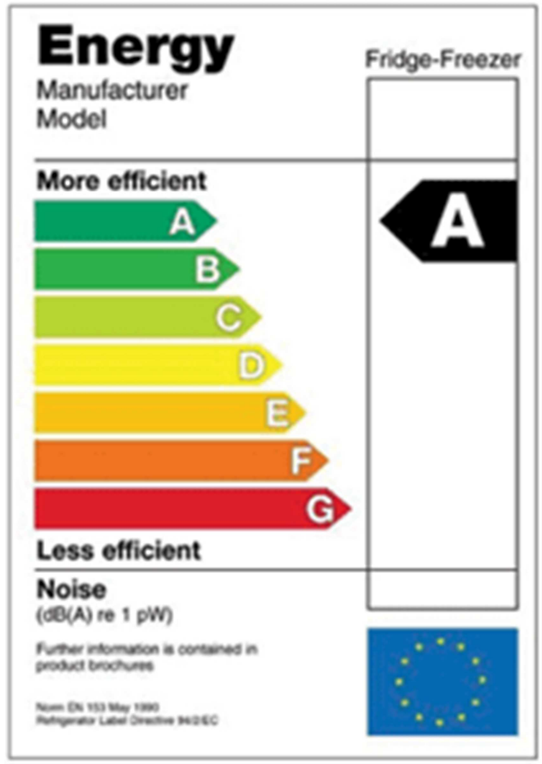
According to EPBD, a nearly zero-energy building is understood to be a building that has a very high energy performance. The nearly zero or very low amount of energy required should be covered to a very significant extent by energy from renewable sources, including energy from renewable sources produced on-site or nearby.

The energy performance of a building shall be determined on the basis of the calculated or actual annual energy that is consumed in order to meet the different needs associated with its typical use and shall reflect the heating energy needs and cooling energy needs (energy needed to avoid overheating) to maintain the envisaged temperature conditions of the building, and domestic hot water needs.

Article 9.1 of the EPBD regulates that "Member States shall ensure that by 31 December 2020, all new buildings are nearly zero-energy buildings and after 31 December 2018, new buildings occupied and owned by public authorities are nearly zero-energy buildings."

In addition to the EU directive covering building energy use, another directive 2010/30/EU[7], which extends Council Directive 92/75/EEC for energy labels, targets energy consumption for appliances, light bulbs, air conditioning systems, and commercial products like cold storage rooms, and vending machines (i.e. plug loads).

Figure 1: Example of EU Energy Label



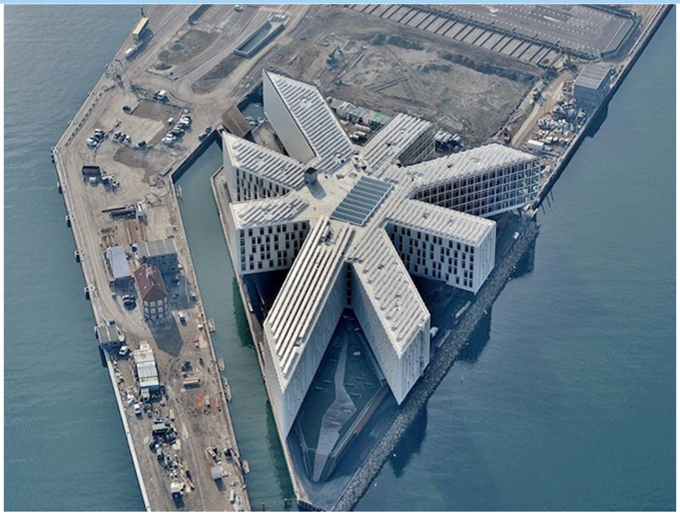
It is mandatory for all covered products sold in the EU to have this energy label. The aim is to make it very clear for consumers which products are energy efficient and very easy to compare products. Most EU member States offer some sort of incentive to people or companies that purchase the best-rated products to further encourage a shift to very energy efficient products. The last revision introduced three new top tiers, A+, A++, and A+++ as a consequence of the system's success in eliminating the worst performers and awarding the top performers.

The directive does not make it mandatory to buy a certain rated appliance, but it has gone a long way to remove the energy hogs within all encompassed product categories from the market. And as such helped curb the growth of the plug loads.

[7] http://ec.europa.eu/enterprise/policies/european-standards/harmonised-standards/ecodesign/index_en.htm

3.1 Europe – Examples

Below are a few examples of European buildings designed to be low-energy, ultra-low energy, or net-zero site energy.

UN City Copenhagen Copenhagen, Denmark	Main Building Data	Other Information
 *Photo: FN-Byen P/S*	2014 Office building 544,000 ft^2 (50,500 m^2) Design site EUI: 34.9 kBtu/ft^2/yr (110 kWh/m^2/yr) District Heating Harbor water cooling 360 kW$_p$ PV system on roof	DK 2008 code Energy Class 1 2012 EU GreenBuilding Award LEED Platinum certification (v3)

Glødelampen Herlev, Denmark	Main Building Data	Other Information
 *Photo: Boligforeningen 3B*	2013 Multi residential 60,000 ft^2 (5,560 m^2) Design site EUI: 9.4 kBtu/ft^2/yr (30 kWh/m^2/yr) District Heating	DK 2010 code Energy Class 2015

Carlsberg City District – Area 8 Copenhagen, Denmark	**Main Building Data**	**Other Information**
 *Rendering: Luxigon*	2016 *(expected)* Mixed-use building 869,000 ft^2 (80,668 m^2) Design site EUI: 25.6 kBtu/ft^2/yr (81 kWh/m^2/yr) District Heating and Cooling 200 kW$_p$ PV on the roof	DK 2010 code Energy Class 2015

Ramboll Head Office Copenhagen, Denmark	**Main Building Data**	**Other Information**
 *Photo: Mikkelsen Architects*	2010 Office building 500,000 ft^2 (46,500 m^2) Design site EUI: 35.5 kBtu/ft^2/yr (112 kWh/m^2/yr) District Heating Ground Water Cooling	DGNB Bronze certification

<table>
<tr><th>The Crystal
Royal Victoria Dock, London</th><th>Main Building Data</th><th>Other Information</th></tr>
<tr><td>
Photo: Traxon</td><td>2012
Conference center
68,000 ft²
(6,300 m²)

Design site EUI:
66.9 kBtu/ft²/yr
(211 kWh/m²/yr)

Ground source heating & cooling

Solar thermal & 300 kWp PV on the roof</td><td>LEED Platinum certification

BREEAM Outstanding certification</td></tr>
</table>

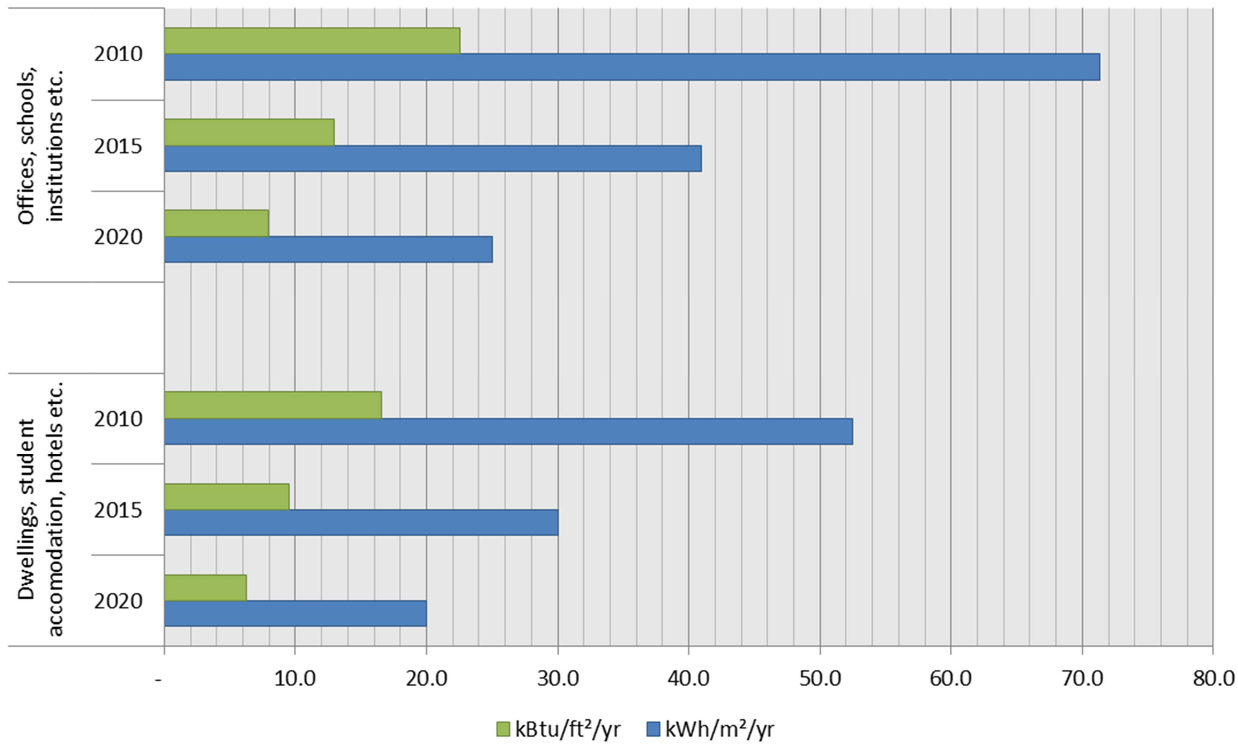
3.2 Denmark – Bygningsreglement 2010 (Building Code 2010)

All new buildings and major renovations in Denmark have to comply with the current building code (Bygningsreglement). Practically all of Denmark will fall within a climate zone similar to ASHRAE's climate zone 5A (like Chicago, IL).

The current Danish building code (BR 2010) defines energy use as the total energy demand of the building for heating, ventilation, cooling, domestic hot water, and lighting per m² of heated floor area. For dwellings, student accommodations, hotels, etc. lighting is not included.

In order to assist the building industry plan for the continued strengthening of the maximum energy usage that are necessary to comply with EPBD's 2021 goal of nearly zero energy buildings, the current code lists not only the current maximum requirement, but also the 2015, and 2020 iterations of the maximum requirements (See Figure 2 and detailed data below). It is voluntary to use the later requirements. However, municipalities can choose to mandate the 2015 or 2020 maximum requirements for a given area in a local plan.

Figure 2: Maximum Energy Usage in Buildings as required by the Danish Building Code in 2010, 2015, and 2020.



2010 Maximum energy usage

- Dwellings, student accommodation, hotels etc.: 52.5 kWh/m²/year plus 1650 kWh/year divided by the heated floor area (16.6 kBtu/ft^2/yr + 5,630 kBtu/yr divided by the heated floor area in ft^2.)

  Offices, schools, institutions etc.: 71.3 kWh/m²/year plus 1650 kWh/year divided by the heated floor area (22.6 kBtu/ft^2/yr + 5,630 kBtu/yr divided by the heated floor area in ft^2.)

Low energy class 2015 (Expected to become maximum energy usage in the coming 2015 building code)

- Dwellings, student accommodation, hotels etc.: 30 kWh/m²/year plus 1000 kWh/year divided by the heated floor area (9.5 kBtu/ft^2/yr + 3,412 kBtu/yr divided by the heated floor area in ft^2.)

- Offices, schools, institutions etc.: 41 kWh/m²/year plus 1100 kWh/year divided by the heated floor area (13.0 kBtu/ft^2/yr + 3,753 kBtu/yr divided by the heated floor area in ft^2.)

Low energy class 2020 (Expected to become maximum energy usage for public buildings in 2018 and all other in 2020)

- Dwellings, student accommodation, hotels etc.: 20 kWh/m²/year (6.3 kBtu/ft^2/yr)

- Offices, schools, institutions etc.: 25 kWh/m²/year (7.9 kBtu/ft^2/yr)

Electricity consumption from electrical devices (plug loads) are not included resulting in the building code ending up regulating a smaller and smaller part of the total energy use in buildings. This problem is currently being addressed to find a way of setting an upper limit to electrical consumption and encouraging very efficient and smart electronics that have a very low standby use or turn themselves off when not in use.

3.3 Germany – Passivhaus (Passive House)

In Germany, the focus is around Passive House. For a building to be considered a Passive House, it must meet the following criteria:

- The Space Heating Energy Demand is not to exceed 15 kWh per square meter of net living space (treated floor area) per year (1.4 kWh/ft^2 or 4.75 $kBtu/ft^2$) or 10 W per square meter peak demand.
  In climates where active cooling is needed, the Space Cooling Energy Demand requirement roughly matches the heat demand requirements above, with a slight additional allowance for dehumidification.

- The Primary Energy Demand (Source energy), the total energy to be used for all domestic applications (heating, hot water and domestic electricity) must not exceed 120 kWh per square meter of treated floor area per year (11 kWh/ft^2 or 38.10 $kBtu/ft^2$).

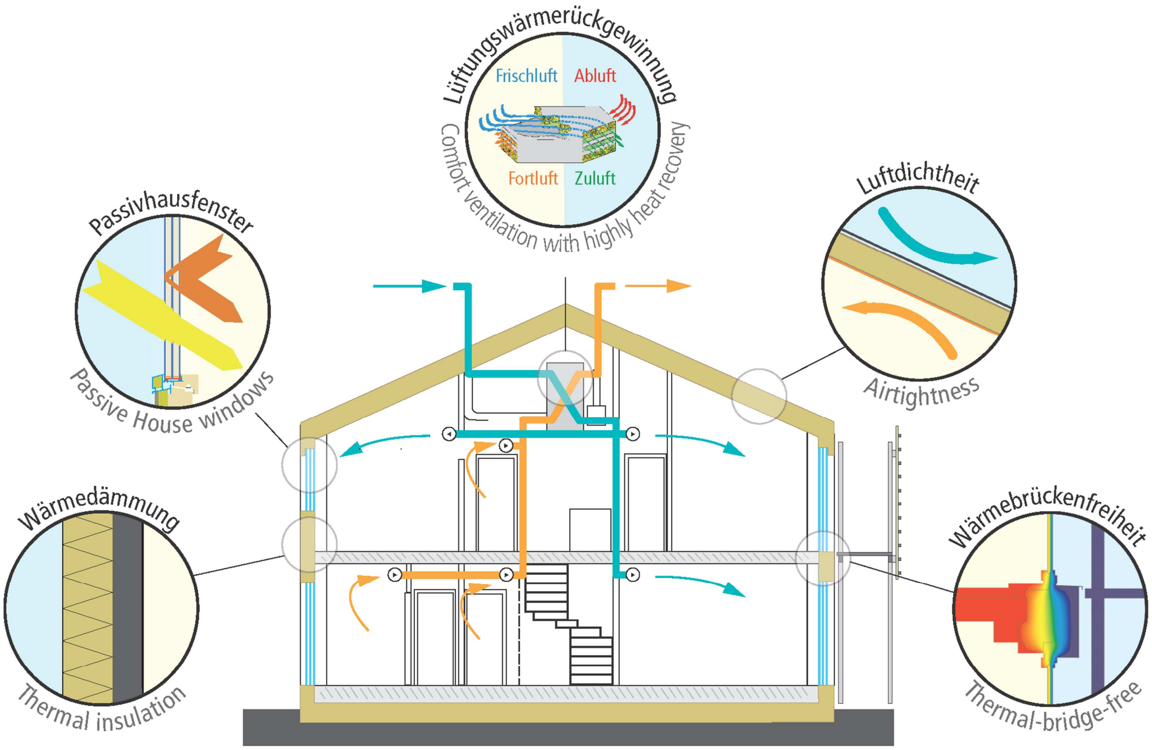
- In terms of Airtightness, a maximum of 0.6 air changes per hour at 50 Pascal pressure (ACH50), as verified with an onsite pressure test (in both pressurized and depressurized states).

- Thermal comfort must be met for all living areas during winter as well as in summer, with not more than 10 % of the hours in a given year over 25 °C (77 °F).

All of the above criteria are achieved through smart design and implementation of the five Passive House principles: thermal bridge free design, superior windows, ventilation with heat recovery, quality insulation, and airtight construction.

The following basic principles apply for the construction of Passive Houses:

Figure 3: Five Passive House Principles - Source: Passivhaus Institut



- *Thermal insulation*
  All opaque building components of the exterior envelope of the house must be very well insulated. For most cool-temperate climates, this means a heat transfer coefficient of 0.15 W/m²K (0.14 Btu/hr-ft^2-°F) at the most.

- *Passive House windows*
  The window frames must be well insulated and fitted with low-e glazing filled with argon or krypton to prevent heat transfer. For most cool-temperate climates, this means a U-value of 0.80 W/m²K or less, with g-values ~ 50%.

- *Ventilation heat recovery*
  Efficient heat recovery ventilation is key, allowing for a good indoor air quality and saving energy. In Passive House, at least 75% of the heat from the exhaust air is transferred to the fresh air again by a heat exchanger.

- *Airtightness of the building*
  Uncontrolled leakage through gaps must be smaller than 0.6 of the total house volume per hour during a pressure test at 50 Pascal.

- *Absence of thermal bridges*
  All edges, corners, connections, and penetrations must be planned and executed with great care, so that thermal bridges can be avoided. Thermal bridges that cannot be avoided must be minimized as far as possible.

Passivhaus considers plug loads in the sense that there is a total primary (source) energy limit including plug loads. In essence, it means that all appliances etc. needs to be very energy efficient, and thus having a high rating within the EU Energy Label system, comply with Energy Star, etc.

4. BEST PRACTICES IN THE U.S.

There are a number of systems available in the U.S. that promotes green and/or energy efficient buildings. Among those are Energy Star, LEED (Leadership in Energy and Environmental Design), Green Globes, Advanced Energy Design Guides, 2030 Challenge, Living Building Challenge, and Passive House.

Each of these has their pros and cons. Most widespread are Energy Star and LEED. Energy Star does not require much in terms of advanced energy efficiency measures. LEED (V4) offers more points if you use 30-50% less energy than a baseline building according to ASHRAE 90.1-2010, however if you are not aiming for the highest levels of LEED certification, then you can get away with just a 10% improvement. In all practicality, the same goes for Green Globes.

The latest Advanced Energy Design Guides provided by ANSI (American National Standards Institute)/ASHRAE/IESNA (Illuminating Engineering Society of North America) in partnership with American Institute of Architects (AIA), United States Green Building Council (USGBC) and DoE offers design guidance to achieve a 50% energy reduction compared to standard 90.1-2004 for a number of different building types.

The 2030 Challenge[8], and indirectly the Minnesota SB 2030[9] , requires a phased reduction in energy consumption of 60% in 2010, 70% in 2015, 80% in 2020, 90% in 2025, and carbon neutral in 2030. So far, site EUI is used as a proxy for carbon reduction, so in essence the 2015 requirement is 70% below the average energy consumption of a similar building in same region as found in EIA's 2003 CBECS (U.S. Energy Information Administration's 2003 Commercial Buildings Energy Consumption Survey) or in case of SB 2030, the 2015 requirement is 70% below a code legal building in 2003 (ASHRAE 90.1-1999). That is a significant reduction. However, it is a reduction from a quite high energy usage level, so not necessarily pushing the boundaries in the beginning.

Passive House[10] and Living Building Challenge[11] are both more rigorous in their energy requirements.

The Passive House system is basically a full North American adaptation of the German Passivhaus system and was introduced in the U.S. in 2007. Currently more than 120 buildings have received a Passive House certification from the Passive House Institute US (PHIUS).

Living Building Challenge's energy petal requires a net positive energy system. One hundred and five percent of the project's energy needs must be supplied by on-site renewable energy on a net annual basis, without the use of on-site combustion. Projects must provide on-site energy storage for resiliency.

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[8] http://www.architecture2030.org/2030_challenge/the_2030_challenge
[9] http://www.b3mn.org/2030energystandard/
[10] http://www.phius.org/home-page
[11] http://living-future.org/lbc

The International Living Future Institute also offers a Net Zero Energy Certification that requires one hundred percent of the building's energy needs on a net annual basis must be supplied by on-site renewable energy.

The Living Future Institute recently introduced a Living Community Challenge that looks at entire communities or campuses, which more easily allows for some larger district systems that can be shared. All energy has to be supplied on-site by renewable non-combustible sources.

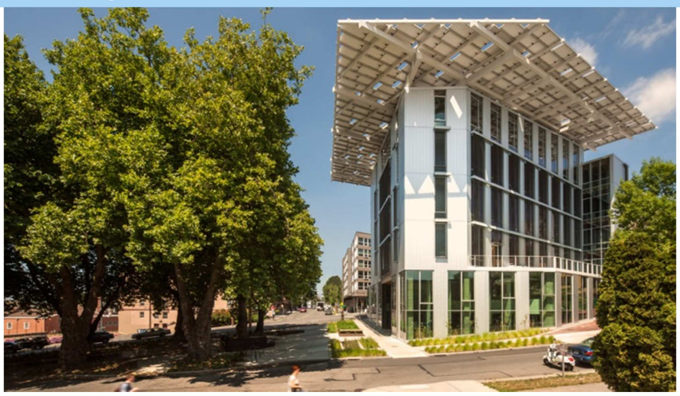
4.1 USA – Examples

Below are a few examples of United States buildings designed to be low-energy, ultra-low energy, or net-zero site energy.

NREL Research Support Facility Golden, CO	Main Building Data	Other Information
 *Photo: NREL*	Office building 360,000 ft^2 (33,500 m^2) Design site EUI: 35.1 kBtu/ft^2/yr (111 kWh/m^2/yr) 2.5 MW_p PV system on roof, guest parking lot and staff parking garage	Net zero site energy building LEED Platinum certification (v2.2 RSF I / v3 RSF II)

Brock Environmental Center Virginia Beach, VA	Main Building Data	Other Information
 *Rendering: Smithgroup JJR*	2014 Educational center and office 10,000 ft^2 (930 m^2) Design site EUI: 18.9 kBtu/ft^2/yr (59.6 kWh/m^2/yr) 39 kW_p PV system on roof 20 kW wind turbines	Net zero site energy building LEED Platinum certification (v3) Living Building Challenge certification (v2)

Bright'n'Green Brooklyn, NY	**Main Building Data**	**Other Information**
 *Photo: Scarano Architects*	2014 Multi Residential 15,000 ft^2 (1,400 m^2) Design site EUI: < 14.3 $kBtu/ft^2/yr$ (<45 $kWh/m^2/yr$) Solar heating and 38 kW_p PV system on roof and facade	Net zero site energy building Passive House certification Living Building Challenge (v2) certification LEED Platinum certification Green Globe (4/4) certification NGBS Emerald certification

Bullitt Center Seattle, WA	**Main Building Data**	**Other Information**
 *Photo: Bullitt Center*	2013 Office building 52,000 ft^2 (4,800 m^2) Design site EUI: 16 $kBtu/ft^2/yr$ (50.5 $kWh/m^2/yr$) Ground source heating and cooling 242 kW_p PV system on roof	Living Building Challenge (v2) certification

5. MODEL BUILDING ENERGY USAGE

The total site EUI for the model buildings shown in the table below (Table 3) are only indicative of that type of building's actual energy consumption. However, the same approximate models are used across all the calculations, so they are comparable within their own class. More detailed information about the calculations can be found in Appendix I, II, and III.

Actual energy consumption depends on the actual design, construction quality, maintenance, weather, and occupant behavior.

5.1 Methodology

In order to compare the energy efficiency level of the different codes, standards and systems on an equal footing, we show the total site Energy Utilization Intensity or EUI.
Plug loads are not included in the Danish Building Code, so we have estimated plug load values based on literature and published research of this. See appendix III

For buildings with a high process load and typical requirements for additional ventilation like a restaurant, hospital, etc., the Danish requirements do not easily and adequately consider those and likely underestimate the allowable EUI for these types of buildings.

For the Passive House requirements, a worst-case scenario of all other allowed source energy is grid-supplied electricity using an average US source energy multiplier provides us with a total site EUI.

For SB 2030 we have used the calculator provided at their website to arrive at current total site EUI values for the different building types. Later steps are reduced by the planned percentage. Values have since been verified by Center for Sustainable Building Research at University of Minnesota.

As a point of reference, using the latest LEED v4 rating system that utilizes ASHRAE 90.1-2010 as baseline, a Platinum certification would typically require all the energy points of the 'Optimize Energy Performance' credit (50% better than the baseline). That brings the energy requirement down to a point where it is better than SB 2030's 2020 requirement and the 2010 Danish building code requirement.

Table 3: Comparative site energy utilization intensity

Estimated Site Energy Utilization Intensity (EUI) for different new building types in climate zone 6A (St. Paul) using different energy codes or certification systems.

kBtu/ft²/yr

Building Type \ Code	Prototype Floor Area (sf)	ASHRAE 90.1-2004 (~ Current MN Energy Code)	2012 IECC / ASHRAE 90.1-2010	2015 IECC / ASHRAE 90.1-2013	SB 2030 (2010) -60%	SB 2030 (2015) -70%	SB 2030 (2020) -80%	SB 2030 (2025) -90%	German Passive House System	Danish Building Code BR 2010	Danish Building Code Class 2015	Danish Building Code Class 2020
Small office	5,502	53.7	41.8	37.2	64.0	48.0	32.0	16.0	14.3	37.1	25.8	18.7
Medium office	53,628	62.2	46.2	42.8	60.0	45.0	30.0	15.0	14.3	36.1	25.2	18.7
Large office	498,588	99.7	84.8	83.5	60.0	45.0	30.0	15.0	14.3	36.1	25.1	18.7
Stand-alone retail	24,692	107.2	71.9	61.9	58.7	44.0	29.3	14.7	14.3	36.3	25.2	18.7
Strip mall retail	22,500	118.3	85.4	77.9	60.0	45.0	30.0	15.0	14.3	36.3	25.3	18.7
Supermarket	n/a	208.0	145.0	128.7	54.7	41.0	27.3	13.7	14.3	36.0	25.1	18.7
Primary school	73,959	100.1	75.1	67.8	68.0	51.0	34.0	17.0	14.3	36.1	25.1	18.7
Secondary school	210,887	98.4	64.7	56.2	58.7	44.0	29.3	14.7	14.3	36.1	25.1	18.7
Hospital	241,501	179.9	138.5	130.5	158.7	119.0	79.3	39.7	14.3	36.1	25.1	18.7
Outpatient health care	40,946	161.5	123.3	118.8	117.3	88.0	58.7	29.3	14.3	36.2	25.2	18.7
Full-service restaurant	5,502	570.2	470.9	450.8	96.0	72.0	48.0	24.0	14.3	37.1	25.8	18.7
Quick-service restaurant	2,501	781.9	723.0	689.6	105.3	79.0	52.7	26.3	14.3	38.3	26.6	18.7
Small hotel	43,202	87.4	75.8	71.5	84.0	63.0	42.0	21.0	14.3	28.5	19.6	15.0
Large hotel	122,120	151.8	119.1	109.4	88.0	66.0	44.0	22.0	14.3	28.5	19.5	15.0
Warehouse	52,045	35.3	25.2	23.6	40.0	30.0	20.0	10.0	14.3	36.2	25.2	18.7
Mid-rise apartment	33,741	68.0	60.4	57.3	101.3	76.0	50.7	25.3	14.3	28.6	19.6	15.0
High-rise apartment	84,360	72.1	65.8	61.2	105.3	79.0	52.7	26.3	14.3	28.5	19.5	15.0

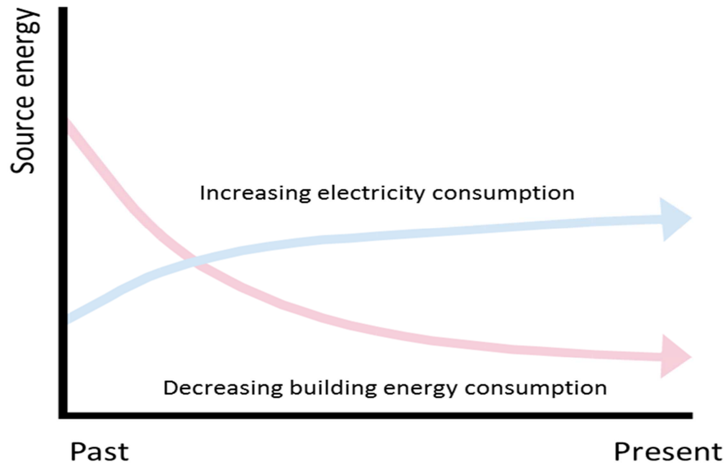
It appears that the different approaches around Europe and North America are moving in the same direction albeit with different time scales.

5.2 Plug loads

Traditional codes and standards offer control over the design and construction of the building related energy. However, there is not a very effective control over plug loads (except partly through the passive house and living building challenge systems), and with the continuing reduction of building related energy, the plug loads will become a larger and larger percentage of the total energy use that is not effectively controlled.

Plug loads are all the electricity used by appliances and electronic equipment that are not a fixed building installation, e.g. refrigerators, vending machines, televisions, computers, smartphone and tablet chargers, etc.
These plug loads are predominately controlled by a building's occupants, whether they are residents or workers. Consequently, it is very difficult to control the usage without treading into a sensitive sphere.

Figure 4: Effect of increased plug loads on total source EUI.



If nothing is done to curb the plug loads for the Ford site, it can be challenging to achieve the goal of net-zero because the reduced energy use by the buildings will be offset by the increased electricity consumption of appliances and electronic devices. Moreover, if this electricity is not from a renewable source, it will likely add to the CO_2, NO_X and SO_X emissions from the region's power plants.

5.3 Cost optimal

The Danish Building Research Institute published a report in 2013 titled "Cost-optimal levels of minimum performance requirements in the Danish Building Regulations"[12] . This report looks at the gap between the calculated cost optimal annual energy use for single-family housing, multi residential housing and office building and the estimated annual energy use calculated using the current 2010 code, Energy Class 2015, and Energy Class 2020. For multi residential and office buildings the cost optimal level is somewhere between the 2010 and 2015 requirements.

Considering that, the climate in Denmark is equal to zone 5A and St. Paul, MN is zone 6A the similar cost optimal result in St. Paul, MN having more cold days and thus using more heating energy, should move more towards the energy levels in Energy Class 2015.

Energy in Denmark is highly taxed and thus more expensive than in St. Paul, MN consequently influencing the results. The other side of the equation, however, the material and labor costs used to achieve the lower energy use, are also higher in Denmark than in St. Paul, MN. As such, the cost optimal level for St. Paul, MN is likely to be within the same range.

Given the above, we have used the "Cost-optimal levels of minimum performance requirements in the Danish Building Regulations" report as a guideline to determine the cost optimal recommendation for site EUI requirements for the Ford site development.

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[12] http://www.sbi.dk/miljo-og-energi/energibesparelser/cost-optimal-levels-of-minimum-energy-performance-requirements-in-the-danish-building-regulations

6. DISTRICT ENERGY SYSTEM COMPATIBILITY WITH NET ZERO OR LOW ENERGY BUILDINGS

How District Energy Systems, DES work with net zero emission goals depends on the frame work, code, standard, or other system that is or will be used. ASHRAE 90.1 works well with DES, and there exist well-used guidelines for how DES is modeled in a whole building energy simulation. Consequently, using LEED as a reference works equally well, as LEED's energy requirement is linked to ASHRAE 90.1 and the specific LEED requirements for DES are covered in a separate guideline.

Related to this, LEED also offer a Neighborhood Development certification (LEED ND), were the Green Infrastructure & Buildings category includes a credit that gives points for integrating a DES system into the neighborhood planning covering at least 80% of the projects annual heating and/or cooling consumption[13].

Living Building Challenge is somewhat more problematic in a DES connection in this site context. Living Building Challenge requires all energy to be produced on-site by non-fossil fuel. There are some openings for providing the energy as a district system, but all of it still has to be non-fossil fuel produced within the defined district.

Passive House requirements for heating and cooling are so stringent that the sum of energy in need of distribution is unlikely to be economically feasible to do as a district system. Similarly, the added cost of getting to the low heating and cooling loads are not always cost effective compared to the cost of DES delivered energy if done correctly.

Furthermore, from an environmental point of view, if a Passive House ends up using grid electricity as heating and cooling source, you have effectively replaced a low emission fuel source with source that typically uses about 3.3 times (US average) the energy to produce at the source.

The Danish Building Code generally works well with DES. There are several reasons for this, but mainly a political decision to promote DES, and thus integrate it into local planning and plans mandating the use of a DES. This decision is followed up by strict requirements as to what fuels are used at the CHP plants to produce the hot water or cooled water for heating and cooling respectively. Concurrently, there is a requirement in the building code to design for low-temperature district heating, which allows for using multiple sources of energy, including industrial waste energy, geothermal, heat pumps, and low-grade heat from other sources.

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[13] http://www.usgbc.org/node/2612936?return=/credits/neighborhood-development/v4/green-infrastructure-%26-buildings

Table 4: Overview of cost-effective DES compatibility with building design requirement

	Good	Neutral	Poor
ASHRAE 90.1-2004		✓	
ASHRAE 90.1-2010		✓	
ASHRAE 90.1-2013	✓		
SB 2030 (2010)		✓	
SB 2030 (2015)		✓	
SB 2030 (2020)	✓		
SB 2030 (2025)			✓
Passive House			✓
Living Building			✓
DK Building Code	✓		
DK Building Code	✓		
DK Building Code			✓
LEED		✓	

To create the basis for a DES, it is imperative that a project arrives at an energy consumption for the area that is predictable and consistent for planning and design purposes. Which technologies are optimal, strongly depends on the sizing and phasing of the expected future loads.

To illustrate the range of energy consumption that the Ford site can be designed for, the two scenarios (2 and 5) are tentatively calculated using ASHRAE 90.1-2010 and SB 2030 (2025) respectively. For more information on the calculation and assumptions, see Appendix IV.

Table 5: Range of total site energy and district heating (DH) load for the Ford site

	Total site energy		DH part	DH load
REDEVELOPMENT SCENARIOS	MBtu/yr (Million Btu)	MWh/yr (Million Watt-hour)	MWh/yr (Million Watt-hour)	2,100 hrs/yr
2- Light Industrial/ Flex Tech				
2012 IECC / ASHRAE 90.1-2010	166,140	48,691	18,000	9 MW
SB 2030 (2025 requirement)	36,848	10,799	4,000	2 MW
5 - Mixed Use: Transit Village				
2012 IECC / ASHRAE 90.1-2010	140,037	41,041	18,000	9 MW
SB 2030 (2025 requirement)	42,839	12,555	6,000	3 MW

It becomes clear that the optimal technologies and solutions are different for a site using a district heating (DH) system designed for 2 MW or 9 MW.

7. CONCLUSION

The best practice in Europe and the U.S. are typically only best practice because the code and/or voluntary system work with, and are embraced by, the local design and construction industry. In other words, it is often better to focus on a well-known and tried system and improve the goals to achieve a successful outcome.

Based on the interest in pursuing a net zero solution for the Ford site, a cost optimal level, and the discussion during Technical Advisory Group meeting #2 and 3, we suggest that the Ford site energy requirement for buildings be set as a maximum site EUI equal to SB 2030's 2020 requirement, which is 80% below a 2003 code legal building of similar type, usage and location.
However, for residential buildings, we suggest a slightly increased requirement of 85% below SB 2030's baseline because the optimum for residential buildings are lower than SB 2030's 2020 (80%) requirement. In addition, a lower energy consumption requirement in residential buildings necessitate better construction materials, better joints, fewer thermal bridges in the building envelope, etc., that will increase thermal comfort for the residents as well.

The below table shows the suggested site EUI at the Ford site for the most common building types.

Table 6: Suggested Ford Site energy requirements for typical buildings

kBtu/ft^2/yr

Building Type \ Code	Prototype Floor Area (sf)	Suggested Ford Site Requirements	Percent below 2003 baseline
Small office	5,502	32.0	80
Medium office	53,628	30.0	80
Large office	498,588	30.0	80
Stand-alone retail	24,692	29.3	80
Strip mall retail	22,500	30.0	80
Supermarket	n/a	27.3	80
Primary school	73,959	34.0	80
Secondary school	210,887	29.3	80
Mid-rise apartment	33,741	38.0	85
High-rise apartment	84,360	39.5	85

In addition, we recommend that some elements of control of process and plug loads are included in the Ford site development requirements. It could be a strengthened requirement for plug load control and/or only Energy Star certified or better appliances to be installed.

For developers, commercial owners and tenants that means all computers, servers, monitors, printer/copiers, coffee machines, commercial food service equipment, etc. they install are Energy Star certified or better.

For homeowners and residential tenants, information that recommends only using Energy Star certified or better electrical equipment as well as timers, smart use, plug load controls, etc. needs to be provided.

In order to ensure that the above issues are implemented in the design of the buildings on the Ford site, some form of mechanism that can provide that needs to be considered. We suggest some form of binding requirement be integrated into the bid requirements to the master developer or as part of a funding scheme for the area.

One of the key elements of the Chicago Lakeside Development[14] project is the development of a Lakeside Green Building Code that among other things sets maximum values to construction element U-factors (or minimum R-values), site EUI, connection to DES, etc. In order to make this an attractive proposal, the Owner and Developer works with the City of Chicago to create a special zoning of the area that allows projects that follow the Lakeside Green Building Code to have a streamlined permitting process with a goal of getting a permit in 1 week. It is modeled on Chicago's Green Permit Program[15]. Perhaps something similar is possible for the Ford site?

[14] http://chicagolakesidedevelopment.com/

[15] http://www.cityofchicago.org/city/en/depts/bldgs/supp_info/overview_of_the_greenpermitprogram.html

Ford Site - St. Paul, MN

New Construction

Estimated Site Energy Utilization Intensity (EUI) for different building types in climate zone 6A (St. Paul)

kBtu/ft^2/yr

		~ Current Minnesota Energy Code												
		ASHRAE 90.1-2004 [1]			**2012 IECC / ASHRAE 90.1-2010** [1] [2]		**2015 IECC / ASHRAE 90.1-2013** [2]		**SB 2030**					
	Prototype Floor Area (sf)	National Average Site EUI	**Climate Zone 6 Average Site EUI**	Factor between National and Climate Zone 6A	National Average Site EUI	**Climate Zone 6 Average Site EUI**	National Average Site EUI	**Climate Zone 6 Average Site EUI**	2003 Baseline	2010 60% below	2015 70% below	2020 80% below	2025 90% below	2030 100% below
Small office	5,502	42.4	**53.7**	1.267	33.0	**41.8**	29.4	**37.2**	160.0	64.0	48.0	32.0	16.0	-
Medium office	53,628	49.5	**62.2**	1.256	36.8	**46.2**	34.1	**42.8**	150.0	60.0	45.0	30.0	15.0	-
Large office	498,588	84.5	**99.7**	1.179	71.9	**84.8**	70.8	**83.5**	150.0	60.0	45.0	30.0	15.0	-
Stand-alone retail	24,692	79.5	**107.2**	1.348	53.4	**71.9**	45.9	**61.9**	146.8	58.7	44.0	29.3	14.7	-
Strip mall retail	22,500	83.7	**118.3**	1.414	60.4	**85.4**	55.1	**77.9**	150.0	60.0	45.0	30.0	15.0	-
Supermarket [3]	n/a	179.0	**208.0**	1.162	*124.8*	**145.0**	*110.8*	**128.7**	136.8	54.7	41.0	27.3	13.7	-
Primary school	73,959	80.1	**100.1**	1.250	60.1	**75.1**	54.2	**67.8**	170.0	68.0	51.0	34.0	17.0	-
Secondary school	210,887	72.9	**98.4**	1.348	48.0	**64.7**	41.7	**56.2**	146.8	58.7	44.0	29.3	14.7	-
Hospital	241,501	170.5	**179.9**	1.055	131.3	**138.5**	123.7	**130.5**	396.8	158.7	119.0	79.3	39.7	-
Outpatient health care	40,946	157.4	**161.5**	1.026	120.2	**123.3**	115.8	**118.8**	293.3	117.3	88.0	58.7	29.3	-
Full-service restaurant	5,502	471.2	**570.2**	1.210	389.1	**470.9**	372.5	**450.8**	240.0	96.0	72.0	48.0	24.0	-
Quick-service restaurant	2,501	653.6	**781.9**	1.196	604.4	**723.0**	576.4	**689.6**	263.3	105.3	79.0	52.7	26.3	-
Small hotel	43,202	73.3	**87.4**	1.192	63.6	**75.8**	60.0	**71.5**	210.0	84.0	63.0	42.0	21.0	-
Large hotel	122,120	123.5	**151.8**	1.230	96.9	**119.1**	89.0	**109.4**	220.0	88.0	66.0	44.0	22.0	-
Warehouse	52,045	25.5	**35.3**	1.381	18.2	**25.2**	17.1	**23.6**	100.0	40.0	30.0	20.0	10.0	-
Mid-rise apartment	33,741	52.1	**68.0**	1.304	46.3	**60.4**	43.9	**57.3**	253.3	101.3	76.0	50.7	25.3	-
High-rise apartment [4]	84,360	55.3	**72.1**	1.304	50.4	**65.8**	46.9	**61.2**	263.3	105.3	79.0	52.7	26.3	-

1) "ASHRAE Standard Benchmark Energy Utilization Index", October 2009. Data updated with "Enhancements to ASHRAE Standard 90.1 Prototype Building Models", April 2014.

2) DOE Standard 90.1-2013 Final Dertermination Quantitative Analysis, March 2014. Specific climate zone data not available. Data generated using proportional factor from [1]

3) Data only exists for 2004. Approximated value for 2010 and 2013 generated based on retail characteristics

4) National climate zone data not available. Data generated using weights from 2)

5) Significant inconsistency between 2004 value and newer 2010 and 2013 values, mostly due to new requirements in 2010 version of 90.1.

Climate Zone [1]	**Mid-rise** [1]	**'eights by Zone**
1A	39	3.24
2A	39	15.22
2B	38	2.98
3A	38	15.03
3B	36	10.08
3C	33	1.61
4A	42	19.29
4B	37	0.52
4C	38	2.98
5A	47	19.37
5B	41	4.34
6A	54	4.21
6B	48	0.57
7	59	0.51
8	76	0.06
		100.00
Sum Product	4,140.7	
National Weighted Average	**41.4**	

Ford Site - St. Paul, MN

Passive House system
Estimated Site Energy Utilization Intensity (EUI)

Maximum energy consumption for heating, cooling, and domestic hot water:	15.0	kWh/m2/yr
	4.8	kBtu/ft2/yr
Maximum total source energy	120.0	kWh/m2/yr
	38.1	kBtu/ft2/yr
If all other energy aside from heating and cooling is electrial, then total site EUI is:		
120 kWh/m2/yr - 15 kWh/m2/yr = 105 kWh/m2/yr (Source energy)		
105 kWh/m2/yr (Source energy) / 2.5 + 15 kWh/m2/yr =	57.0	kWh/m2/yr (Site)
	18.1	
If all 4.75 kBtu/ft2/yr is provided by hot water then the equal source EUI is	6.1	kBtu/ft2/yr (Source)
If all remaining energy is grid electrical then the remaining source EUI is	32.0	kBtu/ft2/yr (Source)
and the maximum grid electrical site EUI is	9.6	kBtu/ft2/yr
which means the total site EUI is	**14.3**	**kBtu/ft2/yr**
or	**45.2**	**kWh/m2/yr**

Table 1
Source-Site Ratios for all Portfolio Manager Fuels

Fuel Type	Source-Site Ratio
Electricity (Grid Purchase)	3.34
Electricity (on-Site Solar or Wind Installation)	1.0
Natural Gas	1.047
Fuel Oil (1,2,4,5,6,Diesel, Kerosene)	1.01
Propane & Liquid Propane	1.01
Steam	1.21
Hot Water	1.28
Chilled Water	1.05
Wood	1.0
Coal/Coke	1.0
Other	1.0

Danish Building Code - BR 2010

Standard

Dwellings, student accommodation, hotels etc.: 52.5 kWh/m²/year plus 1,650 kWh/year divided by the heated floor area.

Offices, schools, institutions etc.: 71.3 kWh/m²/year plus 1,650 kWh/year divided by the heated floor area.

Low energy class 2015 (Expected to become minimum in the coming 2015 building code)

Dwellings, student accommodation, hotels etc.: 30 kWh/m²/year plus 1,000 kWh/year divided by the heated floor area.

Offices, schools, institutions etc.: 41 kWh/m²/year plus 1,100 kWh/year divided by the heated floor area.

Low energy class 2020 (Expected to become minimum for public buildings in 2018 and all other in 2020)

Dwellings, student accommodation, hotels etc.: 20 kWh/m²/year

Offices, schools, institutions etc.: 25 kWh/m²/year

Plug loads

Average DK family uses	5,200	kWh/yr in electricity each year in a 140 m^2 house.			
Of this lighting is	16%	or	832.0	kWh/yr ->	5.9 kWh/m^2/yr
Remaining is plug loads	84%	or	4,368.0	kWh/yr ->	31.2 kWh/m^2/yr

	2015	*2020*
Lighting energy for dwelling, dorms, hotels, etc. is considered proportional to building load reduction. Share compared to 2010.	57.1%	38.1%
Plug loads are expected to be reduced with significantly less. Share compared to 2010	90%	80%

Commercial plug loads in typical office buildings designed after BR 08 will use about 200 kWh/m^2/yr as primary (source) energy. Of this 79% is electricity according to a 2008 report from SBI (National Building Institute). 53% is plug loads, or as site energy: 42.4 kWh/m^2/yr

			2010					2015					2020				
	Prototype Floor Area		Code	Lighting 1)	Plug loads	Total		Code	Lighting 1)	Plug loads	Total		Code	Lighting 1)	Plug loads	Total	
Building Type	ft^2	m^2	kWh/m^2/yr	kWh/m^2/yr	kWh/m^2/yr	kWh/m^2/yr	kBtu/ft^2/yr	kWh/m^2/yr	kWh/m^2/yr	kWh/m^2/yr	kWh/m^2/yr	kBtu/ft^2/yr	kWh/m^2/yr	kWh/m^2/yr	kWh/m^2/yr	kWh/m^2/yr	kBtu/ft^2/yr
Small office	5,502	511	74.5	-	42.4	116.9	37.1	43.2	-	38.2	81.3	25.8	25.0	-	33.9	58.9	18.7
Medium office	53,628	4,982	71.6	-	42.4	114.0	36.1	41.2	-	38.2	79.4	25.2	25.0	-	33.9	58.9	18.7
Large office	498,588	46,320	71.3	-	42.4	113.7	36.1	41.0	-	38.2	79.2	25.1	25.0	-	33.9	58.9	18.7
Stand-alone retail	24,692	2,294	72.0	-	42.4	114.4	36.3	41.5	-	38.2	79.6	25.2	25.0	-	33.9	58.9	18.7
Strip mall retail	22,500	2,090	72.1	-	42.4	114.5	36.3	41.5	-	38.2	79.7	25.3	25.0	-	33.9	58.9	18.7
Supermarket	n/a	n/a	71.3	-	42.4	113.7	36.0	41.0	-	38.2	79.2	25.1	25.0	-	33.9	58.9	18.7
Primary school	73,959	6,871	71.5	-	42.4	113.9	36.1	41.2	-	38.2	79.3	25.1	25.0	-	33.9	58.9	18.7
Secondary school	210,887	19,592	71.4	-	42.4	113.8	36.1	41.1	-	38.2	79.2	25.1	25.0	-	33.9	58.9	18.7
Hospital	241,501	22,436	71.4	-	42.4	113.8	36.1	41.0	-	38.2	79.2	25.1	25.0	-	33.9	58.9	18.7
Outpatient health care	40,946	3,804	71.7	-	42.4	114.1	36.2	41.3	-	38.2	79.4	25.2	25.0	-	33.9	58.9	18.7
Full-service restaurant	5,502	511	74.5	-	42.4	116.9	37.1	43.2	-	38.2	81.3	25.8	25.0	-	33.9	58.9	18.7
Quick-service restaurant	2,501	232	78.4	-	42.4	120.8	38.3	45.7	-	38.2	83.9	26.6	25.0	-	33.9	58.9	18.7
Small hotel	43,202	4,014	52.9	5.9	31.2	90.1	28.5	30.2	3.4	28.1	61.7	19.6	20.0	2.3	25.0	47.2	15.0
Large hotel	122,120	11,345	52.6	5.9	31.2	89.8	28.5	30.1	3.4	28.1	61.6	19.5	20.0	2.3	25.0	47.2	15.0
Warehouse	52,045	4,835	71.6	-	42.4	114.0	36.2	41.2	-	38.2	79.4	25.2	25.0	-	33.9	58.9	18.7
Mid-rise apartment	33,741	3,135	53.0	5.9	31.2	90.2	28.6	30.3	3.4	28.1	61.8	19.6	20.0	2.3	25.0	47.2	15.0
High-rise apartment	84,360	7,837	52.7	5.9	31.2	89.9	28.5	30.1	3.4	28.1	61.6	19.5	20.0	2.3	25.0	47.2	15.0

1) Lighting is included in code requirement for offices, schools, instituitions, etc.

Ford Site - St. Paul, MN

Tentative Energy Calculation

		Residential units						Square Feet Other Uses			Total site energy		DH part	DH load
REDEVELOPMENT SCENARIOS		Single-Family	Town-home	Multi-family low density (3-10 units per building - 1 to 4 stories)	Multi-family med density (10-40 units per building - 4 to 8 stories)	Multi-family high density (40 or more units per building - 8 stories or taller)	TOTAL Resid. Units	Office/ Institu.	Retail	Industrial	MBtu/yr (Million Btu)	MWh/yr (Million Watt-hour)	MWh/yr (Million Watt-hour)	2,100 hrs/yr
2- Light Industrial/ Flex Tech		87	36	250	251	-	624	250,000	135,000	590,000				
2012 IECC / ASHRAE 90.1-2010	kBtu/yr	21,297,260	3,263,948	18,133,043	18,205,576	-	60,899,827	14,400,689	13,604,519	77,235,352	166,140	48,691	18,000	9 MW
SB 2030 (2025 requirement)	kBtu/yr	8,914,455	1,366,200	7,590,000	7,620,360	-	25,491,015	3,833,333	1,953,000	20,355,000	51,632	15,132	6,000	3 MW
5 - Mixed Use: Transit Village		-	-	300	730	320	1,350	375,000	194,000	-				
2012 IECC / ASHRAE 90.1-2010	kBtu/yr			21,759,652	52,948,487	24,177,391	98,885,530	21,601,033	19,550,197	-	140,037	41,041	18,000	9 MW
SB 2030 (2025 requirement)	kBtu/yr			9,108,000	22,162,800	9,715,200	40,986,000	5,750,000	2,806,533	-	49,543	14,519	7,000	3 MW

Average site EUI's for Office and Retail used.
Industrial is equaled to average health-care as no data for industrial is available.
Apartments in multiresidential buildings are estimated to be an average of 1,200 ft^2

Single Family homes and Town Homes would be covered by the 2012 IRC, but for this purpose is estimated using the 2012 IECC.

Average new single familiy home was 2,700 ft^2 in 2014 1Q. Site EUI for mid-rise used with a 50% addition.	90.7 $kBtu/ft^2/yr$ =	286.0 $kWh/m^2/yr$
Average townhouse is about 1,200 ft^2 per unit. Site EUI for Mid-rise used with a 25% addition.	75.6 $kBtu/ft^2/yr$ =	238.3 $kWh/m^2/yr$

It is likely that electrical plug loads are underestimated in the SB 2030 (2025) case, as most models assign a 25% addition to building loads for plug loads, but with significant reduction in building loads, this percentage will likely be too low.

AC 1.7: BUILDING REQUIREMENTS GUIDE

Activity description:
Outline in a brief document the requirements to technical design of the building heating systems for it to be adoptable for connection to the district heating network.
The aim has been to produce a brief and simple guide. That, to some extent, allow for design flexibility.

Intended for
The City of St Paul

Document type
Report

Date
January, 2015

DISTRICT ENERGY FOR DEVELOPERS
INTRODUCTION

RAMBOLL

DISTRICT ENERGY FOR DEVELOPERS INTRODUCTION

Revision	**2**
Date	**2015-01-23**
Made by	**JAKB, PKO**
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Approved by	**PMO**
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1. INTRODUCTION

This document is intended to serve as an introduction to district energy systems for property developers.

The document outlines the characteristics of a district energy system as well as the typical setup. The document deals with both district heating and district cooling, with focus on the connection of buildings (consumers).
The document does not in detail deal with the production of heating and cooling.
The buildings internal systems and their requirements related to district heating and cooling systems are briefly outlined.

The document is not intended to elaborate on all details of building a district energy system, but the focus is to give developers an introduction and idea of the critical factors when choosing a district energy solution and the resulting impact on building installations and operation.

2. WHAT IS DISTRICT ENERGY

District energy (DE) is a system that provides heating and sometimes also cooling from central production plants to a number of consumers to meet the consumers need for space heating and domestic hot water and cooling. The heating and cooling is distributed by means of a piped distribution network using hot or chilled water.

The network consists of supply pipes and return pipes and the proposed network in St Paul for the Ford Site can be split into two levels: The branches and connections to supply the buildings and the distribution heating and cooling networks themselves. The distribution network connects the supply from the Energy Centre's central plant, where the heating and/or cooling is produced to the buildings via the branches and connections.

Modern DE systems combine district heating, district cooling with combined heat and power (CHP) also known as co-generation, thermal storage, heat pumps and/or decentralised energy.

DE is characterised by a high degree of fuel flexibility as a wide range of fuels can be used as heating and /or cooling source. DE can be produced from fossil fuel sources such as natural gas, oil or by renewable energy (e.g. biomass, solar thermal, geothermal or heat pump solutions) or waste heat from industrial processes. The fuel is burned directly in boilers or through CHP. The heat to a heat network can also be produced by solar thermal panels or large scale heat pumps connected to the network.

The high degree of fuel flexibility often helps securing low and stable heat prices. By CHP the surplus heat from electricity production is utilised to supply heating and/or cooling to the networks.

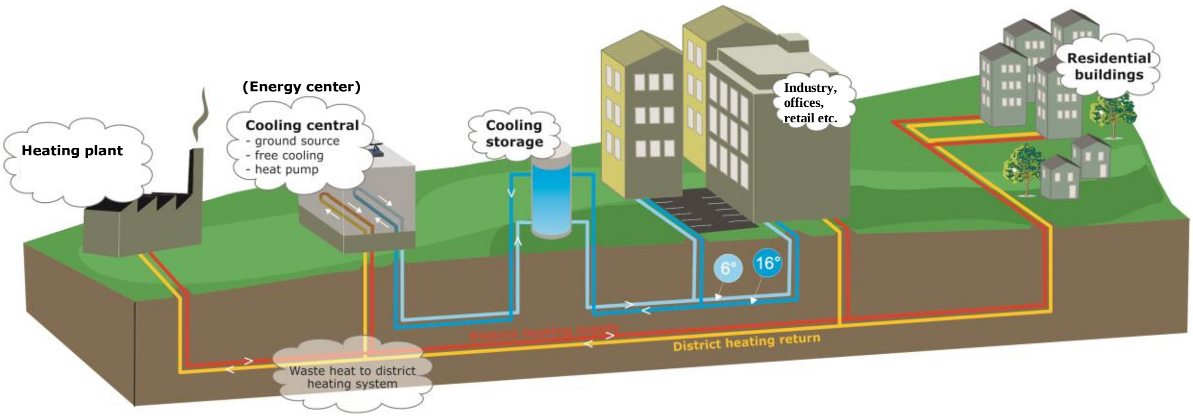

Figure 2-1 Supply concept for district heating and cooling.

The DE concept takes advantage of the effectiveness of central and large scale production, or even surplus energy from other processes, to produce energy more efficiently than individual small scale energy conversions such as gas boilers. These advantages outweigh the downsides of any heat losses in the distribution networks, which with the right design are relatively small.

Having both a district heating and a district cooling system brings a number of synergies, which is beneficial for both the DE utility company and the consumers. Most important to mention, is that surplus heat from the cooling system can be used in the district heating system by means of large heat pumps. Utilizing this heat can potentially give lower heat and cooling prices for the consumers.

It is recommended that modern district energy systems are designed according to the principle of low temperature district heating and high temperature district cooling to provide the most efficient and cost effective systems.

3. DOMESTIC HEATING INSTALLATIONS

3.1 Connecting buildings to district heating

The individual apartment, condo, house or building's heating system can be either directly or indirectly connected to a district heating (DH) network.

Two service pipes connect an apartment, condo, house or building ("the building") to the district heating network. One brings the hot water to "the building" and the other returns the "cooled" water to bring it back to be reheated at the energy center or plant building.

The domestic hot water (DHW) can either be supplied through a hot water cylinder or instantaneously.

"The building" can be heated either by radiators, floor heating or by a combination of radiators and floor heating. Hot air can also be used, however, radiators and floor heating give a better thermal comfort than air heating.

3.2 Typical setup – indirect connections

The most typical setup connecting the domestic heating system with the DH network is through substations. The hot water coming from the DH system is run through a plate heat exchanger to heat the water of the domestic heating system. Which effectively is two closed loop systems transferring energy.

Domestic hot water is produced in the same way, although this is not a closed loop.
A hot water tank can be added depending on the setup, as well as an expansion body for safety reasons in case of changes in pressure in the main system.
Substations create a minor temperature loss, as the temperature on the domestic system can never be as high as in the distribution system, but they also provide a separation of the systems that many operators prefer.

For high-rise buildings, multi-dwelling houses and one family houses separate substations, with meters, can be applied for each end-user.

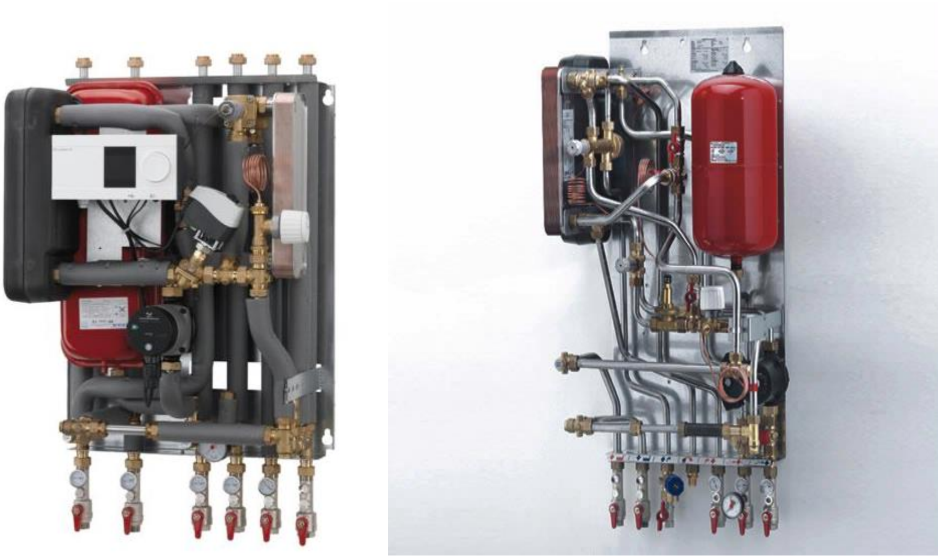

Figure 3-1 Examples of a wall mounted consumer substation for an individual residence. The substations are illustrated without casing. The substation to the right is shown without any insulation (Photo: Danfoss)

You can find DH substations with integrated floor heating systems like the below examples.

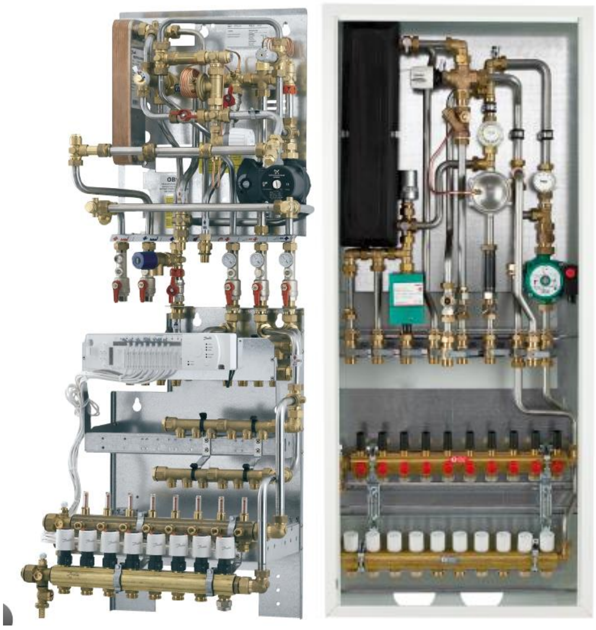

Figure 3-2 Examples of consumer substations for an individual residence with integrated heating manifolds. The installations are shown without casing / insulation (Photo: Danfoss and PEWO)

In the larger apartment buildings there can be a central substation with a heat exchanger at the ground floor supplying every flat with direct heating (no heat-exchanger) to radiators and/or through a mixing circuit (loop) for the floor heating system as well as for the domestic hot water via a small heat exchanger.

A typical example of a larger central floor mounted substation is seen below and it will be supplying into larger or high rise buildings via a heat exchanger. Such a large substation solution could also be used for commercial, retail and offices buildings. These substations are shown without large domestic hot water tanks, which could also be an option.

Figure 3-3 Examples of floor mounted substations with heat exchanger for blocks or large commercial, retail or office connections. The components are illustrated without insulation /casing (Photo: Danfoss)

3.3 Apartment block / high rise building: 3-pipe vs. 5-pipe riser system

Instead of having a large central substation in the basement of an apartment block / high rise building, which require a 5-pipe system for heating and domestic water supply (incl. circulation) another concept can be to have a system with individual sub-stations or Hydraulic interface units (HIU). Such a system will only require a 3-pipe distribution system in the building and installation of a small individual consumer substation in each living unit.

The concept is shown in the figures below.

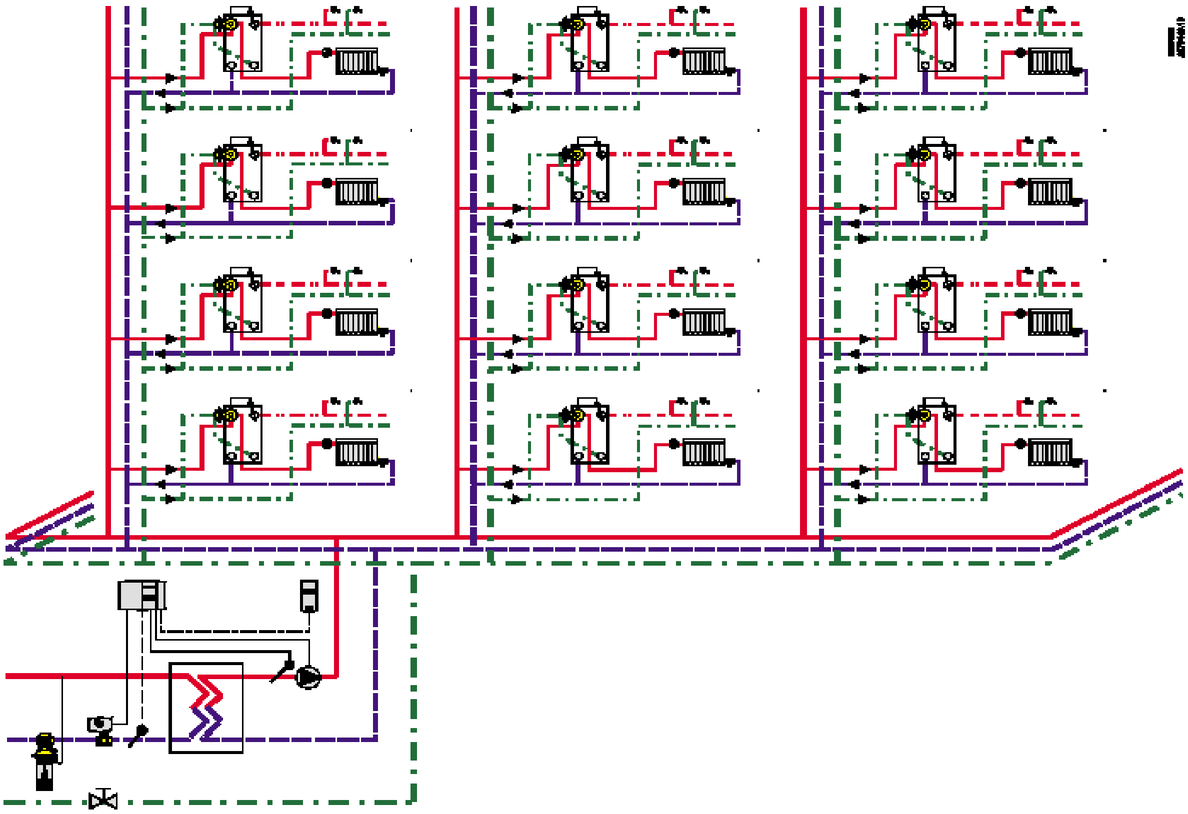

Figure 3-4 Example of district heating system connection in a high rise building (Illustration: Danfoss).

Here it is shown with radiator panels, but it could also be with floor heating or hot air units.

This type of design is considered to be a more modern heat supply concept and should be considered for new buildings, including hotels and domestic sector. Main advantages of the individual sub-station system compared to the central production of domestic hot water are:

- Possible to supply with a lower DH temperature (and the design can be suitable / prepared for low-temperature DH).
- Reduced distribution heat loss
- Individual metering of heating and domestic hot water energy consumption with only one meter
- Low volume of domestic hot water resulting in reduced risk of bacterial growth.

3.4 Temperature requirements from the DH supply

The temperature supplied from the DH system can vary depending on a number of factors. Generally it should be noted that there has been a move from steam systems with super-heated water towards lower temperatures, in some cases down to 140°F (60°C) supply temperature.
One reason is that hot water at lower temperatures is “cheaper” to produce; it allows for more renewable energy, and it results in lower heat losses in the distribution networks.

The temperature of the water in the return aspect of the system, and more importantly the temperature difference between supply and return water (delta-T), is of paramount importance for the system effectiveness. Generally the delta-T is between 35-80°F (20-45°C) and illustrates how much energy is utilized in the buildings. The greater the delta-T, the more efficient use of the energy, although systems with lower supply temperature will naturally have a smaller delta-T.

Many DH suppliers will reward customers for helping them maintain a high delta-T.

3.5 Domestic hot water

The requirements in the building code of the state should be fulfilled. The temperature requirement for showers and wash sinks could be about 104°F (40°C) and for kitchen sinks 113°F (45°C). Note that in (larger) internal domestic hot water systems with circulation the temperature in the system must not drop below e.g. 131°F (55°C) anywhere in the system in order to avoid bacterial (legionella) risk.

In systems with individual sub-substations and with an instantaneous heat exchanger and no domestic hot water storage, the risk of bacterial growth is prevented by having no water storage and the water content in each DHW supply line, including the volume in the secondary side of the DHW heat exchanger kept to a minimum (below 3 liters). This is the allowable water content for the instantaneous DHW preparation systems that is considered to assure safety in relation to the Legionella risk, even without any treatments. This needs to be checked with local guidelines.

3.6 Internal heating system

To enhance a high delta-T in the DH network an efficient internal heating system within the buildings are required. Most commonly a two-string water based heating system with radiant heat through radiators, wall or underfloor-heating in each room is preferred, as it provides thermal comfort. In general, a setup with large heated surfaces such as underfloor heating allows for a greater heat transfer and, as such, optimal for enhancing a higher delta-T and/or use lower supply temperature. Larger radiator surfaces are also a solution.

Traditional building design with very small radiators should be avoided, since it requires high temperatures and result in a very low delta T.

The requirements in the building code of the state or as set by the City of St Paul for the Ford development should be fulfilled. Optimal indoor temperatures could be e.g. 70-71.5°F (21-22°C) in living rooms and 71.5-75°F (22-24°C) in bath rooms.

3.7 Examples of other district heating utilization possibilities

Briefly examples of other utilization possibilities for district heating (than room heating and normal domestic hot water heating) are described below.

3.7.1 Snow-melting and freeze protection

A practical solution – not an energy saving solution – is to utilize district heating to heat up exterior / outdoor construction surfaces in order to remove snow and ice.

Snowmelt technology can reduce or eliminate conventional snow removal, reduce wear and tear on walking and driving surfaces, and provide clean, safe, ice-free traffic areas. Walkways that are snow, ice, and salt-free will increase the comfort and confidence of users and building owners. Snowmelt systems can be designed into new or existing district systems. Buildings already connected to a district system can be readily connected to a supply or return line to heat and clear sidewalks, driveways, parking lots or ramps, and other major pedestrian or automotive traffic areas. These snowmelt applications reduce maintenance efforts for snow clearing and improve the safety of these areas.

Snowmelt systems utilize low water temperatures (for example at 95-120°F (35-50°C)) to circulate through the snowmelt tubing. Utilizing the lower temperature hot water allows for the incorporation of a wide variety of low-grade energy sources such as waste heat, condensate return, or district heating return lines. If the district heating is produced by a CHP plant, a lower return temperature to the plant will lead to higher energy efficiency of the plant.

Selection of piping for these installations is an important consideration for effective operations. Polyethylene (PEX) pipes are an attractive option because they are corrosion-free, manufactured in long sections with fewer joints, easy to handle, and require reduced installation time. Glycol selection is important in order to secure freeze protection, corrosion resistance, and low viscosity impacts for the circulating loop. Glycol selection should also consider design intent, pumping resistance, tubing spacing, r-value, freezing points, and load design.

3.7.2 Domestic appliances with hot water connection

Another idea to increase the potential for district heating is for households to install domestic appliances with hot water connection. Instead of using electrical power for heating up water, the appliances use hot water heated up by district heating. For households this will convert power consumption into an increased district heating consumption.

The economic benefit of this technology depends on the local prices of electricity and district heating, while the environmental benefit depends on the actual carbon emissions for electricity and district heating. District heating systems with a large share of surplus heat, solar heating etc. will particularly benefit from the technology, because it will increase the potential heat consumption during summer time.

Appliances on the market in Europe suitable for hot water supply:

Appliances with a heat exchanger – district heating can be connected directly HWC-machines (Heating Water Circuit):	Appliances with a direct domestic hot water intake / connection:
• Dishwasher • Washing machine (laundry) • Tumble dryer (laundry)	• Dishwasher • Washing machine (laundry)

Test studies of household appliances with built-in heat exchangers and/or washing machines with separate cold-and hot-water intake have been made in Denmark and Sweden. Results show that under ideal conditions, tumble dryers, washing machines and dishwashers with built-in heat exchangers can replace more than 80% of electricity consumption with district heating. For washing machines that use hot water, over 70% of electricity demand can be replaced by district heating.

Washing machines with cold and hot water intake have been on the market in Europe for the professional segment e.g. for common laundries, institutions, etc. for a number of years. In the market for household appliances there have also been various attempts from the manufacturers. At the moment about 3 washing machines are being sold on the Danish market. In addition, many dishwashers on the market are designed in such a way that hot water can be connected directly –it is usually indicated in the user manual, if it is possible.

Studies from Denmark show that, the hot water usage increases in the range of 5-15 % with hot water connection of washer and dish washer machines, which in particular, will have a positive impact on district heating network's operation in the summer months. In addition, it is assessed that the introduction of hot water connected machines will not affect the design conditions of the layout design of the district heating network.

Increased district heating consumption during summer in particular will be an advantage for the pipe network heat loss, because it will be relatively smaller.

4. DOMESTIC COOLING INSTALLATIONS

The overall principles of district cooling are very similar to district heating.

4.1 Connecting buildings to district cooling

Two service pipes connect a building to the district cooling network. One brings the cold water to the building and the other returns the “heated” water to bring it back to be re-cooled at the energy center or plant building.
The district cooling connection has a small space requirement for one or more heat exchanger and other equipment. The figures below show an example of how the district cooling can be connected to internal cooling distribution system in a building.

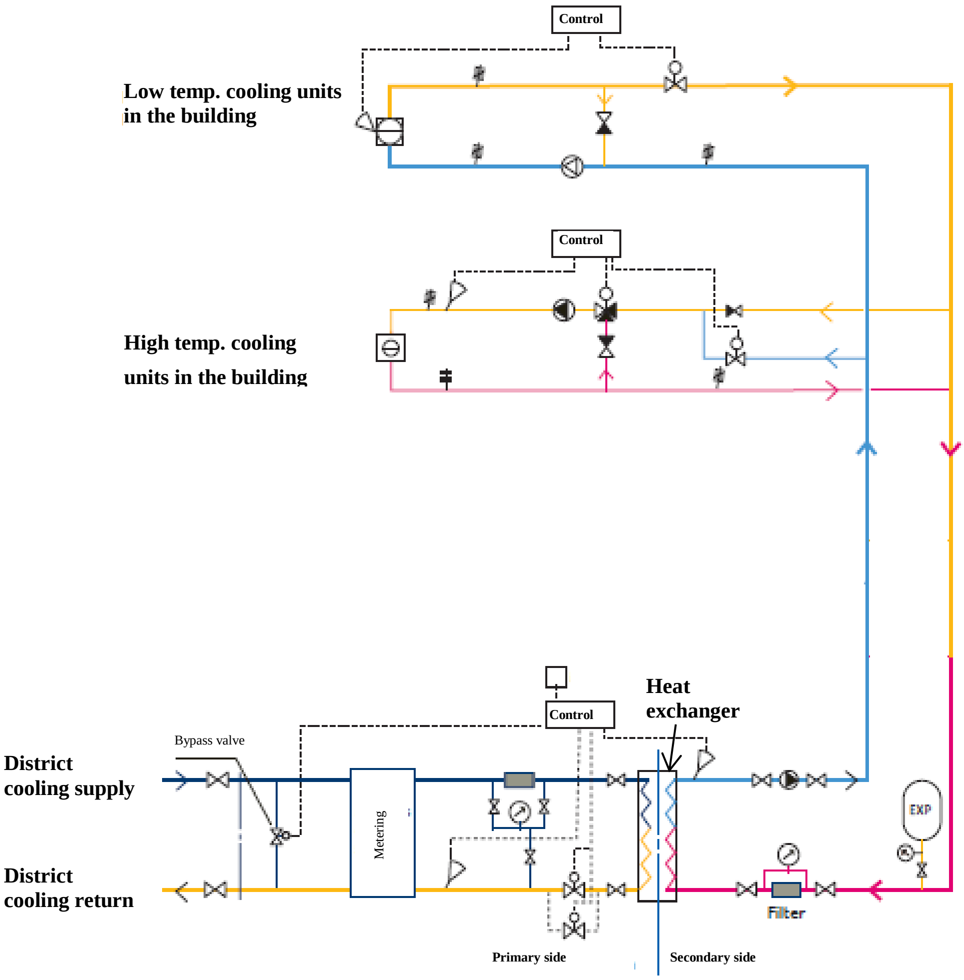

Figure 4-1 Example of a district cooling connection of a building

4.2 Temperaures in DC systems

Typical temperatures in a district cooling distribution network could be:

- Primary supply: 43°F (6°C)
- Primary return: 61°F (16°C)

Some buildings can have special cooling demands. Very low temperatures could be required. Buildings like supermarkets or other buildings with food storages etc. could need a lower supply temperature. For example if an air temperature of 35.5°F (2°C) is needed, it could be necessary to have a supply temperature of 23°F (-5°C) in order to provide that. In such cases the base cooling load could be delivered by the district network with 6°C in supply and then by small-scale units locally at the consumer level for be cooling further to the exact demand.

5. OPERATION, MAINTENANCE AND METERING

A DE scheme is a high cost capital asset and the investment is generally to be justified over a long operating period and it is important to look after the investment.
It is also essential that everybody involved have confidence in the system and that the asset can be and is maintained in operation without undue maintenance costs.

A high quality maintenance regime for the central plant will improve energy efficiency, provide a more reliable service, maximize environmental benefits and prolong the life of the plant and the network.

There are a number of established standards and industry guidance available including specific guidance for each type of heat source that might be used.

The substation and internal heating system requires very little attention in general. Modern substations automatically switch on and off when needed, and only need a general service check once a year or every other year to ensure that everything is in order.

Generally the district energy utility supplier will deal with all maintenance requirements up to and sometimes including the customer heat exchanger and/or the individual sub-station.

These days the utility meters are not only used for the settlement of the customer's energy consumption. The meter is also a natural tool for a constructive dialogue between the supplier and the customer. The possibilities of the meter are such that it can help the customers to ensure that their needs are covered at the lowest possible costs.

Modern meters and control systems also enable the DE operator to monitor and read all units remotely and smooth debugging and billing.

It is preferable that each consumer has installed a heat or chilled water meter as well as maybe domestic hot and cold water meters.

Heating or cooling meters are normally installed in the return pipe and typically it is mounted in the substation at a pre-defined place. Remote monitored heat meters can be used to detect malfunctions in the building heating system or at the consumer installation. For the district energy utility it is very useful to be able to detect possible operational errors in the district heating and cooling network in order to optimize the overall operation. The figure below shows example meters.

Figure 5-1 Example of energy meters for heating / cooling (left). Example of meters for hot and cold water (right) (Photo: Kamstrup).

6. DESIGN COORDINATION AND ADVISE

It is important that the internal heating and/or cooling systems in the buildings are designed to fit to the design of the DE network. Therefore, it is of great importance that the recommendations given in this folder are followed. This will help secure the lowest operational costs for the system as a whole and thereby the lowest price for the consumers.

For further information and advice on the Ford DE scheme and design of internal heating systems in the buildings please contact:

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APPENDIX 4 – ENERGY SYSTEMS
AC 1.5: ENERGY TECHNOLOGIES AND DISTRICT ENERGY DESIGNS

Activity description:
Outline good practice district energy design options in terms of optimisation of temperature and pressure, highlighting opportunities and barriers.
We will outline preferred interface design for the different type of buildings. This will consider issues such as direct/indirect connection.
This work undertakes a review of the most advantageous pipe system, which will include e.g. material choice, insulation thickness and joint selection. Advantages and disadvantages of the pipes will be outlined.

Intended for
City of St Paul

Document type
Activity 1.5 Energy Technologies and district energy designs

Date
January 2015

DESIGN OVERVIEW FOR DISTRICT ENERGY

DESIGN OVERVIEW FOR DISTRICT ENERGY

Revision	**1**
Date	**January 13th 2015**
Made by	**PKO & PMO**
Checked by	**JAKB, PKO & PMO**
Approved by	**PMO**
Description	**Overview of available energy technologies and district energy designs used in comparable developments around the world.**

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1. INTRODUCTION

The City of St. Paul is in a process of preparing for the redevelopment the former Ford production facility into a sustainable urban neighbourhood which aims to be a show case for an attractive and liveable community developed around a district energy system.

This memorandum responds to Activity 1.5 Energy technologies and district energy design with the objective to provide an overview of available energy technologies and district energy design based on the good practices from Europe and in particular Denmark.

District energy offers the opportunity to implement the most efficient, clean and future proof energy supply, but it is important to ensure that the solution chosen is optimised both in terms of its production, distribution and usage.

This report gives an introduction to the fundamentals of a district energy system, both district heating and district cooling including setup and components of the network and building systems. Some general guidelines are also outlined regarding design temperature and pressure conditions.

The city of St. Paul has already a well-functioning district energy system, District Energy St. Paul that provides highly efficient hot water service to almost 200 buildings in Downtown.

Although the Ford site is somewhat remote from the Downtown, it makes good sense that a potential new energy system in the town aims to be compatible and/or aims to be capable of connecting to the existing system if such an opportunity should arise in the future.

The existing system is designed for a supply temperature of 250°F (121°C) in the winter and 190°F (88°C) in the summer time.

A district energy system is a great foundation for low-carbon energy supply of buildings. By having both district heating and district cooling, certain synergies can be achieved, which can increase the energy efficiency and reduce the price of both heating and cooling for the end consumers.

The design recommendations in this memorandum are inspired by know-how and experience from European countries like Denmark where district heating is well established. In Denmark more than 63% of all building stock is connected to district heating. Likewise, district cooling is becoming widespread. Historically the Danish heat act has not supported district cooling systems, but this has changed in recent years, as it has been proven to be more efficient and thereby beneficial for an overall district energy system. District cooling systems are now being installed more frequently also in Denmark, but it is European countries like Sweden and France, which have the most district cooling capacity installed.

2. DISTRICT HEATING SYSTEM DESIGN

2.1 What is District Heating

The district heating (DH) system produces thermal energy in the form of hot water (or steam) at one or more central plants (heat sources) and then distributes this energy through underground pipes to buildings connected to the system. Buildings connected to district heating no longer need boilers or to maintain redundancy for heating needs. Customers use the hot water provided to meet their space heating, domestic water heating and heat processing needs. Once used, the water is returned to the central plant for reheating and then recirculated through the closed-loop piping system.

The heat is delivered to the buildings through a network of highly insulated pipes that are normally buried underground. DH networks are heat technology and fuel neutral. Any heat generating technology using a variety of fuels can in principal connect to DH networks such as conventional boilers, gas engines, energy from waste plants, power stations, biomass fuelled technologies, geothermal heat, solar heating, waste heat from industry and excessive power from wind and solar panels.

2.2 Overall design concept

In general a DH network can be divided into three main parts:

- The transmission network
- The distribution network
- The internal heating system at the consumer.

Generally the transmission network is used for larger systems and operates at high temperatures and pressures, carrying large amounts of heat from larger heat producing units such as central power plants, waste incineration plants etc., to strategically placed heat exchanger stations where the heat is transferred to a distribution network.

The distribution network generally operates at lower temperatures and pressures than the transmission network and supplies heat to each individual consumer. The consumers range from large companies/schools etc. with huge heating demands to blocks of flats and down to individual one-family houses.

Normally, the transmission and distribution network interact only through heat exchangers meaning that they are hydraulically separated. In many cases this also applies for the interface between the distribution network and the internal heating system at the consumers.

Back-up and peak-load plants are also strategically placed around the network to secure the supply of heat in case of service or maintenance but also at peak load demanding situations.

The figure below illustrates the overall district heating concept.

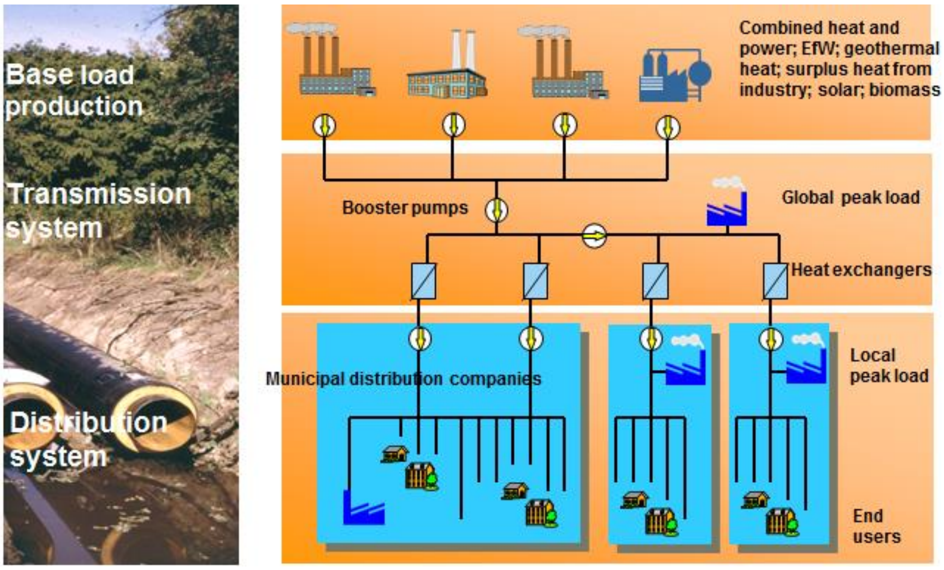

Figure 2-2 Example of an overall district heating supply concept (Photo curtesy of CTR)

A transmission network is not presently envisaged for the Ford Site project, but could be a future option to consider for the connection in some way with the Downtown system. E.g. it could be envisaged that waste heat is captured from the Xcel Power Station close to Downtown and transported to the Ford Site, to the district energy St. Paul Downtown system and/or any other cluster distribution networks that can be established.

The design of a heat network should always seek to employ the smallest diameter pipes to help reduce the capital costs of its implementation. For this to happen, the operating temperature difference between the temperatures in the supply and return pipes needs to be as large as possible. In addition low supply and return temperatures are preferred to reduce the heat losses and thereby ensure high energy efficiency.

However, the heat network must also deliver energy at a temperature suitable for use in any given type of building which it will connect. The difficulty, therefore, is to satisfy all criteria simultaneously.

When planning a DH system for the Ford site and once the overall vision is decided a detailed hydraulic modelling of the planned network must be carried out. This should be done in order to find the optimal dimensions of the pipe network, in relation to the proposed consumers.

For an efficient network and low network heat loss, high heat density also becomes an important parameter for a better overall economy.

When implementing a district energy system, the network generally carries the largest cost and it is therefore important that great consideration is given to its design parameters and optimisation both in respect to capital costs and ongoing operational expenses.

2.3 Consumer connection

The choice of consumer connection method is central to the design and operation of the DH network since it:

1) Dictates the constraints on the resulting temperatures and pressures adopted in the network.

2) Defines the opportunities and constraints around ownership models, operational risks and operating regimes during the operational phase of the project.

The recommendation around connection method therefore needs to reflect all of these factors as well as consider construction and operational costs and the need to retain as much flexibility as possible. For the Ford site this means leaving flexibility for a single site or for individual plot developers to develop according to their particular requirements (domestic, office, retail, industry, swimming pool, school, hotel etc.).

The main options available for connecting individual consumers to a district heating distribution network are as follows:

1) Direct heating and direct hot water connection
2) Indirect heating and indirect hot water connection
3) Direct heating and indirect hot water connection

The direct approach involves connecting the network system to the consumer's internal heating system directly, without any physical separation of the two systems (i.e. without a heat interface unit like a heat exchanger).

The indirect approach involves introducing physical separation between the network (primary side) and the consumer's internal heating system (secondary side) in the form of a heat exchanger (or hydraulic interface unit - HIU) so that the two systems are hydraulically separated. This type of connection allows, in principle, any DH system to connect to any building. The differing temperatures and pressures are accommodated by the heat exchanger within the limits of the overall operating temperatures and pressures. This type of connection helps eliminate issues of ownership and responsibility between DH system operator and building owner.

The interface can be located at each individual building or apartment or in the form of a communal interface located in the basement/ground floor of an apartment block.

The figure below shows a simple schematic of a network with either a direct connection or an indirect connection.

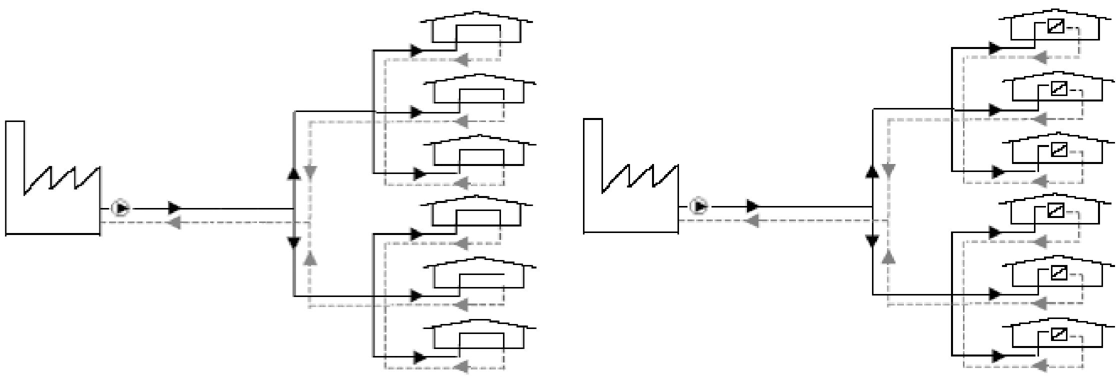

Figure 2-3: Simple schematic of a network with a direct connection (left) and a network with an indirect connection [Source: Euroheat & Power]

2.4 System Pressures

The system pressures are determined through the combination of the pressure required for pumping hot water around a network to meet the maximum heat demand and the pressure required to maintain the static head in a system and efficiently deliver the heat required to all consumers.

The design pressure of distribution networks typically ranges between 87-232 psi (6-16 bar), depending on the type of installation at the consumer, the altitude levels in the network and depending on the size of the distribution network.

If consumers are directly connected to the distribution network, then it is the internal heating system in the buildings that determines the maximum allowed pressure in the distribution network. The design pressure in district heating networks where the consumers are directly connected is typically 87 psi (6 bar).

If consumers are indirectly connected to the distribution network, then the design pressure is typically around 145 psi (10 bar). The higher design pressure allows pipe sizes to be reduced (through increased pumping head) and the indirect connection avoids then need to specify higher pressure ratings for the heating systems within the dwellings.

Design pressures above 145 psi (10 bar) are optimal for larger distribution networks or where there are large variations in terrain profiles altitudes or high-rise buildings. In such cases, it could be necessary with a design pressure of up to 232 psi (16 bar), but it should be analysed further in hydraulic models of the system in order to find the economically optimal solution for the system.

A 16 bar system could give higher costs of the energy plant/centre equipment, but in return lower pipe network costs because pipe dimensions can be smaller (compared to a 10 bar system).

Design pressure for transmission networks are generally 232 psi (16bar) or 362.6 psi (25 bar). Transmission networks operates at high temperatures and pressures so to carry large amounts of heat for longer distances with a minimum heat loss from larger heat producing units such as central power plants, waste incineration plants etc. to strategically placed heat exchanger stations where the heat is transferred to the distribution network.

2.5 System temperatures

The system temperatures will be determined partly by the requirements of the buildings connected to the heat network, partly by the choice of pipe technology and partly by the primary energy source.

In order to find the optimum supply temperature it is necessary to find a compromise between temperature difference (between supply and return) and low supply temperature.

An increase in temperature difference is an advantage as smaller pipe dimensions can be used and subsequently installation costs can be reduced. Furthermore, operation and maintenance costs are also likely to be reduced. An increase in the temperature difference between supply and return is achieved by optimising the end-user installations, but can also be achieved by increasing the supply temperature.

Low supply temperature has the advantage of reducing the heat loss from the network significantly and subsequently reducing the operation costs. However, reducing the supply temperature could also lead to a reduction in temperature difference (delta T) and thereby increased flow and pumping energy.

Furthermore, it is worth noting that every time there is a heat exchanger in the system there is a temperature loss, which generally means that the supply temperature in the distribution network needs to be higher than the supply temperature required internally in the buildings that are to be connected.

The ideal DH temperatures needs should be finally determined as part of the hydraulic optimisation of the network as a whole once the principal system and development concept has been determined.

2.5.1 Low temperature district heating

The optimum operating temperatures have been investigated in a research financed by the IEA District Heating and Cooling programme. The report "The Optimisation of District Heating Operating Temperatures and an Appraisal of the Benefits of Low Temperature District Heating" from 1999 describes the research. The research identified the optimum operating temperatures for district heating schemes by minimising the total costs, which is the sum of operation costs, network costs and building internals costs. The optimum design temperature for a distribution network was then here found to be 194ºF (90ºC) for the supply and 131ºF (55ºC) for the return when supplying heat to a residential building.

However, 4th generation district heating seen in Europe and in particular in Denmark, look to quite low sets of temperatures for buildings build to newer design standards and with lower heat demand. But this should also be seen in combination with the instruction of renewable fuel sources such as solar thermal for low or near zero carbon systems and the utilisation of heat pumps.

Below is seen an example of rather low DH temperatures, where the operating supply temperatures in the system (at the consumer) will range from 140ºF (60ºC) during summer time to 176 ºF (80°C) during the coldest winter time. The return temperatures in the network are 77-95 ºF (25-35°C) which represents a mix of return temperatures from the customers heating and domestic hot water system.

The example is based on an indirect system with heat exchangers for hydraulic separation of the primary side (distribution network) and the secondary side (consumer system). The heating system is floor heating, which has a very low temperature demand.

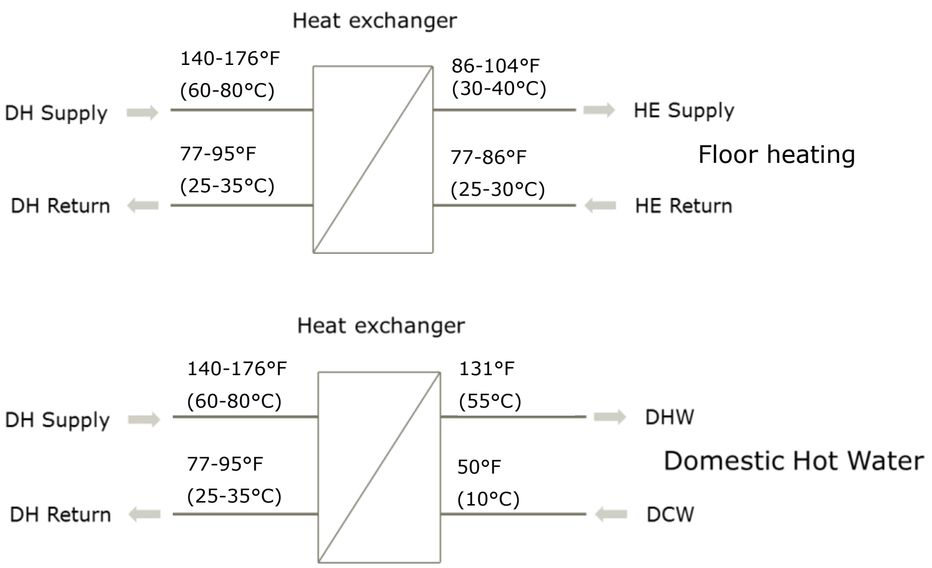

Figure 2-5-1 Example of (low) DH temperatures in a heating circuit and a domestic hot water circuit

2.5.2 Connection of new buildings

With respect to new buildings construction, new building standards generally lead to lower heat demand requirements and as such the design of the individual buildings heating systems can be for lower supply temperatures to accommodate condensing and near condensing boilers. Typically supply temperatures in the range of 130-160ºF (54-71ºC) supply is seen and return temperatures of 110-140ºF (43-60ºC) depending on the specified delta-T and the use of condensing boilers. In Denmark, The Danish District Heating Association recommend a supply temperature of 158ºF (70ºC) and a delta T of 95ºF (35ºC) for heating systems and a hot water return temperature of 86ºF (30ºC).

The supply temperature will depend on whether the heating systems are hydronic or air based and if hydronic, whether glycol has been used.

2.5.3 Connection of (older) existing buildings

If older existing buildings are to be connected to the district heating network, higher DH temperatures would normally be required, because the internal system of the buildings traditionally are designed for higher operation temperatures. It could be in the range of 180ºF (~ 82 ºC) in supply and 160ºF (~ 71ºC) in return. However, indications are that the supply temperature could range from 170-200ºF (~ 77-93ºC) depending how they have been designed.

The supply temperature will depend on whether the heating systems are hydronic or air based and if hydronic, whether glycol has been used.

In some cases the heating surface area (area of the radiators) may be very small, which leads to a low temperature difference. Therefore connecting existing buildings to the district heating network is likely to lead to the need for delivery of higher supply temperatures whilst also incurring higher return temperatures by virtue of the design of the building's internal systems.

For this reason if existing buildings of older design standards are to be connected, the design of the internal heating system in the buildings may need to be modified to ensure that they can operate based on the requirements of the distribution network set by the delivered supply temperature and the limit for the maximum return temperatures. For example, a building with an internal heating system designed for supply/return at 180ºF/160ºF (82ºC/71ºC), can be designed to operate with 176ºF/122ºF (80ºC/50ºC) if the heat losses from the building can be reduced by 25% since the reduction in heat output from the heating system will be compensated for by the reduction in thermal losses from the building.

2.6 Consumer substation

Consumer substations, also known as hydraulic interface units (HIU), are normally equipped completely with circulating pumps, heat meter, controls and other ancillary equipment required for a heating installation. An individual residence substation (for smaller thermal loads) are relatively simple to install and easy to start-up.

There are many producers of substations and they also come in many designs with many different suppliers of components. Typically the larger ones are built to order either on site or in a factory, whereas the smaller and medium sized are standardized in design and size and are produced to stock (pre-fabricated units). The large substations are floor mounted whereas the smaller substations are designed to be wall hung to fit within standard kitchen module spaces.

The choice of unit reflects the type of connection i.e. direct / indirect heating and cylinder / instantaneous domestic hot water connection. Temperatures and pressure levels, also for the mains cold water supply and for the domestic hot water, are among the important parameters when specifying the units.

One important issue is the capacity of the unit in relation to the building's heat demand and the demand for domestic hot water. This will lead to requirements in terms of flow over the installation, combined with the obtainable supply and return temperature.

The pre-fabricated units have to be designed for the special conditions in the US.
These conditions include water quality and pressure as well as the way in which the heating system is operated. Generally, there will not be significant differences in layout and size of these units between different manufactures but there can be a difference in the quality of the components used. A cheaper brand may be compromising on the quality of for instance the heat exchanger and/or the control valves.

A minimum design pressure difference at the consumer interfaces will be specified to accommodate losses through the heat exchanger station and associated equipment and to ensure adequate control valve authority. This will typically lie between 7.3-14.5 psi (0.5-1 bar (g)), depending on the type of connection.

A typical consumer substation for individual residences (for apartments, one-family houses and row of houses) could look like the examples below. One of the substations in Figure 2-6a is equipped with a heat exchanger for the heating system as well as a heat exchanger for the domestic hot water system, while the other substation only has a heat exchanger for domestic hot water (i.e. direct system on heating).

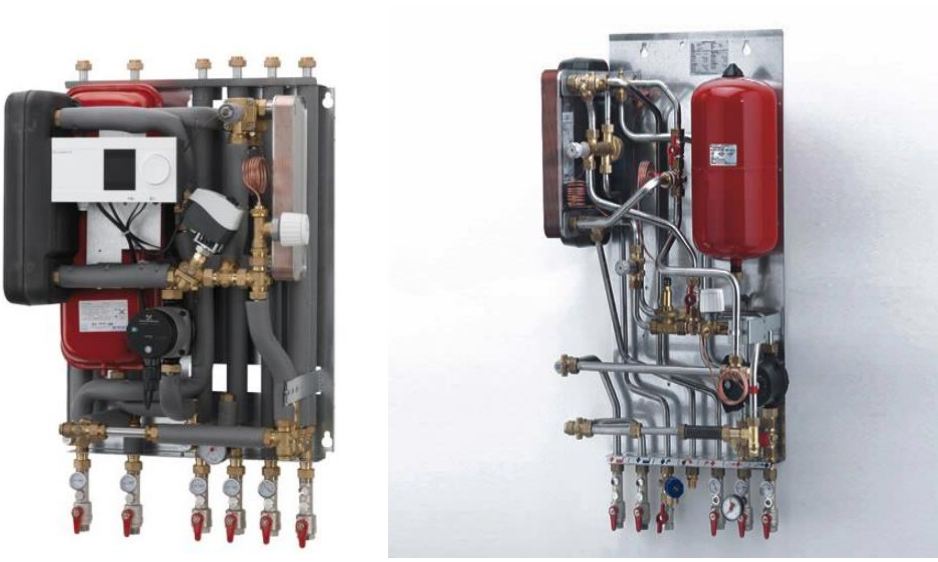

Figure 2-6a Examples of a consumer substation for an individual residence. The substations are illustrated without casing (Photo: Danfoss)

Also you can find district heating substations with integrated floor heating systems like the below examples from Danfoss and PEWO.

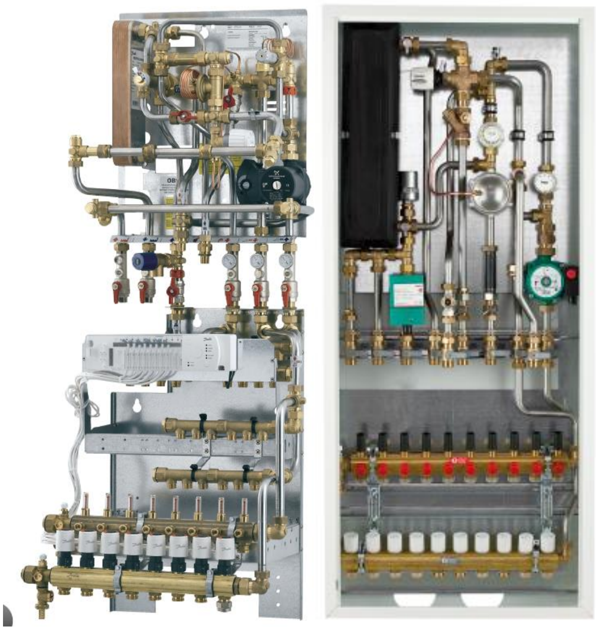

Figure 2-1b Examples of consumer substations for an individual residence with integrated heating manifolds (Photo: Danfoss and PEWO)

In the larger apartment buildings there can be a central substation with a heat exchanger at the ground floor supplying every flat with direct heating (no heat-exchanger) to radiators and/or through a mixing circuit (loop) for the floor heating system as well as for the domestic hot water via a small heat exchanger.

A typical example of a larger central floor mounted substation is seen below and will be supplying into larger and high rise buildings via a heat exchanger. Such a large substation solution could also be used commercial, retail and offices buildings.

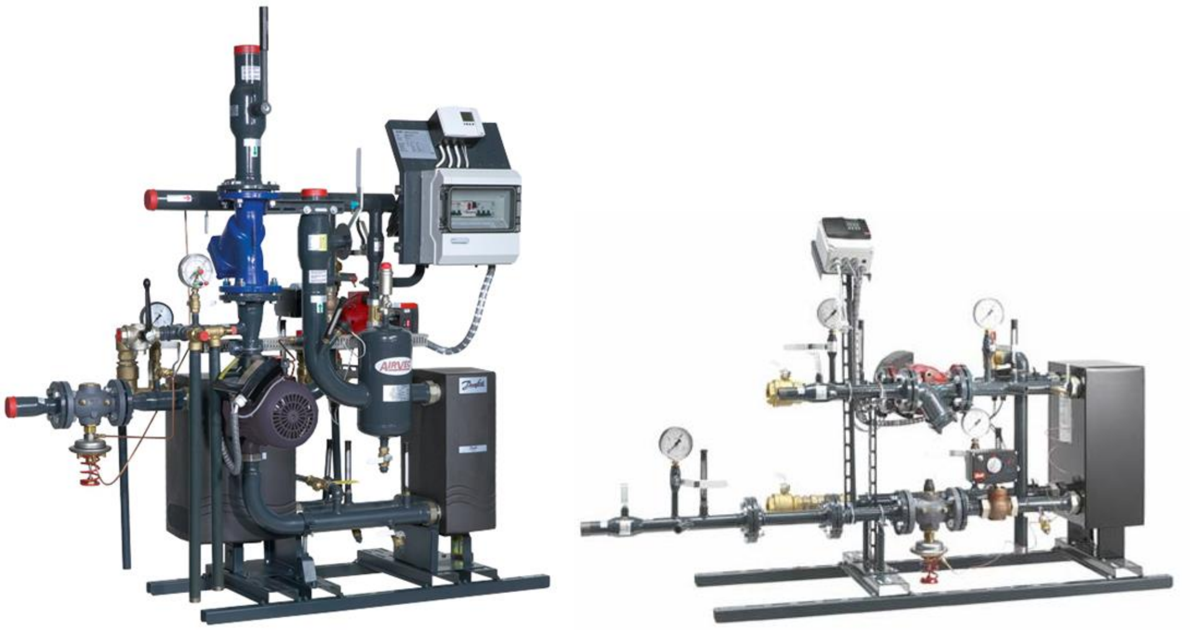

Figure 2-6c Examples of floor mounted substations with heat exchanger for blocks or large commercial, retail or office connections. The components are illustrated without insulation /casing (Photo: Danfoss)

Instead of having a large central substation in the basement of an apartment block / high rise building, which require a 5-pipe system for heating and water supply (incl. circulation) another concept, can be to have a system with "flat stations". This will be heating and domestic water supply with decentralised produced domestic hot water. Such a system will only require a 3 pipe distribution system in the building and installation of a small individual consumer substation in each flat.

The 3-pipe system can also be made without the large heat exchanger in the basement, so heating is supplied directly to the "flat stations" optionally also with a small heat exchanger for heating (the radiator / floor heating circuit) if an indirect system is required.

The concept is shown in the figures below.

Here it is applied with radiator panels, but it could also be with floor heating. The floor heating system will require a small mixing loop for each apartment to control the supply temperature into the apartment. The mixing loop is to be applied before the pipe manifold to the floor heating circuits. By applying a substation with an integrated floor heating system the mixing loop is already built in.

It is considered to be a more modern heat supply concept and should be considered for new buildings, including hotels and residential sector. Main advantages for the flat system compared to the central production of domestic hot water are:

- Possible to supply with a lower DH temperature (and the design can be suitable / prepared for low-temperature DH).
- Reduced distribution heat loss
- Individual metering of heating and domestic hot water energy consumption with only one meter
- Low volume of domestic hot water resulting in reduced risk of bacterial growth.

In case of high buildings the number of totally needed riser pipes is less for the flat station concept due to pressure zones. For each pressure zone typically two riser pipes are saved for every 2 flats per floor. Therefore especially for high buildings the flat station concept should be considered.

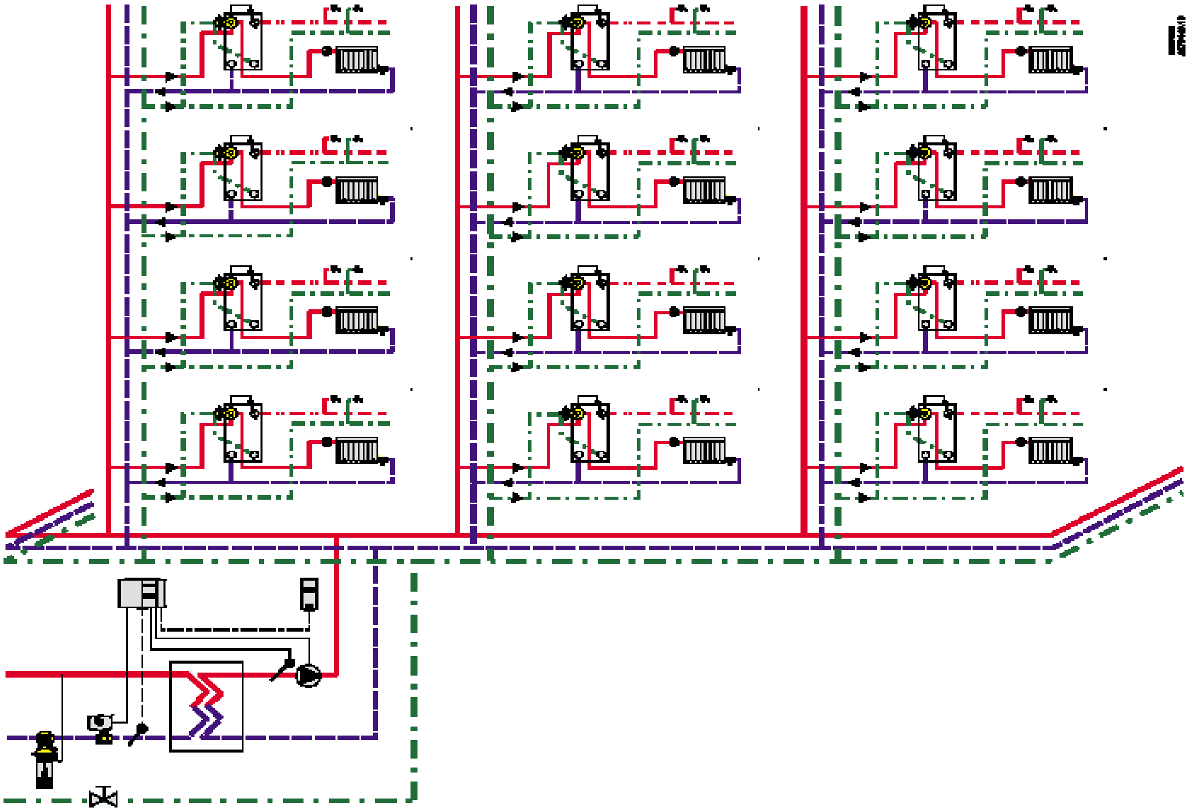

Figure 2-6d Example of district heating system connection in a high rise building (Illustration: Danfoss).

The next figure shows the same principle. It is seen that a buffer tank for the supply system in the building could be added. The necessity of such a buffer tank is to be verified by more specific system calculations for the larger apartment buildings.

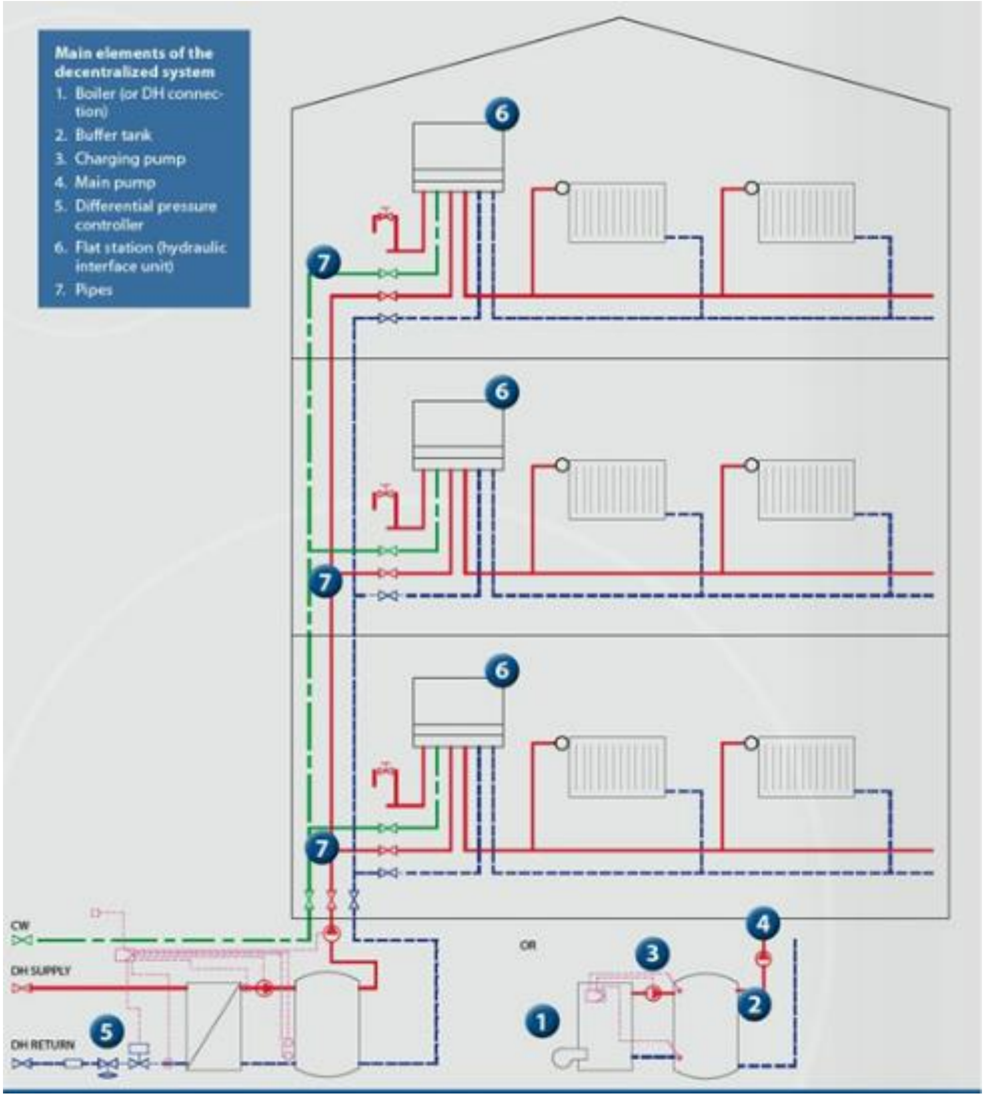

Figure 2-6f Example of district heating system connection in a high rise building (Illustration: Danfoss)

2.7 Metering equipment

Each individual costumer should have their own heat meter. Heat meters are normally installed in the return pipe and typically it is mounted in the substation at a pre-defined place.

Ultrasonic heat meters are the right solution for district heating and they are able to interface with the following communication devices/protocols;

- Optical ZVEI or similar
- M-Bus
- L-Bus
- Pulse output
- Analogue output
- RS232
- RS485

These can provide remote data collection for an operator, and a number of software products exist that can undertake automatic metering and billing functions. Remote monitored heat meters can also be used to help detect malfunctions in the building heating system.

Energy or utility metering, metering of electricity, domestic water and heat or gas has developed rapidly over the last 10 years. Individual heat metering specifically is especially used in the district heating business.

These days the energy meter is not only used for the settlement of the customer's energy consumption. The meter is also a natural tool for a constructive dialogue between the heat or cooling supplier and the consumer. The possibilities of the meter are such that it can help the consumer ensure that their heating or cooling needs are covered at the lowest possible costs.

Also energy meters are an important tool for the district energy supplier to detect possible operational errors in the district heating and cooling network. In larger buildings and heating or cooling plants it is also recommend with internal meters in order to get an overview of the operation conditions such as different internal specific energy consumptions, temperatures, pressure levels etc. The figure below shows an example of energy meters for district heating and cooling.

Figure 2-7a Example of energy meters for heating or cooling (Photo: Kamstrup).

Figure 2-7b Example of meters for heating or cooling (Photo: Kamstrup).

For the Ford Site, heat and cooling metering could for instance be provided at each building interface. Or in each flat if "flat stations" are installed, which will give the opportunity for direct settlement of the customer's energy and water consumption. The meters will record the heat or cooling delivered on the primary side of the heat interface units (i.e. upstream of the heat interface units). The meters could be connected to a SCADA system to enable automatic meter reading to take place at the energy plant/centre. Ultrasonic flow meters should be specified. These could be linked back to the energy plant/centre though a dedicated fibre optic network or via a broadband connection. Radio or mobile phone communication is also an option. Radio controlled remote reading meters are starting to be commonly used.

District heating utilities (in e.g. Denmark) are increasingly introducing intelligent district heating meters at the consumers. The meters provide, among other things the heating companies an exact overview of the actual heat consumption in the network and at the same time costs are saved due to no (yearly) physical reading at the consumers. The figure below shows an example of such a remote reading system.

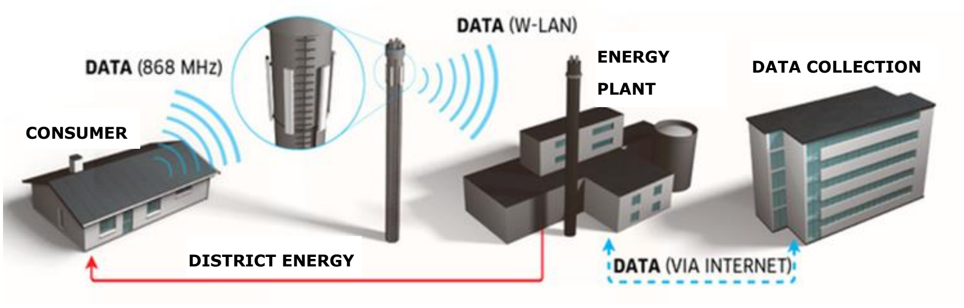

Figure 2-7c Example of an intelligent remote reading system with energy meters (Photo: www.ing.dk)

2.8 Communication

At the energy plant/centre a communication (SCADA) system can be installed to both gather information to help control the district heating network but also to receive data from each consumer or connection.

The energy plant/centre will also rely on one or more signals from specific locations in the network to control both pressure and temperature of the outgoing supply water.

2.9 Types of district heating pipes

Modern district heating (DH) systems generally use pre-insulated pipes directly buried in the ground. Several types of pipe are available and the selection of appropriate pipe depends mainly on operating conditions and cost.

The different type of pipe systems are ranging from rigid steel pipes to flexible plastic pipes produced as pre-insulated bonded pipe systems. A pre-insulated pipe consists of a medium pipe that can be of steel, copper, plastic (PEX - cross linked polyethylene) or Aluminium PEX. Common to each is a layer of polyurethane foam insulation and an outer protective casing. The outer casing is normally made of high density polyethylene.

A diffusion barrier is recommended (if possible for the type of DH pipe) between the insulation foam and the outer casing in order to guarantee a high quality of insulation properties during the whole service life of a pipe system.

The insulating foam thickness can vary to provide lower heat losses. DH pipes are typically available in different insulation classes (also called "series"), where series 1 has a standard insulation layer thickness, series 2 has a larger insulation layer thickness and series 3 has an even larger insulation layer thickness.

In most cases alarm wires, made of copper, are contained within the insulation for leakage monitoring (not possible in combination with PEX-plastic pipes).

Pipes can be either single or twin pipes, meaning that for single pipes you need two pipes for supplying district heating - one pipe for the supply and another pipe for the return. Twin pipes have two medium pipes (one supply and one return) within the same outer casing.

2.9.1 Pre-insulated steel pipes – single pipe system

Pre-insulated steel pipes in single pipe system are very commonly used in DH systems, particularly for the main distribution network.

The figure below shows an example of the structure in a pre-insulated steel single pipe.

Figure 2-9-1 Structure of a pre-insulated single pipe for DH (Photo: Logstor)

2.9.2 Pre-insulated steel pipes – twin pipe system

Pre-insulated steel pipes in twin pipe system are very commonly used in DH systems, particularly for the main distribution network, but also for service pipes.

Twin pipe systems can reduce the construction costs by some 10% (rough estimate) and reduce the system heat losses. It must be noted that twin pipes normally "only" are available in dimensions up to DN200 (ø219). In larger dimensions it is the single pipe system that has to be used.
In countries like Denmark twin pipes have become commonly used, especially when installing long length of pipes with no or few connections.

The figure below shows an example of the structure in a pre-insulated steel twin pipe.

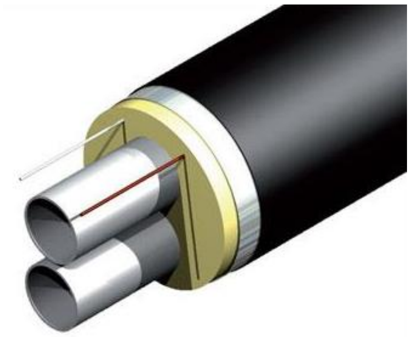

Figure 2-9-2 Structure of a pre-insulated twin pipe for district heating (Photo: Logstor)

2.9.3 Flexible pipes

Flexible pipes are typically most suitable for service pipes connecting the distribution network to the buildings. The following types are available:

- Flexible pre-insulated DH pipe with medium pipe of copper (cu-flex)
- Flexible pre-insulated DH pipe with medium pipe of PEX or AluPEX (diffusion tight) material
- Flexible pre-insulated DH pipe with medium pipe of steel (steelflex)

These DH pipe types are available in smaller pipe dimensions and can be delivered as twin pipes (recommended), but also in single pipe system.

Flexible pipes have operational limits in relation to maximum allowable pressure and temperatures. So if high DH operation temperatures are chosen for the Ford development area, flexible pipes are not recommended. For service pipes should instead be used steel pipes e.g. twin pipes.

2.9.4 Protection against water leakage

A leakage protection system can be built in to the heat network through an in-built surveillance system that continuously monitors the insulation for moisture through copper wires embedded into the insulation. If moisture is detected through a disturbance in the measured ohmic resistance, a fault will be generated at one or more monitoring stations. These monitoring stations will be linked to the SCADA system at the Energy plant across a communication network so that they provide immediate notice of an impending problem by raising an alarm.

It is recommended that leakage protection systems are also installed in the individual blocks to detect leakages within the risers and laterals within the blocks prior to entry to the individual apartments.

3. HISTORICAL DEVELOPMENT FOR DISTRICT HEATING TEMPERATURES

In a historical perspective, low temperature DH, can be categorized as the 4th generation of the technology development, following the steam-based systems (1st generation), the superheated water systems (2nd generation) and hot water systems (3rd generation). The district heating generations (supply temperatures):

- 1st generation, Steam: 572°F (300°C)
- 2nd generation, Superheated water: > 212°F (100°C)
- 3rd generation, Hot water: < 212°F (100°C)
- 4th generation, Low temperature water: 122-140°F (50-60°C)

The first generation of DH systems use steam as heat carrier and were introduced in particular the USA in the late 19th century; the majority of DH systems established until the Second World War used this technology. Steam-based DH represents an outdated technology, because of high heat loss, high operating and maintenance costs and it limits the application of community energy systems.

The technology is still used on many university campuses etc. across the US, in cities such as Seattle and Manhattan. In Europe most have been (e.g. Hamburg and Munich) or are being replaced e.g. in Copenhagen, where an ongoing replacement program is in place.
Where there is a (industrial) process need for steam. Often it can then be seen that a hospital or industry is supplied by hot water DH and then raise this to steam locally.

The second generation switched to pressurized hot water (e.g. 266°F ~ 130°C) as the heat carrier and they were applied until the 1970s. Remains of this technology can still be found in the older parts of the current water-based district heating systems.

The third generation of systems came after and gained a major success in the 1980s; they are the most used systems both in upgrading of existing network and in new projects as well including projects in USA and Canada and the UK. The energy carrier is still pressurised water, but supply temperatures are lower (e.g. 176°F ~ 80°C) and they are often combined with the use of the twin pipe system and plastic media pipes, when it is possible.

3.1 Low-temperature district heating

Low-temperature district heating (DH) is an interesting design concept, because it can meet the challenges of the future with high energy efficiency and a large or full share of renewable energy sources in the energy system. Renewable energy sources are normally exploitable and available in larger amounts at lower temperature than traditional DH temperatures. Low-temperature district heating could play a key role in the concept of (climate) smart cities, where the aim is to lower carbon emissions.

A low-temperature DH system is typically defined by having 122-140°F (50-60°C) in supply. To have a DH system with about 176-212°F (80-100°C) in supply can also in some countries / for some DH utilities be seen as "low-temperature" and could be the first step towards lower DH temperatures.

Design of a low-temperature DH system is not just all about lowering the DH temperature in the network. The consumer substations must be designed for the low temperature. Also the pipe network is preferred with twin pipes (in dimensions where this is possible) and must be in a high insulation class if the low heat loss and thereby high energy efficiency is to be achieved.

In Europe the low-temperature concept is especially suitable for new buildings, because the building design can be prepared in such a way, that the heat installation will fulfill all requirements for heating and hot water. However, the concept can also be implemented for existing buildings, but it will normally require that each building have undergone energy retrofit or just some heating installation upgrades.

It is possible to use low-temperature DH to buildings or areas placed next to existing areas with traditional DH temperatures. In that case decentralized mixing shunts could ensure the lower supply temperature. If the whole area then later is converted to low-temperature DH, the mixing shunt(s) could be removed again. An innovative solution would be to design the mixing shunt in such a way that return water from the traditional DH area can be used as supply in the low-temperature area if/when the flow is sufficient. This will increase the energy efficiency and the capacity of the network.

Several low-temperature networks have already been built in Denmark, but there are a few examples from other countries. In Denmark low-temperature DH has been implanted for both low energy houses and for existing buildings. The flow temperature in these district heating networks is as low as 122-140ºF (50-60ºC). Development is ongoing of consumer installations suitable for even lower DH supply temperature at 104-113ºF (40-45ºC) combined with an electric heating element). In these systems there is no storage tank for Domestic Hot Water (DHW). This heating is carried out with an instantaneous heat exchanger. The risk of bacterial growth in the DHW system is prevented by having no water storage and a water content in each DHW supply line, including the volume in the secondary side of the DHW heat exchanger kept to a minimum (below 3 litres). This is the allowable water content for the instantaneous DHW preparation systems that is considered to assure safety in relation to the Legionella risk, even without any treatments, according to the German guidelines for DHW systems (DVGW, W551).

Examples of low-temperature DH networks in operation are described in Section 6.

4. HEAT PRODUCTION TECHNOLOGIES AND FUEL

Conventionally the heat demand in a DH system is met by waste heat from power stations (co-generation) and/or Energy from Waste (EfW) utilising a heat generation which would otherwise be wasted and subsequently it comes at a very low cost. In smaller schemes it is common to look at installing the heat production, which often unfortunately adds cost to the scheme.

Traditionally co-generation plants are fuelled on gas (or coal for large systems) but gas CHP will meet potential renewables target. The next obvious step would be to turn to biomass as a fuel. However, biomass fuelled technologies adds other complexities with fuel transportation and flue gas emissions and the surrounding air quality.

There is no doubt that local air quality will be affected by the installation of a biomass plant. However, for larger plants there are a number of possible gas cleaning technologies available that may be employed in order to meet regulatory requirements

Alternative technologies such as solar (both for generating electricity and heat), wind or heat pumps could come into play especially if low temperature systems are employed.

Once a DH network is in place it opens up for utilising a variation of heat producing sources. The potential phasing of the Ford development and its network may open up possibilities for changing technologies over time.

Go-generation should as a rule of thumb only be operated as a base load, as depending on the technology it may be difficult to operate according to daily variations in demand. This also accounts to some extent to biomass heat only boilers. Biomass boilers will for a given capacity BTUh (MW) have a given rate of modulation BTU (MWh).

A well-designed district heating network heat from go-generation will provide between 60% and 80% of the annual heat requirement with heat-only boiler plants providing the peak load and back-up.

For new developments where interim boilers have been used during build out these can later be utilised for peak load and back-up.

Where district heating is being installed to replace conventional heating systems there are opportunities to re-use existing boilers as heat-only boiler plant.

The use of thermal storage and the flexibility it gives should also be evaluated as it can add benefit to a scheme.

As mentioned earlier the advantage of a district heating system is the flexibility and the ability to utilise a variety of heat sources, including what can be called low-grade heat.

One example is the use of solar thermal energy. There are a number of examples in Europe where large-scale solar thermal arrays have been integrated with district heating networks as district heating schemes offer maximum energy utilisation from solar thermal as a heat sink for the low temperature water. The largest system in Denmark is connected to the district heating network in a small town, covering 30% of the annual heat demand of 1,200 single-family houses, a few public buildings, a school and a hotel.

4.1 Co-generation/Combined Heat and Power (CHP)

Co-generation or combined heat and power (CHP) is the simultaneous generation of electricity and heat.

Gas-engine CHP has been the CHP plant of choice in Denmark smaller communities for a number of years and also in the UK in hospitals, university campuses and housing estates. The Netherlands has also build up their DH around de-centralised gas CHP.

Biomass fuelled CHP plants have for many years been part of the Danish electricity and heat supply industry but for quite large scale power station units. The technology for medium range and small scale units are still seen to be technically and commercially viable, although it can vary depending on the proposed technology.

The most common used technology for producing heat and power with biomass is the steam circuit process. Initially the fuel is converted to thermal energy primarily in a heavy-duty steam boiler as high-pressure steam. The steam is expanded and subsequently cooled in the steam turbine driving a generator and producing electricity. The district heating water is afterwards used to cool the steam further, before it is returned to the boiler.

Newer technologies like gasification of biomass, Stirling engines etc. are being developed, though most of them are still not at a commercial level.

The specific heat demand and following the size of the CHP plant together with the electricity sales price are decisive determinants when choosing between a CHP and a heat only producing unit. CHP plants are considerable more expensive than boilers producing the same amount of heat. For small-scale biomass plants especially, the market price for electricity is not sufficient to cover the extra initial costs. Accordingly an investment grant for the plant or subsidies on the electricity tariff is essential.

In general, experience shows that plants with an installed capacity (use of fuels) less than 10 MW and a generating (power) capacity less than 2-3 MW would very seldom be economically feasible and other reasons will be the driving factor.

Small-scale demonstration plants in Denmark and Finland based on gasification technologies have shown promising results and are envisaged to be ready for commercial operation within a few years, albeit the sizing is fairly small >2MW heat.

4.2 Biomass heat only boilers

The use of solid bio fuels for heat production on heating boilers has increased significantly in many countries during the latest years. The new boilers are typically based on wood (pellets or chips) or straw substituting the more expensive and environmental hazardous fossil fuels.

In relation to solid bio fuels the matters concerning the transportation of the fuels (logistics) and the residuals from the incineration process should be considered beforehand.

4.3 Biomass issues

In Denmark we have several systems which incorporate biomass and which are placed close to the town. We do not in Denmark experience the same concerns over biomass emissions as seen in some other countries.

It may be down to a question of size of boilers and how the system is designed and installed. Larger boilers are more efficient but for larger boilers there are also more strenuous requirements to the allowed emissions resulting in better equipment and flue gas technologies. Some air emission technologies are not possible to implement for smaller boilers.

Generally there are three issues that should be given attention when considering biomass fuelled technology:

Emissions (dust, NOx, CO); the emissions allowed varies depending on the fuel and the size of plant. Generally there are less strenuous demand for emissions when considering smaller plants.

Comment: It is important that the demand in relation to emissions is met though combustion technique and/or flue gas cleaning.

Biomass storage; the store is likely to generate fungus spore and similar.

Comment: The store can be designed with vacuum (under pressure) avoiding the spores generating a problem to the local environment. Although the spores can be a problem to the local work environment and special precautions needs to be taken.

Transport of biomass and aches; the transport of biomass and ashes is generally the one which causes greatest concern and one which it is difficult to change. The plant need to be supplied with fuel and the ashes needs to be removed.

Comment: The plant should ideally be sensitively located to cause the least issues concerning the increase in local transport.

4.3.1 Wood Pellet / Wood chip comparison

District heating boilers or CHP plants designed for wood chips varies essentially from similar units based on wood pellets, as the fuels need to be handled in different ways. Both pellets and chips are made of wood, but they vary significantly concerning the size, density, water content etc.

Wood chips are typically made of fresh wood and have a relatively high content of water compared to wood pellets. Accordingly wood chips cause an increased corrosion and deterioration of the boiler.

Wood pellets are typically made of wood-waste e.g. from industrial processes. Typically the quality of the pellets varies a lot and can cause some troubles during incineration. For instance the content of problematic substances such as glue from a manufacturing process can cause some serious technical- and environmental impacts.

Accordingly the quality of the fuels is crucial and decisive for the maintenance level and durability of the heat producing unit. A guarantee for the quality should be applied by the supplier in all cases.

Grate combustion is the traditional technology used for burning both wood pellets and wood chips. Grates are still widely used for both boilers and steam production in small scale CHP plants. Grates are less tolerant for fuel quality than for instance fluidised bed boilers but they have been able to compete with modern combustion technologies due to a comprehensive technological development. Hence, improved grate firing technologies have made it possible to burn very wet fuels like certain wood-chips.

However, steam/heat producing boilers based on wood chips typically create higher demands for maintenance and reduce durability due to the higher water content of the chips. On the other hand wood chips are considerably cheaper than wood pellets taking into account the energy content of the solids.

Considering the lifetime economics of the plant and the existing technological level, a wood chip fired boiler with a grate is the most favourable option. There may be a higher rate of corrosion of the boiler, depending on the water content of the fuel but the quality of the fuel is generally more stable and the combustion is easier to control.

In a fuel market with an increasing interest in bio fuels it may also be advantageous to rely on a fuel that requires less processing and therefore should be available in larger quantities and at a more stable price.

For the purpose of this study wood chip has been assumed as the bio fuel. However, the final conclusion concerning the choice between wood pellets and chips should be based on a more thorough analysis.

4.4 Consideration of thermal storage

Thermal stores (heating or cooling storage tanks) make it possible to create a time delay between heat consumption and heat production. The purpose of such time delay is mainly of economical nature and is related to the fact that the cost of heat /cool production may vary with time. By introducing thermal stores into district heating / cooling systems it is possible to produce heat / cool at a time where the heat production price is low and then utilise this low cost heat / cool at a time, where the production cost for the heat / cool would be high. If the heat / cool is produced at a CHP plant, then the heat / cool production price is not only related to the fuel costs but also to the selling price of the electricity.

A thermal store can also be used to reduce the investment cost in the district heating / cooling system. Depending on the design, a storage tank can make it possible to reduce investments in peak load capacity although this is not something we generally recommend as it will affect the security of supply. If the thermal store is located further out in the network, it might be possible to reduce the network pipe size and the investment in the piping system. This same effect can be created by individual storage tanks (e.g. for domestic hot water) however.

With the right design, decentralised thermal stores may be able to act as a peak and/or reserve load capacity locally and therefore it is not necessary to design the network for peak load supply from the main heat / cool production installation i.e. the pipes can be smaller. However, the installation of decentralised thermal stores in order to reduce the mentioned investments may not be economically feasible and often the peak and/or back-up boiler / cooling unit is more economical to install locally. Therefore in a heating system, thermal stores are usually installed centrally at the heat production plant for the purposes of maximising the run hours of the CHP plant and for acting as a buffer between the varying demand in the heat network system and the biomass heating plant, which is generally not capable of rapidly modulating to meet these changes in demand. Likewise is there the same advantages in a cooling system, where thermal stores are usually installed centrally at the heat production plant for the purposes of maximising the run hours of the cooling units. The size of the thermal stores are generally determined through an optimisation process between the overall capital and operational costs which in turn will also be decided by the size of the network and the heat demand which is to be met.

4.5 Large heat pumps

A heat pump moves heat energy from one temperature level to another, which makes the heat sources crucial. If a district heating utility company is considering investing in a heat pump, is one of the first steps to identify which heat sources that are available in the immediate vicinity. After heat sources are identified, the potential of the heat sources must be assessed. This is done i.e. by looking at the availability, temperature, flow and variation during the year. Possible heat sources could be:

- Flue gas
- Waste heat (from industrial and cooling processes, including individual cooling or district cooling)
- Geothermal energy
- Wastewater
- Groundwater, including groundwater storage (ATES), and drain water (drainage wells) etc.
- River water
- Other heat sources (air, ground source, drinking water, solar heat and heat storage)

The heat pump could be a good option for the Ford Site but must be assessed in more detail, see also further in section 5.5 where synergies with district cooling are described.

A heat pump makes it possible to collect thermal energy from a heat source with low temperature and emit energy again at a higher temperature. It is necessary to supply energy, either in the form of power, i.e. electricity, or in the form of heat at a relatively high temperature, e.g. flue gas. The principle opens up a number of opportunities to exploit energy resources at low temperatures and therefore it entails a number of advantages for district heating:

1. Lower heat prices – the primary motivation to invest in a heat pump is an expectation of lower heat prices either now or in the long term.
2. Risk diversification – By introduction of a new "fuel" (electricity) in production, large heat pumps contribute to spread the financial risk in the heat production (diversification), making production more robust to variations in electricity and fuel prices.
3. Efficiency – possible to exploit residual and waste heat into the existing production facilities, or nearby industrial production. Furthermore, the possibility to optimize the utilization of solar thermal heating.
4. Introduction of new business areas – the ability to produce and sell cooling related to district heating production.
5. Strengthen environmental profile – by making use of RE based electricity generation and partly to take advantage of previously unexploited low-temperature heat sources in the surroundings such as wastewater, industrial waste heat, geothermal energy, groundwater, etc. and thereby delivers a renewable energy contribution to the heat production.
6. Strengthening new collaborations — by district heating’s interacting with the electricity utility and with the possibility of cooling, and thus the role of district heating in integrated energy supply planning for the future.

It should be noted that an electrical driven heat pump only is truly renewable if the electricity comes from a renewable source.

4.5.1 Types of heat pumps

Heat pumps can generally be divided into two different types. A heat driven (also known as absorption heat pump) and a mechanical driven type, where the mechanical heat pump as a general rule, is driven by an electric motor. The ratio between the delivered heat and the “drive energy” is called the efficiency factor of the heat pump, COP (Coefficient of Performance). Electrically powered heat pumps typically have a COP of between 3 and 5. For each unit of electricity that drives the heat pump, between 3 and 5 units of heat will be delivered. The COP is very dependent of the temperature of the heat source and the temperature demand.

The COP will decrease if there is a demand of high district heating temperature. A demand of a district heating supply temperature of above 176-194°F (80-90°C) can be a barrier for implementing heat pumps in the district heating system due the drop in efficiency and limitations in available heat pump technology on the market.

The thermally driven heat pumps have a COP of approx. 1.7 and require so much more driving energy than the mechanical types. On the other hand, is the driving energy is heat, which often is cheaper than electricity, and therefore are the thermally driven heat pumps also interesting, both from an economic and an energy point of view. Mechanical heat pumps are usually compression heat pumps in accordance with the same principle as traditional cooling systems. Heat-driven heat pumps are typically absorption heat pumps with refrigerant and absorbent. In recent times, so-called hybrid heat pumps are also brought into use, which is a mechanically driven heat pump that combines compression and absorption technologies. Although the COP for absorption heat pumps is low compared with electrically driven, it is important to note that the technology does not have any energy consumption as such. It just exploits a high energy quality, which would otherwise have been lost. Therefore, should the COP for absorption heat pumps not be considered as energy consumption in relation to heat production, but just increased heat production.

Thermally driven heat pumps require that surplus heat at a high temperature is available. It could be minimum 80-140°C (176-284°F) depending on the type of absorption chiller.

4.5.2 Refrigerants

A wide range of synthetic (HFC) refrigerants have been developed over the years. Those have a various thermal and chemical properties that make them usable in a wide temperature range. All synthetic refrigerants are, however, associated with environmental issues, and today many of them banned in a number of countries. In Denmark are synthetic refrigerants not allowed in chillers, where refrigerant filling is greater than 10 kg. The European Union has decided to down phase the consumption of synthetic refrigerants.

For larger electrically powered heat pumps in Denmark are therefore used only natural refrigerants. This does not affect the efficiencies and performances, but means that some components developed for synthetic refrigerants, cannot be used directly for heat pumps in Denmark. Worldwide, however, the trend is primarily towards natural refrigerants, why the selection also gets larger and larger. In practice, the refrigerant legislation that excludes synthetic refrigerants, therefore not a problem for the prevalence / application of large heat pumps. The refrigerants which might be used for larger electrically powered heat pumps will be primarily carbon dioxide (CO_2), ammonia (NH_3), isobutane (C_4H_{10}) and propane (C_3H_8). In hybrid heat pumps are used ammonia as refrigerant and water as absorbent. Just as the hybrid heat pump, the heat-powered heat pumps take advantage of the absorption principle. Water is used as the refrigerant and a solution with lithium bromide as absorbent.

5. DISTRICT COOLING SYSTEM DESIGN

5.1 What is district cooling?

District cooling is distribution of chilled water to buildings, where there is a cooling demand. The water is cooled in a central plant and distributed through pipelines to customers, where a heat exchanger uses the chilled water to cool the water in the building systems. Subsequently the water is sent return to the central cooling plant, where it is cooled again. District cooling works in principle like district heating and has the advantage of achieving economies of scale because each individual building do not have to have its own cooling-producing plant, which can be more costly in investment and operation.

Advantages for consumers (building owners) with district cooling compared with individual solutions:

- Opportunity for lower costs for cooling
- Reduction of environmental impact.
- The consumer doesn’t have to take care of operation of cooling plants.
- Fewer places with noise nuisance and fewer costs for noise reduction arrangements
- Release of building area (inside and on roof etc.) for other purposes
- No visual pollution by cooling plants around the building and at the roof.

The benefits for the local society:

- It can be more attractive for a company to settle down in the city if district cooling if offered
- Better environment profile for the municipality / state.
- Cheaper cooling (and heating) for the citizens and local companies /business.

A district energy utility company having both district cooling and district heating supply can achieve a number of benefits:

- Surplus heat from the district cooling can be exploited for the local district heating system. This can make both the price of district cooling and district heating lower and thereby more attractive.
- Large energy savings and lower carbon foot print –> greener profile.
- Utilization of synergy between heat, cooling, cooling storage, heat storage and thereby ensure an efficient and future-proof production of cooling and heating.
- Large volume in the company organization = optimization of staff resources by having both district heating and cooling delivery.
- Closer relation to the large consumers in the area and thereby be able to give better guidance about energy savings at the consumers both regarding heating and cooling.

5.2 Overall design concept

This section describes the overall concept for a typical district cooling system.

Typical temperatures in the district cooling distribution network could be:

- Primary supply: 6°C
- Primary return: 16°C

Some buildings can have special cooling demands. Very low temperatures could be required. Buildings like supermarkets or other buildings with food storages etc. could need a lower supply temperature. For example if an air temperature of 2°C is needed, it could be necessary to have a supply temperature of -2°C in order to provide that. In such cases the base cooling load could be delivered by the district network with 6°C in supply and then by small-scale units locally at the consumer be cooling further down for the exact demand.

The figure below shows an overall principle for a district cooling system inclusive the cooling production plant and storage. The cooling is produced with chillers. Periods where the outdoor air temperature is optimal free cooling (with dry coolers) can be used directly.

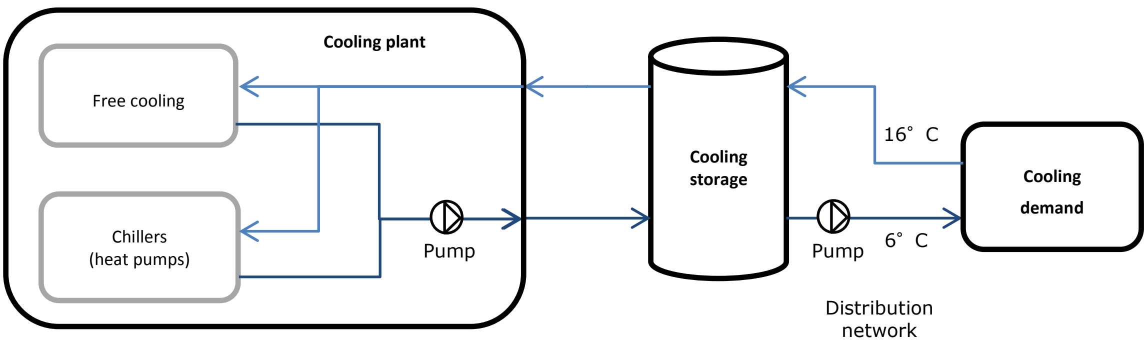

Figure 5-1 District cooling principle with cooling plant, storage and connection to the demand in the network.

From the cooling plant the produced cooling can be distributed to a cooling storage or directly to the cooling consumer in the network. The cooling storage will be necessary to reduce the size of the cooling plant (chillers etc.) and thereby the investment costs. It will level out daily peak loads and ensure more stable operation of the chillers. Also storage could reduce the pipe dimensions in the network if storage tanks are placed in high cooling density areas in the network. This will also increase the security of supply (redundancy).

Typical pressure level in the distribution network is between 6-16 bar (g).

5.3 Pipe network

A key component in the district cooling system is the pipe network for distribution of chilled water. It consists of supply and return flow to all the connected buildings (cooling consumers). In general the pipe network can be divided into two main parts:

1. The main distribution network incl. service pipes to the buildings.
2. The internal pipe system in each building (or group of buildings) connected via an energy transfer substation.

Different types of pipe for the distribution network can be used, but if the utility also offers district heating, it can be an advantage to use district heating pipes also for district cooling, because in that case the expertise and an attractive purchase agreements may already be established.

Pipe insulation thickness is of less importance compared to district heating, because the district cooling temperature are closer to the soil temperature. But it will be an advantage with pre-insulated pipes to protect the media pipe and in order to be able to have a leakage alarm system.

5.3.1 District heating pipes

District heating pipes are described earlier in section 2.9. In the following are alternatively pipe types for cooling briefly described.

5.3.2 Insulated PE-pipes

Another solution for the main distribution network could be a pre-insulated PE-pipe system typical in HDPE (10 bar) PE80/PE100. PE is polyethylene, which is type of plastic material. Except from the medium pipe, the pipe type is quite similar to the pre-insulated steel pipe system. It is available with the same type of insulation, with alarm wires, diffusion barriers and outer casing. The leakage alarm system can also include monitoring of pipe joints.
The advantage with this pipe type rather than steel is less weight, which can make the transport and installation easier. The reduced weight would also be an advantage for the mounting in a potential utility corridor.
Further, PE-pipes will have longer lifetime than steel pipes, because of lower risk of corrosion. PE-pipes are assumed to have lower cost especially for the large pipe dimensions mainly due to fewer requirements for control of the welding. Since it is electric welding, x-ray examination is not needed. This pipe type is also use for potable water etc.

5.3.3 Uninsulated PE-pipes

This type is like the PE-pipe described above, but without insulation, leakage alarm, casing etc. This type of pipe will have lower costs because of the less material required. The major disadvantages is the energy loss (depending on the yearly soil temperature conditions) - the chilled water (both supply and return) will be heated up in the soil or in the utility corridor – this also means that the supply temperature has to be delivered with an even lower temperature out of the cooling plant. Further, without insulation there can be a risk of condensation water outside the pipe and the pipe is generally less protected against the surroundings. And without the alarm wires it will be very difficult to locate a possible leakage.

5.3.4 Glass fibre pipes

This pipe type is corrosion resistant interior and exterior (suitable for chemistry and industry). It is light weight and easy to fabricate / install. The smooth interior can give higher flow rates, reducing energy consumption. But to be noticed is that experience previous from district cooling shows that this material is not suitable when there are heavy loads on pipes resulting in longitudinal cracks in the pipe. Like the uninsulated PE-pipe, glass fibre pipes are typical without insulation and have no alarm wires.

5.4 Consumer connections and substations

Consumer connections (and substations) are quite similar to what is used for district heating. In indirect systems the consumer connection includes a heat exchanger to separate the internal building chill water circuit from the distribution network. This will typical be necessary in district cooling systems which operates with pressures above 6 bar(g). If the pressure level is 6 bar(g) or lower in the distribution network, the consumer can be connected directly if preferred and no heat exchanger is needed. This has the advantage that the temperature demand from the cooling plant can be decreased – the cooling supply temperature can be higher, which can improve energy efficiency (COP) of the cooling plant and maybe reduce the investment cost for chillers. On the other hand, having higher pressure in the distribution network smaller pipe dimensions can be used, which will reduce the costs for the pipe network.

See further about consumer connections and substations in section 2.3.

5.5 District cooling and heating supply concepts

With both district cooling and district heating the supplier can achieve a number of benefits / synergies, in particularly that surplus heat from the cooling production can be exploited for the local district heating system. Thereby the heat removed by the cooling in the buildings is not wasted to the surroundings. This can lead to increased energy efficiency and a lower price of both district heating and cooling for the consumers.
However, such a solution depends on the actual temperature conditions in the district heating system etc. The technical solution will typical be with a heat pump (chiller) driven by electrical power. See the principle in the figure below. Heat can be exploited with up approx. 80°C, but lower temperatures e.g. 60°C will improve the energy efficiency of the heat pump and reduce investment costs as well.

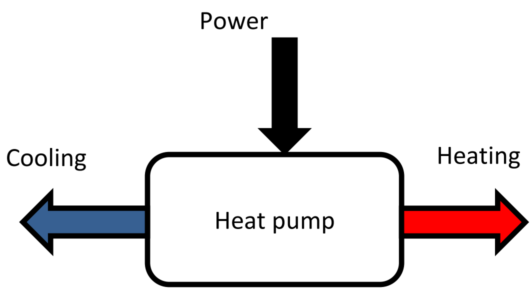

Figure 5.5a: Co-production of cooling and heating in a heat pump. The heat pump is placed in a thermal energy plant (cooling plant), which supplies both the district cooling network and the district heating network.

Such a solution with a heat pump with co-production of cool and heat will lead to energy savings. It will be a future proof solution and if a large share of the electrical power comes from renewable energy sources, it will be a very sustainable / low-carbon solution.

In case groundwater / ATES (Aquifer Thermal Energy Storage) is possible to use, it can improve the overall energy efficiency. Surplus heat from the summer period can be stored in the ground and utilized in the following winter period. Thereby an optimal energy balance can be achieved.

If large amounts of heat are accessible in the district heating network also during summer, a solution with a heat driven heat pump, a so called absorption chiller, could be an alternative. If the heating system is to be used to generate chilled water locally e.g. through absorption cooling it is important that the flow temperature is as high as possible.

The heat pump will be placed in a thermal energy / cooling plant, which supplies both the district cooling network and the district heating network. See principle of a district cooling system connected to district heating for delivery of surplus heat.

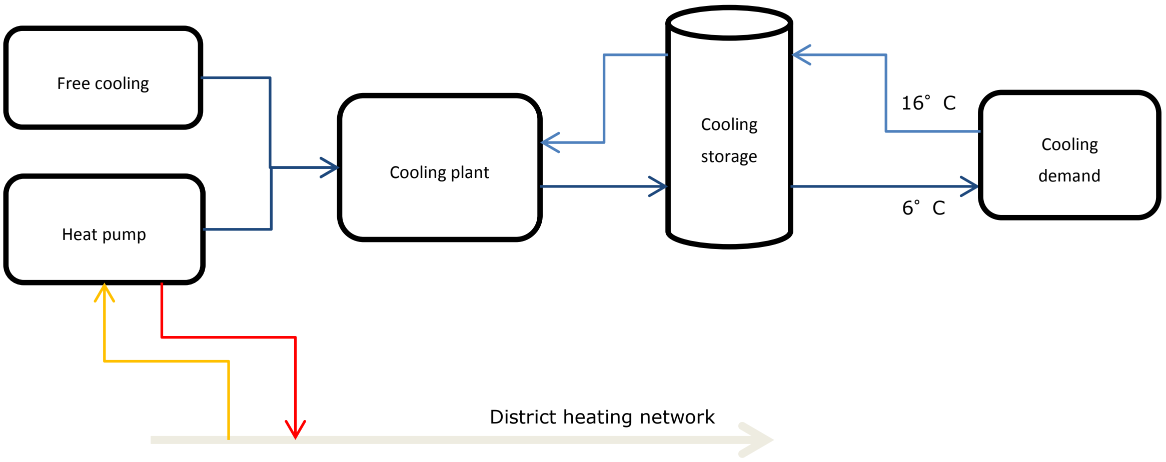

Figure 5.5b: District cooling principle with possible utilisation of surplus delivery heat to heating

The figure below shows an example of an overall design of a district energy system with both district cooling and district heating.

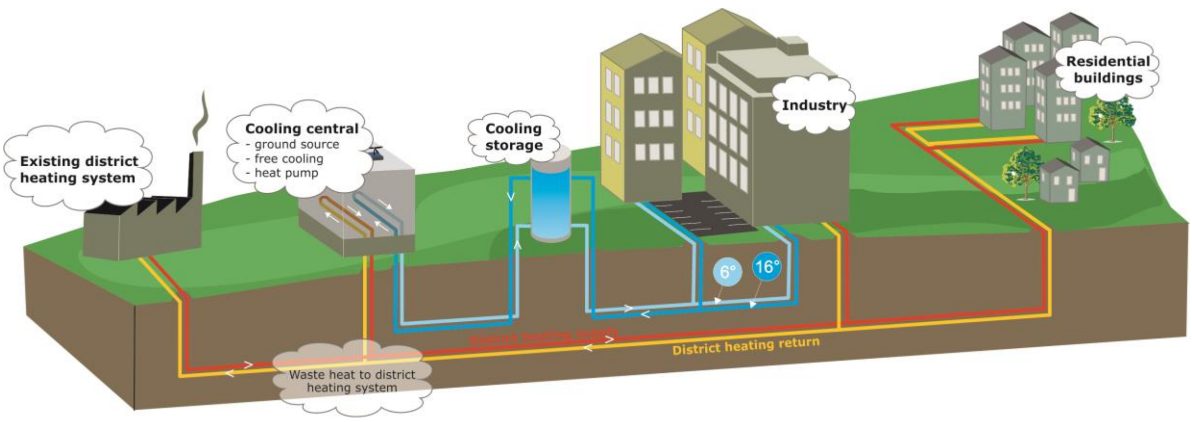

Figure 5.5c: Supply concept for district cooling and heating (Figure: Ramboll).

6. EXAMPLES OF LOW-TEMPERATURE DISTRICT HEATING

6.1 Brief case examples

6.1.1 Sønderby, Høje Taastrup, Greater Copenhagen, Denmark

A low-temperature heating network for 75 existing detached brick houses built in 1997/1998. Room heating is provided by floor heating in all houses. The district heating is delivered by the utility at a higher temperature and then lowered in a mixing shunt to about 127-131°F (53-55°C) before it is distributed in the low-temperature pipe network. The return temperature is about 95°F (35°C). The pipe network consists of twin pipes (supply and return pipe in one casing) in a high insulation class.

Although the existing local and privately owned district network for these 75 houses was only approximately 15 years old, the distribution pipelines – pair of single pipes with plastic media pipes – were in poor conditions. The annual network heat loss accounted for about 41% of the total heat delivery to the network. Due to the heat losses the heat costs where relatively high. It was decided to renew the existing district heating network and transfer the ownership of the network to the local district heating utility. Heat loss in the network was decreased to 13-14% corresponding to a reduction of 69%.

Total heated area: 11,230 sqm. Developer: Høje Taastrup Fjernvarme (district heating utility).

6.1.2 Lystrup near Aarhus, Denmark

A site which comprises of 40 low-energy terraced houses built in 2009/2010. Two types of consumer substations is installed; one type with primary side storage tank, which enables the reduction of design capacity to 3 kW and supply pipe dimensions accordingly, and one type with an heat exchanger designed for domestic hot water of 32 kW. Room heating is provided by mainly radiators, but also floor heating in the bathrooms. The district heating is delivered by the local district heating utility at a higher temperature and then lowered in a mixing shunt to about 126-131°F (52-55°C) before it is distributed in the low-temperature pipe network. The return temperature is about 86-95°F (30-35°C). The pipe network consist of twin pipes (supply and return pipe in one casing) in a medium-high insulation class.

Compared to a reference scenario with 176°F (80°C) in supply, 104°F (40°C) in return and single pipe pairs in standard insulation class, saved heat loss reduction has been measured to about 75%.

Total heated area: 4,115 sqm. Developer: Housing association BF Ringgården.

6.1.3 Østre Hageby, Stavanger, Norway

A low-temperature heating network for 66 new low-energy houses consisting of a mixture of terraced houses and blocks of flats. Heat is supplied with a temperature of about 131°F (55°C) from an energy central with heat pumps and drill holes in the mountain. A small local pipe network distributes the heat from the energy central. Each apartment has its own consumer substation with an instantaneous heat exchanger for heating up the domestic hot water. The low-temperature concept is ideal for the heat pumps, because with the lower temperature demand a higher energy efficiency (COP) can be achieved during the heat production. The low-temperature system will be put into operation in the end of 2014. Total heated area: 6,800 sqm. Developer: INEO Eiendom.

6.2 Examples of other district heating utilization possibilities

Briefly examples of other utilization possibilities for district heating (than room heating and normal domestic hot water heating) are described below.

6.2.1 Snow-melting and freeze protection

A practical solution – not an energy saving solution – is to utilize district heating to heat up exterior / outdoor construction surfaces in order to remove snow and ice.

Snowmelt technology can reduce or eliminate conventional snow removal, reduce wear and tear on walking and driving surfaces, and provide clean, safe, ice-free traffic areas. Walkways that are snow, ice, and salt-free will increase the comfort and confidence of users and building owners. Snowmelt systems can be designed into new or existing district systems. Buildings already connected to a district system can be readily connected to a supply or return line to heat and clear sidewalks, driveways, parking lots or ramps, and other major pedestrian or automotive traffic areas. These snowmelt applications reduce maintenance efforts for snow clearing and improve the safety of these areas.

Snowmelt systems utilize low water temperatures (for example at 95-120°F (35-50°C)) to circulate through the snowmelt tubing. Utilizing the lower temperature hot water allows for the incorporation of a wide variety of low-grade energy sources such as waste heat, condensate return, or district heating return lines. If the district heating is produced by a CHP plant, a lower return temperature to the plant will lead to higher energy efficiency of the plant.

Selection of piping for these installations is an important consideration for effective operations. Polyethylene (PEX) pipes are an attractive option because they are corrosion-free, manufactured in long sections with fewer joints, easy to handle, and require reduced installation time. Glycol selection is important in order to secure freeze protection, corrosion resistance, and low viscosity impacts for the circulating loop. Glycol selection should also consider design intent, pumping resistance, tubing spacing, r-value, freezing points, and load design.

6.2.2 Domestic appliances with hot water connection

Another idea to increase the potential for district heating is for households to install domestic appliances with hot water connection. Instead of usage of electrical power for heating up water, the appliances use hot water heated up by district heating. For households this will convert power consumption into an increased district heating consumption.

The economic benefit of this technology depends on the local prices of electricity and district heating, while the environmental benefit depends on the actual carbon emissions for electricity and district heating. District heating systems with a large share of surplus heat, solar heating etc. will particularly benefit from the technology, because it will increase the potential heat consumption during summer time.

Appliances on the market in Europe suitable for hot water supply:

Appliances with a heat exchanger – district heating can be connected directly HWC-machines (Heating Water Circuit):	Appliances with a direct domestic hot water intake / connection:
• Dishwasher • Washing machine (laundry) • Tumble dryer (laundry)	• Dishwasher • Washing machine (laundry)

Test studies of household appliances with built-in heat exchangers and/or washing machines with separate cold-and hot-water intake have been made in Denmark and Sweden. Results show that under ideal conditions, tumble dryers, washing machines and dishwashers with built-in heat exchangers can replace more than 80% of electricity consumption with district heating. For washing machines, that uses hot water over 70% of electricity demand can be replaced by district heating.

Washing machines with cold and hot water intake has been on the market in Europe for the professional segment e.g. for common laundries, institutions, etc. for a number of years. In the market for household appliances there have also been various attempts from the manufacturers. At the moment about 3 washing machines is being sold on the Danish market. In addition, many dishwashers on the market is designed in such a way that hot water can be connected directly – usually it is usually indicated in the user manual, if it is possible.

Studies from Denmark show that, the hot water usage increases in the range of 5-15 % with hot water connection of washer and dish washer machines, which in particular, will have a positive impact on district heating network's operation in the summer months. In addition, it is assessed that the introduction of hot water connected machines will not affect the design conditions of the layout design of the district heating network.

Increased district heating consumption during summer in particular will be an advantage for the pipe network heat loss, because it will be relatively smaller.

AC 1.4 & 1.6: ENERGY TECHNOLOGIES AND SYSTEMS REPORT

Activity description:

Evaluate options for different mixes of renewable energy, energy efficiency, demand response, energy storage, new technologies and consider system reliability.

Exploring the opportunities for energy supply technologies and systems is intended to serve as an introduction for discussing which system setup to take forward for more detailed financial assessment.

To
The City of St Paul & The Technical Advisory Group

Document type
Report

Date
December 4, 2014

Intended for the review and discussion of the Technical Advisory Group, Subcommittee on Technical Issues

FORD SITE ENERGY STUDY
ENERGY TECHNOLOGIES AND SYSTEM REPORT

FORD SITE ENERGY STUDY
ENERGY TECHNOLOGIES AND SYSTEM REPORT

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1. INTRODUCTION

Ramboll have been appointed to carry out a study of the opportunities for a future energy system for the redevelopment of the site of the former Ford assembly plant.

This document outlines the work done in relation to exploring opportunities for energy supply technologies and systems. It serves as an introduction for discussing which system setup to take forward for more detailed concept design.

The work has been carried out in a 4-step process:
1. Creation of gross list with all interesting technologies
2. Initial screening of technologies filtering clearly incompatible or non-viable technologies
3. Evaluation of technologies based on priorities
4. Production system scenarios creation and evaluation.

2. INITIAL GROS LIST AND SCREENING

An initial gross list was identified, consisting of the most relevant and promising technologies for the Ford site within production and storage of energy covering total 35 technologies. Some technologies are generic basic technologies that can be applied (almost) anywhere such as boilers and regular heat pumps, whereas other technologies are very specific in their requirements for input or conditions, such as industrial waste heat recovery or deep geothermal.

2.1 Decentralized vs centralized solutions

The gross list of technologies includes both decentralized solutions and centralized energy production:
- Decentralized production is when heating and cooling is produced locally at the individual customers - subsidiary for a building block with a group of customers.
- Centralized production is when heating and cooling are produced at a large central plant - inclusive a peak load or backup plant that can be situated at another location in order to enhance the supply security.

For all centralized heating and cooling solutions water-based distribution networks are required. The networks use pre-insulated piping systems in steel, or in cross-linked polyethylene (PEX), or reinforced combinations (AluPEX). The centralized solutions are named district heating and district cooling with piped systems for distributing hot or chilled water generated in centralized locations.

For district heating the pipes are heavily insulated with PUR (polyurethane) to minimize the heat losses. For district cooling PEX pipes with limited or no insulation can be used.

It is common to use a twin pipe system in which the supply and return pipes are integrated in the same casing pipes. This reduces the installation costs and minimizes heat losses as well.

District heating is recognized as a key measure for ensuring long-term energy security, due to its technological flexibility and the capability of networks to be switched to renewable and local resources of e.g. surplus energy. Thus district heating recognized as a cost efficiency way of cutting carbon emissions.

Decentralised heating and cooling can be so-called central heating and cooling, i.e. building or block heating and cooling where hot water or chilled water (or air) is distributed via piped systems to the apartments/rooms from a central boiler room, which attached to or integrated in the building or block.

Fully decentralised heating and cooling is when heat for space heating and DHW and cooling is produced as closed as possible to the end users, i.e. at each apartment or room. The energy source is normally either electricity or gas, and there is no or very limited requirements for a piped distribution system based on water or air.

Decentralized solutions where energy is generated or stored by a variety of small, often grid-connected devices close to the customers they serve, are called Distributed Energy Systems.

Decentralized solution benefits are related by being close to the consumer, the independence of central systems, low or no distribution losses, etc. Disadvantages are often related to noise, dirt and allocation of space, especially in private residential areas.

2.2 Limitations in the choice of technology

All of the technologies described in the following can in principle be attractive solutions - given the right circumstances/context. Therefore, an evaluation should not only focus on the technology, but also under what conditions (price structures, consumer demands, laws, regulations, space available, impact on the local environment (smoke, noise, waste), synergy with other infrastructure, etc.) they can be exploited.

An initial screening ruled out four technologies for various reasons:

- Wind turbines in the vicinity: It's unlikely to receive permits and public acceptance for setting up wind turbines in close proximity of the site
- Waste incineration plant: The size of plant required to achieve a viable business case is not compatible with the site dimensions and the stress on the traffic system for supplying the waste is deemed unacceptable.
- Deep-geothermal: The potential and risks associated with such a project cannot be rightly evaluated through this general study.
- Small-scale nuclear power plant: Small scale nuclear power plants are yet to become economically viable and also pose a safety threat for the community.

Some technologies are still included, although the right circumstances may not be in place. This is true for e.g. cooling storage in the old sand tunnels, but they cannot be ruled out already, and will be considered for the project, while the specific requirements and conditions is looked into.

3. SCORING OF TECHNOLOGIES

To evaluate the potential of the different technologies in a future energy system for the Ford Site, all technologies have been rated on a scale from 1 to 5, 1 being useless/counterproductive and 5 being outstanding/perfect, in five categories stemming from the priorities and goals for the site, as discussed and agreed with the technical advisory group (TAG).
No weighting or priority has been given to any of the categories, which essentially means that a technology can receive a high score without being e.g. economically viable or a low carbon technology.

The five categories are:

- Net Zero: Net Zero concerns the CO_2 emissions and primary energy use of the technology. The highest score have been given to 100% renewable technologies. Other GHG emissions have also been taken into account.

- Resilience: Resilience is understood as the security for energy supply that the technology delivers, in particular in case of power grid failures. On site power production has been given high rankings, but fuel diversification and -independence has also been considered.
- Legacy/Innovation: Developing technologies with high potential have high score, whereas traditional concepts with no innovation are evaluated poorly.
- Energy efficiency: Energy efficiency is evaluated on the conversion efficiencies and energy losses for the technologies. Renewable energy has not been given preference as is often the case due to a 0 primary energy factor by definition.
- Cost effectiveness: The technologies are evaluated primarily on the expected levelized cost of energy (LCOE) over the technical lifetime. The levels of economic risk related to the technology have been considered. There is uncertainty towards the relative value of power vs heat, which may lead to changes in evaluation later on.

The evaluations are based on comparison with the expected business as usual scenario being, heating supplied from individual gas boilers, electricity supplied from the power distribution company, Xcel plus possibly an air-air heat pump for cooling.

For ease of comparison the technologies have been divided into the following sub-groups, which will be presented and evaluated below one by one:

- Combustion technologies
- Heat pump technologies
- Solar energy technologies
- Alternative technologies

3.1 Combustion technologies

Table 1: Technology evaluations - Combustion

	Total	Net Zero	Resilience	Innovation	Energy efficient	Cost effective
Frying/vegetarian oil boiler	19	5	4	3	4	3
Biomass CHP	18	5	5	3	3	2
Natural gas CHP	18	3	4	2	5	4
Industrial waste boiler	18	5	3	3	4	3
Biomass boiler	16	5	4	2	2	3
Natural gas boiler	16	2	4	1	4	5

The combustion technologies are in general evaluated highly on resilience, as they provide security of supply to the system, CHPs' obviously more than boilers due to the local power production. The exception is the industrial-waste-boiler, because sourcing of the fuel could be unstable. The net zero category depends very much on the renewability of the fuel input. CHP's are rated higher than boilers using the same fuel as emissions per energy output are lower.

Innovation level is generally low for the combustion technologies, "new" fuel types and the advanced technologies in CHP's add to the innovation.

Energy efficiency is generally good, although some smaller plants do often not perform as good as larger plants, and boilers are less efficient than CHP's, which provides simultaneous generation of heat and power in a single process.

The boilers are relatively cheap and so the cost efficiency depends solely on the access to cheap fuels, natural gas is regarded very cheap, whereas the others are more uncertain and needs investigation. CHP's are more capital intensive, and therefore the potential power price for electricity delivered to the grid is essential.

3.2 Heat pump technologies

Table 2: Technology evaluations – Heat pump technologies

	Total	Net Zero	Resilience	Innovation	Energy efficient	Cost effective
Absorption cooling	17	5	2	5	3	2
Compressor cooling	14	2	3	2	2	5
Cooling Tower with River water	14	4	3	2	2	3
Electric heat pumps	23	5	3	5	5	5
Electrical heater/boiler	13	3	2	2	2	4
Free cooling, river	21	5	3	3	5	5
Gas driven heat pump	15	3	4	2	4	2
Ice/Snow cooling/storage	20	5	3	5	5	2
Industrial surplus heat	18	4	2	3	5	4
Sewage water Heat pump	19	4	4	5	4	2
Shallow Geothermal	18	4	4	4	4	2

Heat pumps employ the same technology as air conditioners for cooling, but when heat is called for DHW and space heating in cool months - their simultaneous reverse operation can also be exploited, by moving heat from a low-temperature level to the desired warmer comfort temperature level. . Heat pumps usually draw heat from the ambient (input heat) and convert the heat to a higher temperature (output heat) through a closed process; either compressor heat pumps (using electricity) or absorption heat pumps (using heat; e.g. steam, hot water or flue gas).

A general advantage of heat pumps is that the heat pump is able to utilize energy at a low temperature level. Additionally the heat pump is flexible concerning use of renewable energy, waste and surplus heat. The combined utilization of a heat source at a low temperature level and the use of for example gas as driving power enables more effective resource utilization compared with conventional heat production technologies.

Compared with traditional heating technologies, heat pumps are more complex and have high investments costs. However, this is counterbalanced by considerable savings in operating costs.

3.3 Solar energy technologies

Table 3: Technology evaluations – Solar energy

	Total	Net Zero	Resilience	Innovation	Energy efficient	Cost effective
Photovoltaic, centralised	19	5	3	4	5	2
Photovoltaic, decentralised	18	5	3	4	5	1
Solar heating, centralised	20	5	3	4	5	3
Solar heating, decentralised	19	5	3	4	5	2

The solar energy technologies are all driven by solar energy and as such considered fully net zero. They do not affect resilience of the energy system much in itself, as they only produce energy in summer during daytime. However, solar thermal can together with thermal storage deliver a stable heat production for long periods during the year.

The systems are considered innovative and energy efficient, the de-central solutions maybe a bit less than the central technologies due to scale.
The decentralised PV are the least cost inefficient due to high initial costs and inflexible operation, whereas solar heating and in particular decentralised solar thermal panels are more capable of aligning consumption and production when storage is used.

3.4 Alternative technologies

Table 4: Technology evaluations – alternative technologies

	Total	Net Zero	Resilience	Innovation	Energy efficient	Cost effective
Anaerobic digestion	15	5	2	4	2	2
Gasification	16	5	2	5	3	1
Nat gas Fuel-cell CHP	17	3	4	5	4	1
Off-site PV or Wind electricity	20	5	2	3	5	5

A number of technologies that do not conform to the more conventional groupings above have also been evaluated.
The anaerobic digestion (AD) and the gasification are novel technologies running on waste and biomass respectively. They are both considered renewable energy producers although it depends on the input. The resilience is questionable, AD is hardly flexible and unused gas has to be stored or flared, or exported to the natural gas network after being upgraded to natural gas quality level. Gasification is very innovative, but also not very reliable and will need time for testing. The energy efficiency is hard to asses, as it depends on the alternative, but the process in itself is not very efficient. Cost effectiveness is not good.

Fuel cells are also an emerging technology. The net zero performance is somewhat medium, when considering a gas driven version. It has good resilience and energy efficiency, but short technical lifetime and high capital investment makes the business case hard to prove positive.

Off-site renewable energy production is efficient on energy and cost, but adds no resilience to the site. It also does not add much to the legacy of the project.

4. SYSTEM DESIGNS

Following the scoring of the individual technologies a number interesting system designs have been put together. The idea is to highlight the opportunities and synergies of the technologies. Due to the large number of interesting technologies it has not been possible to include all technologies in a system design.

4.1 Assumptions

Due to the great uncertainty towards the future development of the Ford Site, the consultants have used a rough estimate of in total 10MW site energy demand for the system designs. The expectation is that around half of the energy demand will come from domestic hot water and space heating; electricity will take up around 30% and cooling demand around 15%.

For individual supply designs the following specific energy demand is assumed in modern dwellings:

Heating (approx.):
- DHW: 3 Kbtu/sf/yr (11 kWh/sqrm/yr)
- Space heating: 2,5 Kbtu/sf/yr (9 kWh/sqrm/yr)

Electricity (approx.):
- Appliances: 3 Kbtu/sf/yr (11 kWh/sqrm/yr)
- Comfort cooling: 1,5 Kbtu/sf/yr (5 kWh/sqrm/yr)

Power grid and market
For the scenarios created it has been assumed that excess power from CHP production can be sold to the power grid for a meaningful price through a power purchase agreement with the power distribution company.

River water
It is assumed that a permit for utilising the river water for cooling purposes can be obtained.

4.2 SC0: BAU

The business as usual (BAU) scenario with individual gas boilers for space heating, electricity from the power grid and electric air-air-heat pumps for cooling has been assessed as the baseline scenario. The electricity from the grid is considered to have a share of 25% renewable energy, 25% nuclear energy and 50% fossil fuel based energy (coal and natural gas).

System components:
- Individual gas boilers for space heating and DHW
- Electric air-air heat pumps for comfort cooling.

Evaluation:
The system delivers a relatively clean energy based on natural gas and electricity from the power grid. In terms of resilience the technologies are reliable, although it does not provide any heating and electricity supply to the site in case of respectively gas cut off and power grid failure.
The system can hardly be seen as innovative, but it is fairly energy efficient and cost effective.

Table 5: SC0 – Business as usual evaluation

Total	Net Zero	Resilience	Innovation	Energy efficient	Cost effective
13	3	3	1	3	3

4.3 SC1: ALL GAS

A basic district energy scenario based on natural gas would consist of a central natural gas CHP with a peak-load and backup gas boiler, and comfort cooling coming from a centralized compressor plant in combination with free river-cooling.

System components:

- Gas engine/ Gas turbine, single cycle 5-10 MW
- Gas boiler, 5-10 MW
- Central compressor heat pump for comfort cooling
- District heating network and cold water network.

A large hot water tank could be added to the setup, but it would require variation in electricity prices to be economically viable.

Evaluation:
The system delivers a fossil fuelled energy based on the natural gas CHP. In terms of resilience the technologies are proven and reliable, although it does not provide any energy supply to the site in case of gas cut off and down time in the power grid.

The system can hardly be seen as innovative, but it is fairly energy efficient and cost effective.

Total	Net Zero	Resilience	Innovation	Energy efficient	Cost effective
18	2	4	2	5	5

Specific assumptions and critical factors: None

4.4 SC2: Centralized Biomass CHP scenario

A scenario with centralized CO_2 neutral generation of heat and electricity has been set up. A central CHP plant provides heat for space heating and domestic hot water and produces at the same time electricity to the power grid (back pressure mode). A central cooling plant (electric heat pump supplemented with cold river water) provides comfort cooling during the summer and heat for DHW at the same time and can thereby (partly) replace the central CHP plant in the summer period. Central short-term heat tank could be beneficial for the optimization of heating/cooling production.

As the investment in a biomass CHP plant is high it requires high utilization level (many hours of operation), therefore intermittent renewables are not expected to be compatible.

System components:

- Biomass CHP for heat and power production
- Biomass boiler (or gas boiler) as backup
- Biomass storage
- Central electric heat pump supplemented with river water for comfort cooling
- District heating network and cold water network.

Evaluation:
The system provides CO_2 neutral heat and power production. But transportation, handling and combustion of biomass could cause impact on the local air environment. In terms of resilience the technologies are proven and reliable, if biomass supply is reliable. The system can hardly be seen as innovative, but it is energy efficient and cost effective.

Total	Net Zero	Resilience	Innovation	Energy efficient	Cost effective
18	4	4	3	4	3

Specific assumptions and critical factors: Access to sustainable biomass. Biomass transportation and handling should be carried out without critical impact on the surrounding town environment.

4.5 SC3: Centralized Biomass Boiler scenario

A scenario with centralized CO_2 neutral generation of heat-only been set up. A biomass boiler plant provides heat for space heating and domestic hot water. A central solar heat plant with central seasonal heat storage (Sunstore) will decrease the use of biomass. A central cooling plant (electric heat pump supplemented with cold river water) provides comfort cooling during the summer and heat for DHW at the same time, and replaces together with solar heat the biomass boiler, especially in the summer period. The central seasonal heat storage will be used for system optimization and as peak load/backup.

System components:

- Biomass boiler for heat production
- Solar heat plant with seasonal heat storage (Sunstore)
- Biomass storage
- Central electric heat pump supplemented with river water for comfort cooling
- District heating network and cold water network.

Evaluation:
The system provides CO_2 neutral heat production. But transportation, handling and combustion of biomass could cause impact on the local air environment. In terms of resilience the technologies are proven and reliable, if biomass supply is reliable. The system can hardly be seen as innovative – except for the seasonal heat storage, but it is energy efficient and cost effective.

Total	Net Zero	Resilience	Innovation	Energy efficient	Cost effective
19	5	5	4	3	2

4.6 SC4 & SC5: Biomass Gasification & Anaerobic Biomass Digestion scenarios

Biomass gasification and anaerobic biomass digestion are considered as high risk solutions: Biomass gasification cannot be regarded as fully market mature and anaerobic digestion to produce biogas for CHP can be considered to be problematic in a town environment (smell risks, biomass/digested biomass management) in addition to being expensive.

Therefore no further evaluation is presented in the report for these alternatives. In case of special favourable conditions arise, they might be revived.

4.7 SC6: Centralized Sun-Heat Pump scenario

A scenario with centralized generation of energy has been set up. A central electric heat pump provides heat for space heating and domestic hot water. The heat pump is a reverse cycle type that also provides comfort cooling during the summer, and storage surplus heat from the cooling process in a seasonal storage. A central solar collector plant is together with a central seasonal heat storage connected to deliver a share of the annual heat demand. Underground cooling when using the heat pump during the heating season is an option.

If demand for local CO_2 Net Zero is ranged highly: A central photovoltaics (PV) plant - or a share of a large wind farm - produces electricity equal to the total electricity demand throughout the year inclusive electricity for the heat pump.

System components:

- Central electric reversible heat pump for heating/cooling
- Seasonal heat storage
- Central solar heating plant
- District heating network and cold water network
- Central PV plant/Share of a large wind farm.

Evaluation:
The system delivers a relatively clean energy based on decentralized heat and power production. However, dependency on the power grid is required anyway. In terms of resilience the technologies are proven and reliable. The system - except for the central seasonal heat storage- can hardly be seen as innovative, but it is fairly energy efficient and cost effective.

Total	Net Zero	Resilience	Innovation	Energy efficient	Cost effective
19	5	3	3	4	4

Specific assumptions and critical factors:
We assume that the electricity grid will balance the supply and demand timing mismatch by the PV in such a way that the customers only pay a minor fee.

4.8 SC7: Individual Sun-Heat Pump scenario

A scenario with decentralized generation of energy has been set up. An individual air-water heat pump provides heat for space heating and domestic hot water. The heat pump is a reverse cycle type that also provides comfort cooling during the summer. Roof mounted solar collectors are together with individual hot water tanks connected to deliver a major share of the annual DHW demand.

If demand for local CO_2 Net Zero is ranged highly: Roof/wall integrated photovoltaics (PV) installation produces electricity equal to the electricity demand throughout the year inclusive electricity for the individual heat pumps.

System components per individual dwelling unit:

- Electric heat pump (air-water) for heating/cooling
- 2,5 m2 thermal solar collector for DHW
- 2 m3 hot water tank
- PV (1/3 of room sf), equivalent to electricity use, 160 W/m2, 1000 h/y.

Evaluation
The system delivers a relatively clean energy based on decentralized heat and power production. However, dependency on the power grid is required anyway. In terms of resilience the technologies are proven and reliable. The system can hardly be seen as innovative, but it is fairly energy efficient and cost effective.

Total	Net Zero	Resilience	Innovation	Energy efficient	Cost effective
17	5	3	3	4	2

Specific assumptions and critical factors:
We assume that the electricity grid will balance the supply and demand timing mismatch by the PV in such a way that the customers only pay a minor fee.

4.9 SC8: Individual ALL ELECTRIC scenario

A scenario with decentralized generation of energy has been set up. Electric heaters provide heat for space heating and domestic hot water. Use of electric baseboards can minimize the allocation of space. Electricity is also used for comfort cooling during the summer by an electric air conditioner. In general, air conditioning can refer to any form of decentralized grid-connected devices that modifies the condition of indoor air (heating, cooling, humidification, cleaning, ventilation).

If demand for local CO2 Net Zero is ranged highly: Roof/wall integrated photovoltaics (PV) installation produces electricity equal to the electricity demand throughout the year inclusive electricity for heating, HTW and cooling.

System components per individual dwelling unit:
- De-central electric devices for heating/cooling and HTW.
- PV (1/3 of room sf), equivalent to electricity use, 160 W/m2, 1000 h/y.

Evaluation
The scenario delivers a relatively clean energy based on decentralized heat and power production. However, dependency on the power grid is required anyway. In terms of resilience the technologies are proven and reliable. The system can hardly be seen as innovative, but it is fairly cost effective and also energy efficient due to nearly no distribution losses.

Total	Net Zero	Resilience	Innovation	Energy efficient	Cost effective
17	5	3	1	4	4

Specific assumptions and critical factors:
We assume that the electricity grid will balance the supply and demand timing mismatch by the PV in such a way that the customers only pay a minor fee.

4.10 Substitutes and complements

Some technologies that received a good evaluation have not been used in any of the proposed system designs. That does not necessarily mean that they could not meaningfully be deployed.

Some are direct substitutes of chosen technologies e.g. one type of boiler for another, and can easily be switched. Others could complement the systems, if e.g. solar thermal panels were replaced with PV’s. It would affect the rest of the setup, but could eventually be viable, if the power purchase agreement is attractive enough.

5. CONSIDERATIONS

For the further work the consultant askes the TAG to consider the following:
- Is any technology missing that should be in the list?
- Are the ratings fair?
- Do you agree with the assumptions laid out in the paper?
- How should the agreed 5 goals (Net-Zero, Resilience, Innovation, Energy Efficiency and Cost Effectiveness) be weighted and prioritised if any?
- Which setup should be taken forward for further detailed design?

AC 1.7: CONCEPT DESIGN AND FINANCIAL ANALYSIS

Activity description:
Based on agreed assumption outline the overall high level design concepts for three options for the site. A high level financial analysis is conducted based on the concepts and financial assumptions given.

Intended for
City of St Paul

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FORD SITE ENERGY STUDY
FINANCIAL ANALYSIS

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1. INTRODUCTION

The City of St. Paul is in the process of planning for redevelopment of the former Ford production facility into a sustainable urban neighborhood which aims to be a showcase for an attractive and livable community developed around a district energy system.

Building on the Energy Study work for the Ford Site Redevelopment to date, this memorandum responds to a revised Activity 1.7 outlining the findings of an analysis of the financial viability of the derived energy supply concepts.

Ramboll has worked on the following analysis:

- Based on **development Scenario 5,** estimations of the likely build out phasing of the site, and the likely energy demand and its duration throughout the year.

- Analysis of three (3) technical concepts for financial viability (as agreed to at the TAG meeting on January 29, 2015):

  - **Concept 0:** Business as usual concept, **BAU** (Grid electricity, natural gas individual heating, and cooling with air conditioning)
  - **Concept 1:** District energy concept, **DHC** (ATES based heat pump/chiller energy production, Solar Thermal, River free cooling, thermal storage (day-to-day) and gas boiler as back-up)
  - **Concept 2:** Individual generation concept, **IND** (Solar PV on roof tops, central (ground source) heat pumps for heating and chillers for cooling, hot water storage (day-to-day))

The district energy concept has changed since the original outline of concepts for the financial analysis ref: CSP-39-001-Activity1.7-Financial Analysis Brief regarding assumptions. It now includes Aquifer Thermal Energy Storage (ATES) instead of the river source heat pump scheme. This change was implemented as a result of poor technical feasibility on the heat pumps since the temperature of the Mississippi drops to below freezing during approximately 4 months of the year.

It was a prerequisite that biomass could not be used in this study, even though biomass is an increasingly utilized energy source. A total capacity of more than 5,100 MBTU/h (1,500 MW) is either proposed or under construction[1] in the United States. Biomass could be an option for reducing Green House Gas (GHG) emissions and has been used for years in Denmark for very small facilities (a few MW of electricity) as well as larger facilities up to more than 340 MBTU/h (100 MW) for cogeneration as well as for heat only. The first plants were established in mid-80s. Location of the plants varies from being in middle of the cities to outside city areas.

There are environmental challenges with biomass but the experiences to meet these challenges are many. For instance a plant near city areas will have a closed storage for biomass with a slight vacuum in the building to prevent smelling and spreading of possible fungus spores. Noise from a facility can be regulated by noise barriers. Flue gas cleaning equipment today is very efficient. On the downside, there would be an increased traffic to a facility. With a fully developed heat demand by 2024, between 200 and 250 trucks would supply fuel to the plant per year. During peak demand in winter it would be necessary with 5 to 7 trucks per day.

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[1] Biomass Magazine http://biomassmagazine.com/plants/listplants/biomass/US/page:1/sort:capacity/direction:desc

Not utilizing biomass as an option limits the viable opportunities for introducing a low or net zero carbon energy solution for the site.

Hence despite still requiring further investigation and testing to establish the suitability and capacity of the soil as the use of aquifer storage (ATES) is possible in most regions is is considered worth introducing as part of the DHC option.

The proposed energy objectives for the site are:

1. Cost effectiveness
2. Energy efficiency
3. Net Zero
4. Resilience
5. Legacy/Innovation

It is unlikely that a solution can be found that equally meets all five objectives. Therefore an exercise to prioritize and weight the objectives was conducted during a TAG meeting. No weighting was agreed on but objective 4 and 5 were noted to be of slightly lower priority than objective 1, 2 and 3.

The financial analysis' methodology and process is briefly outlined below.

To add the most value to the study, a Technical Advisory Group (TAG) subcommittee provided input to the financial analysis, especially regarding some of the financial assumptions, pricing of installations, pipes, and the expected build out of the site.

An initial outline of the proposed analysis and its basic assumptions and base information was presented to the TAG subcommittee prior to a conference call on May 5, 2015. Its purpose was to clarify analysis setup, align expectations, and engage the TAG subcommittee to provide the input needed. Ref.: CSP-39-001-Activity1.7-Financial Analysis Brief regarding assumptions.

Following the completion of the financial analysis, the findings were presented at a TAG meeting on July 8th, 2015. This led to the TAG wanting to change some of their initial assumptions to more clearly reflect the market situation. This revised report reflects the financial analysis based on these new assumptions.

In order to compare the three concepts, all assumptions must be aligned and coordinated across the chosen concepts.

Concept 0 - BAU was chosen as the reference scenario, since it represents the business as usual with regards to energy supply. The weighted average heating and cooling price of the BAU concept will be calculated based on all investments and costs of installing and supplying energy.

Estimating the average price per MMBtu (MWh) energy that a customer will pay in a business as usual (BAU) scenario, it is possible to compare the three concepts. This is done by using the reference heating and cooling price from the BAU concept as the reference prices in concept 1 and 2. In other words, the customers are expected to pay the same price per MMBtu (MWh) energy in all three concepts, determined by the BAU scenario. Thus, the economic analysis will be able to identify which project is viable. Furthermore, if concept 1 and 2 are less viable from a financial viewpoint than concept 0, a potential investment gap can be identified.

2. SITE BUILD OUT AND CONNECTIONS

As noted in Section 1, all financial analysis is based on the Scenario 5 from the Phase 1 Summary Report[2].

Based on input from a subcommittee of the TAG, the following phasing for site build out was assumed.

Table 1 Start development year

Area	Year
Green	0
Yellow	3
Blue	6
Red	10

Each area is assumed to be completed within 5 years from the starting development year, and buildings fully occupied within 5 years of completion.

Figure 1 Site Development

[2] http://www.stpaul.gov/DocumentCenter/Home/View/3162

3. ENERGY DEMAND

The client and their advisors chose to proceed with Activity 1.7 using Scenario 5, which has a strong residential density, as the baseline for building stock area and type distribution.

An overview of the building type areas included in Scenario 5 is listed in Table 2 below:

Table 2 - Scenario 5 Building Type Areas

Unit	Total Heated/Cooled Floor Area (ft^2)	Total Heated/Cooled Floor Area (m^2)
Apartment/Condo (Low Density - 28 units/acre)	534,000	49,610
Apartment/Condo (Medium Density - 45 units/acre)	1,296,000	120,402
Apartment/Condo (High Density - 80 units/acre)	570,000	52,955
Civic	50,000	4,645
Retail/Mixed use	375,000	34,839
Official/Institutional	194,000	18,023

The estimated Site Energy Utilization Intensity (EUI) for different building types have been provided according to climate zone 6A (St. Paul) and the SB 2030 code, and are outlined below in Table 3. The SB 2020 energy demands used for this assessment are shown below highlighted in blue. To account for any uncertainty regarding which category to apply (small, medium or large in Table 3), median values of the three categories are used.

Table 3 - Site Energy Utilization Intensity (EUI)

kBtu/ft²/yr

Code / Building Type	Prototype Floor Area (ft^2)	ASHRAE 90.1-2004	2012 IECC / ASHRAE 90.1-2010	SB 2030 Suggested Ford Site Requirements	Percent below 2003 baseline
Small office	5,502	53.7	41.8	32.0	80
Medium office	53,628	62.2	46.2	30.0	80
Large office	498,588	99.7	84.8	30.0	80
Stand-alone retail	24,692	107.2	71.9	29.3	80
Strip mall retail	22,500	118.3	85.4	30.0	80
Supermarket	n/a	208.0	145.0	27.3	80
Primary school	73,959	100.1	75.1	34.0	80
Secondary school	210,887	98.4	64.7	29.3	80
Hospital	241,501	179.9	138.5	79.3	80
Outpatient health care	40,946	161.5	123.3	58.7	80
Full-service restaurant	5,502	570.2	470.9	48.0	80
Quick-service restaurant	2,501	781.9	723.0	52.7	80
Small hotel	43,202	87.4	75.8	42.0	80
Large hotel	122,120	151.8	119.1	44.0	80
Warehouse	52,045	35.3	25.2	20.0	80
Mid-rise apartment	33,741	68.0	60.4	38.0	85
High-rise apartment	84,360	72.1	65.8	39.5	85

Using these figures, a total energy demand for each building type has been calculated. The total demands are summarized below in Table 4.

Table 4 - Scenario 5 Total Energy Demands

Unit	Total Heated/Cooled Floor Area (ft^2)	Total Demand (MMBtu/yr)	Total demand (MWh/yr)
Apartment/Condo (Low Density - 28 units/acre)	534,000	21,894	6,416
Apartment/Condo (Medium Density - 45 units/acre)	1,296,000	53,136	15,573
Apartment/Condo (High Density - 80 units/acre)	570,000	25,080	7,350
Civic	50,000	1,500	440
Retail/Mixed use	375,000	11,156	3,270
Official/Institutional	194,000	5,981	1,753

Based on Ramboll's experience, as well as input from the University of Minnesota's Centre for sustainable building research, an energy distribution between heating, cooling, and other has been established. The distribution varies between building types and is summarized in Table 5 below.

Table 5 - Scenario 5 % Energy Distribution

Building type	Total Heated/Cooled Floor Area (ft^2)	Total Demand (MMBtu/yr)	Energy Distribution Heating/Cooling/Other
Apartment/Condo (Low Density - 28 units/acre)	534,000	21,894	40%/20%/40%
Apartment/Condo (Medium Density - 45 units/acre)	1,296,000	53,136	40%/20%/40%
Apartment/Condo (High Density - 80 units/acre)	570,000	25,080	40%/20%/40%
Civic	50,000	1,500	30%/30%/40%
Retail/Mixed use	375,000	11,156	30%/30%/40%
Official/Institutional	194,000	5,981	30%/30%/40%

Based on the distribution of energy, annual heating and cooling demands for Scenario 5 can be summarized as per Table 6:

Table 6 - Scenario 5 Annual Heating and Cooling Demands

Annual Total Heat demand	Annual Total Cooling demand
47,503 MMBtu/yr	25,616 MMBtu/yr
13,922 MWh/yr	7,507 MWh/yr

In order to calculate the peak building heating and cooling load we have estimated[3] the number of equivalent full load hours (eqFLH) that the new energy plant will need to provide annually. These assumptions are detailed in Table 7 below.

[3] Qualified estimate based on Ramboll's experience and TAG input

Table 7 - Scenario 5 Full Load Hours for Heating and Cooling Plant

Unit	Total Demand (MMBtu/yr)	% Energy Distribution Heat/Cooling/Other	Equivalent Full load hours per year Heat/Cooling
Apartment/Condo (Low Density - 28 units/acre)	21,894	40%/20%/40%	1800/1200
Apartment/Condo (Medium Density - 45 units/acre)	53,136	40%/20%/40%	1800/1200
Apartment/Condo (High Density - 80 units/acre)	25,080	40%/20%/40%	1800/1200
Civic	1,500	30%/30%/40%	1800/1500
Retail/Mixed use	11,156	30%/30%/40%	1800/1500
Official/Institutional	5,981	30%/30%/40%	1800/1500

The estimated peak heating and cooling load for Scenario 5 are summarized in Table 8, by totaling the individual peak loads of all individual building units.

Table 8 - Scenario 5 Peak Heating and Cooling loads

Peak Heat load	Peak Cooling load
26.390 MMBtu/hr	20.414 MMBtu/hr
7.73 MW	5.98 MW

The capacity will be lower in the DHC concept (concept 1) due to the diversity that must be factored in. The concept of diversity will be further elaborated on in chapter 2.2.3.

3.1 Further Assumptions

In order to obtain realistic building footprints for each of the 38 building units, the Scenario 5 map from the *Phase 1 summary report* has been integrated into a GIS platform.

Same-type Buildings are assumed to have an equal number of floors so that there is proportionality between footprint area and the actual unit square footage.

Average site EUI's apply according to SB 2030 (year 2020) - 80% of the cooling demand is assumed to be outdoor temperature dependent, compared to 60% of the total heat demand due to the low energy class of new buildings.

Household electricity usage is not included in the comparison under the assumption that it will be constant across all concepts.

In each concept, every building will have a domestic hot water storage tank, with size dependent on building purpose. However, the capital expenditure connected to the tanks is not included in the analysis since cost is constant in all 3 concepts.

Where local assumptions regarding CAPEX and OPEX have not been available, a paper from the Danish Energy Agency, "Technology Data for Energy Plants, Individual Heating Plants and Energy", October 2013, has been used instead. An index of 0.80 will be used as the difference between the DKK and USD prices.

The underground sand tunnels on the Ford site were initially assessed with the purpose of serving as thermal storages. However, integrating these into the preliminary analyses is not possible as this would have required extensive on-site investigation which lies outside the scope of this study.

4. ENERGY CONCEPT

The three concept designs outlined in the current chapter are based on previous knowledge attained in two review memos of December 2014, prepared by Ramboll in collaboration with Krifcon.

1. "*Energy Technologies and System Report*" and
2. "*Best Practices in Building Design*"

4.1 Concept 0: Business As Usual - Individual Energy Production per Building

This is a "Business As Usual" (BAU) case where individual heating and cooling is assumed in each building unit.

4.1.1 Energy Production

Each unit has its own individual heating and cooling production (excluding electricity, which is supplied from the grid).

The chosen technology may differ depending on the building type in question.

- **Small residential unit**: Natural gas boiler (with a domestic Hot Water Tank (HWT)) for heating **and** AC unit for cooling
- **Medium/Large residential unit**: A central natural gas boiler with local distribution for heating **and** a central cooling plant with local distribution
- **Official/Institutional**: A central Natural gas boiler for heating **and** a central cooling plant with local distribution

Table 9 Concept 0 Specifications

Individual Concept	Heating	Cooling	Electricity
Plant type	Natural gas boiler Individual or Common	AC unit Individual or Common	Grid
Plant size, MW	Depending on Building type and size	Depending on Building type and size	
Plant efficiency, %	94% (HHV)	400% (COP = 4)	
Equivalent Full Load Hours	1800	Retail, office, civic: 1500 Apartments: 1200	

4.1.2 Gas network

A natural gas network is established throughout the new development area.

Gas network assumptions provided by Xcel Energy. Figure 2 illustrates the natural gas network connections throughout the area. See also Appendix 8.1.

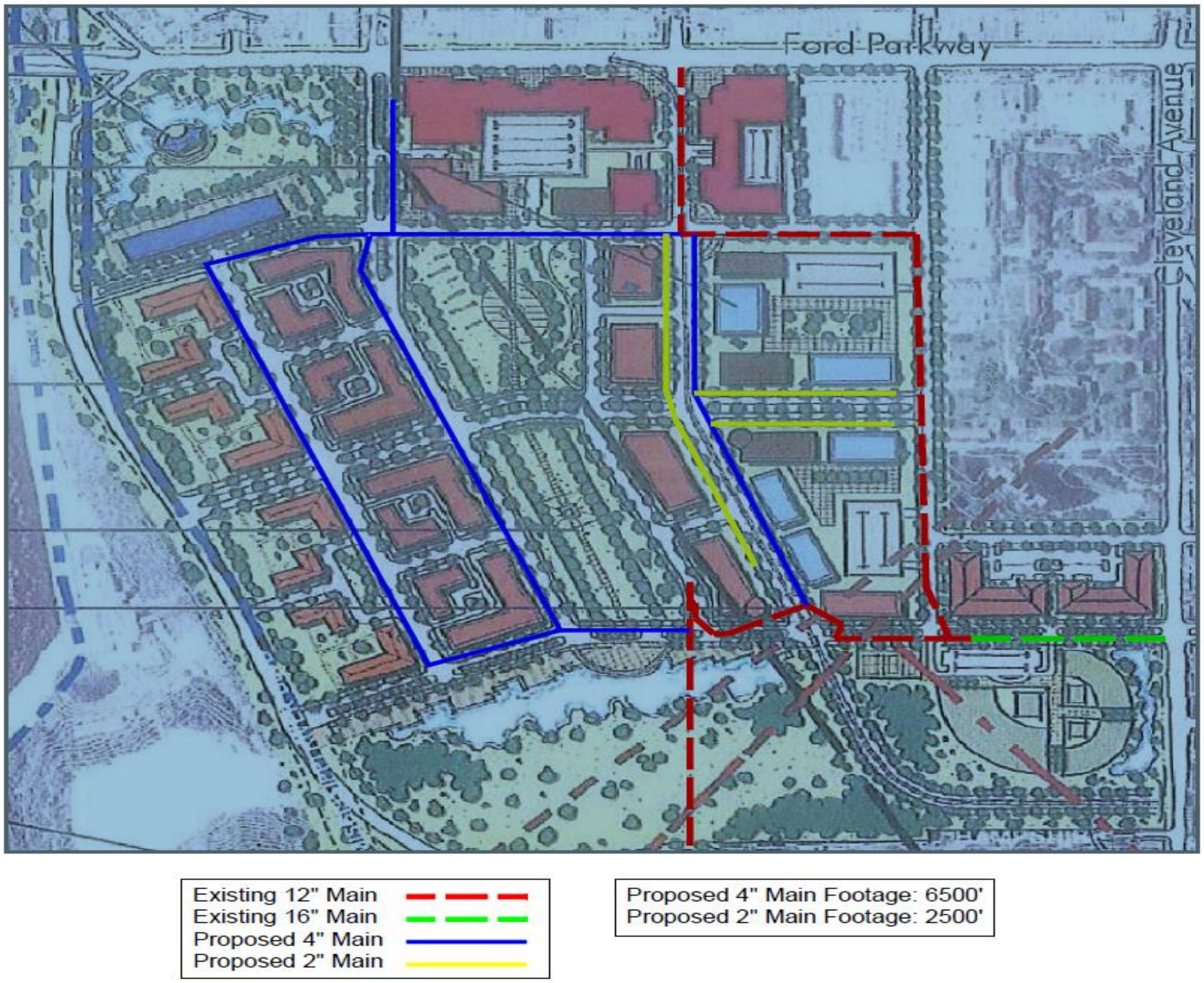

Figure 2 Natural gas network

4.2 Concept 1: District Energy – Centralized Energy Production

Concept 1 is based on energy supply to the site via a District Heating & Cooling (DHC) network.

4.2.1 Energy production

In this concept both heating and cooling will be produced in a central energy center and then distributed via a buried pipe network with individual connections to each building unit.

Ramboll proposes that a groundwater thermal energy storage or aquifer (ATES) storage be applied as the central nerve of the energy center. The use of aquifer storage is possible in most regions but does require some preliminary investigations and testing to establish the suitability and capacity of the soil.

Ground water reservoirs are utilized as seasonal storage to:

- Supply low grade heat as a source for heat production to the district heating network via high efficiency industrial heat pumps.
- Supply low temperature water into the district cooling network either as free cooling or pre- cooling (pre-cooling as first step before entering chillers in the energy center).

Other components in the DHC system are:

- The Mississippi river used as a heat sink for the chillers
- Solar thermal installed on the adjacent 4-acre, concrete-sealed area for increased Renewable Energy Supply (RES)
- Simultaneous heat and cooling production through a high efficiency combined heat pump/chiller aggregate
- Dedicated chiller units
- Dedicated heat pump units
- Short-term energy storage for day-to-day balancing of supply/demand offset.

Table 10 and Table 11 present the production units divided into prioritized groups based on marginal production cost for heat and cooling production, respectively.

Table 10 Heat production

Base load units	Intermediate load units	Peak and reserve load units
1. Flat plate solar thermal **2. Combined heat pump/chiller unit** **3. Dedicated heat pumps**	4. Flat plate solar thermal (Boost to increase HP efficiency) 5. Short term storage	6. Natural gas boiler*

*In order to ensure reliable heat production as well as high flexibility in peak operation a gas boiler is installed.

<u>Heat Pump (HP) heat sources:</u>

- ATES with temperatures up to 77°F (25°C)
- Return water from District Cooling network (source capacity in the combined aggregate and chilled water used to satisfy coinciding cooling demand)
- Solar boost - when solar is not suitable for primary production due to low irradiancy the low temperature heat can be used to boost ground source heated water in order to achieve increased Coefficient of Performance (COP) in the dedicated heat pumps.

Table 11 Cooling production

Base load units	Intermediate load units	Peak and reserve load units
1. Free cooling (ATES) **2. Combined heat pump/chiller unit** **3. Dedicated chiller units**	4. Pre cooling (ATES) 5. Free cooling (River) 6. Short term storage	7. Dedicated chiller unit (N + 1)

<u>Chiller heat sinks:</u>

- River
- ATES (for yearly balancing if necessary)

The DHC system principle is outlined in Figure 3.

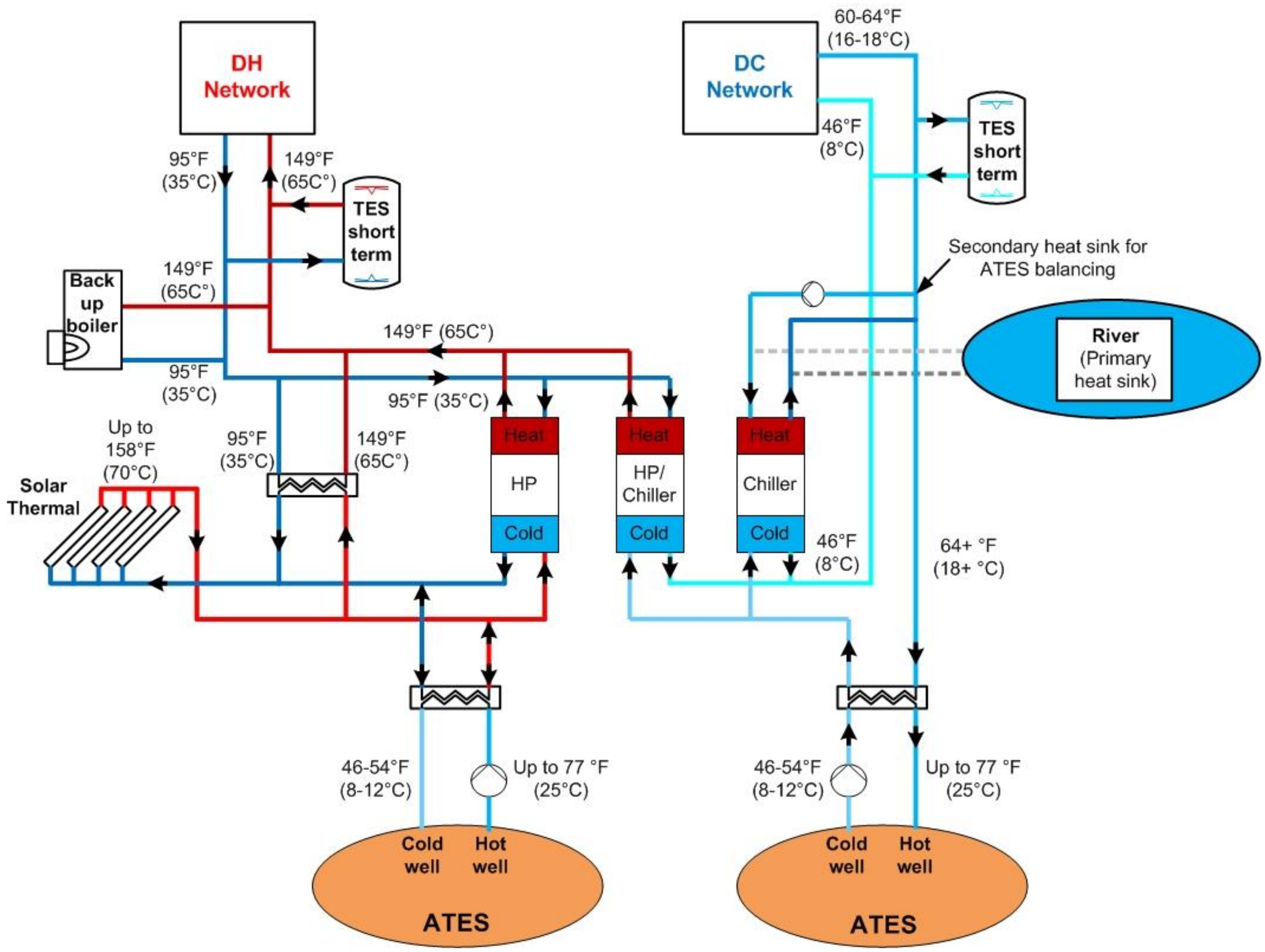

Figure 3 Concept 3 with integrated heating and cooling production + thermal storage

4.2.2 ATES (aquifer thermal energy storage) in principle

In order to utilize heat pumps (HPs) as a base load unit in the DH system, a stable low grade heat source must be readily available. ATES provides this.

Water up to 77°F (25°C) is drawn from the "hot" aquifer through a hot well and sourced to the HPs. While useful high grade heat is discharged in the DH network on the hot side of the HP, the source water on the cold side of the HP is cooled down, heat is extracted in the process, and returned to the ATES in a cold aquifer where it is preserved at a stable temperature of 46–54 °F (8-12°C).

The cooled water that returns to the cold aquifer is a by-product of heat production, however, just as useful in terms of meeting cooling demands in the DC network. Depending on the temperature of the cold water aquifer, cold water can be drawn with one of two purposes:

1. To "free cool" the return water from the DC network down to design temperature of 46°F (8°C), that is if temperature in the aquifer is lower than 46°F (8°C).

   OR

2. To pre-cool the return water as much as possible before cooling to design temperature in the chillers (called partial free cooling or integrated free cooling).

Thus, introducing ATES in the system creates great synergy between summer and winter production.

4.2.3 Sizing of production capacity

Based on the energy demands described in section 2 we have simulated the DHC concept using EnergyPro software. For now, only demand from the fully built-out site has been simulated. A more detailed technical feasibility could consider a phased build out and operation pattern, in the financial assessment here only a basic assumption has been made.

By simulating the energy demand of the site in line with available weather data for the City of St Paul (including irradiance model), we can provide an initial indication of the possible major plant sizes, i.e. solar thermal, heat pumps, chillers, short-term thermal energy storages (TES), etc.

Whereas the required capacity in the individual scenarios is the sum of capacities for all the buildings, the required capacity in the DHC scenario must be factored to take into account that peak demands will not occur in all of the buildings at the same time. This is one of the major advantages of district energy because it enables a decrease in level of investment for production capacity.

The EnergyPro model factors this automatically, and the required peak capacity is reduced compared to the totaled peak capacity shown in the individual concept (Table 8).

The reason that the cooling capacity installed is only reduced by 5 % compared to the individual scenario is due to the fact that an 80% outdoor temperature dependency is assumed in the EnergyPro model.

The outdoor temperature dependent (OTDS) share of the cooling demand might be lowered significantly depending on how much light process (e.g. servers etc.) that eventually will be introduced in the system. Lower outdoor temperature dependency implies less required peak capacity installed.

Sensitivity: Setting the aforementioned dependency share at 70% instead of 80% gives a 17% reduction on the required production capacity.

Table 12 Reduced peak capacity

	Peak Heat load	Peak Cooling load
Individual concept	26,390 MMBtu/hr (7.73 MW)	20,414 MMBtu/hr (5.98 MW)
DHC concept	13,140 MMBtu/hr (3,85 MW)	19,150 MMBtu/hr (5,7 MW)
Capacity Reduction	~51%	~5% (~17% with OTDS at 70%)

To ensure security of supply an N + 1 approach is taken, meaning that the biggest unit can fail (back up unit of equal size is installed).

ATES is assumed to have the required capacity to meet demands in the heat pumps and chillers at all times.

Energy losses in the network have been calculated using a certified Logstor model. Energy loss in the DHC network is in the order of 6% for heating and 2% for cooling.

A schematic overview of the system components can be found in Table 13.

Table 13 Concept 3 Specifications

District Energy Concept	District Heating				Combined heating/ cooling	District Cooling		
Plant type	**Solar thermal**	**Heat pump**	**Natural gas boiler**	**Thermal Store**	**Heat pump**	**ATES Free Cooling**	**Chiller**	**Cold Store**
Plant size	5250 m2	3 x 1MW	1 x 4MW	600m3	1 x 500 kW	1 x 2MW	3 x 2MW	1725m^3
Plant efficiency	Covers approx. 30% of yearly heat demand	600%	94%	-	800%	4000% (only pump)	500%	-

An indication of the annual contribution that each production unit makes to the total energy production is presented in Figure 4 and Figure 5 (below).

The black curve (duration curve) indicates the demand at any given hour of the year. The reason why heat production is way above the aforementioned peak production capacity is because solar thermal production fluctuates significantly (very large peak in limited amount of hours during summer) and because the excess heat (above actual demand) is stored in the short term thermal storage.

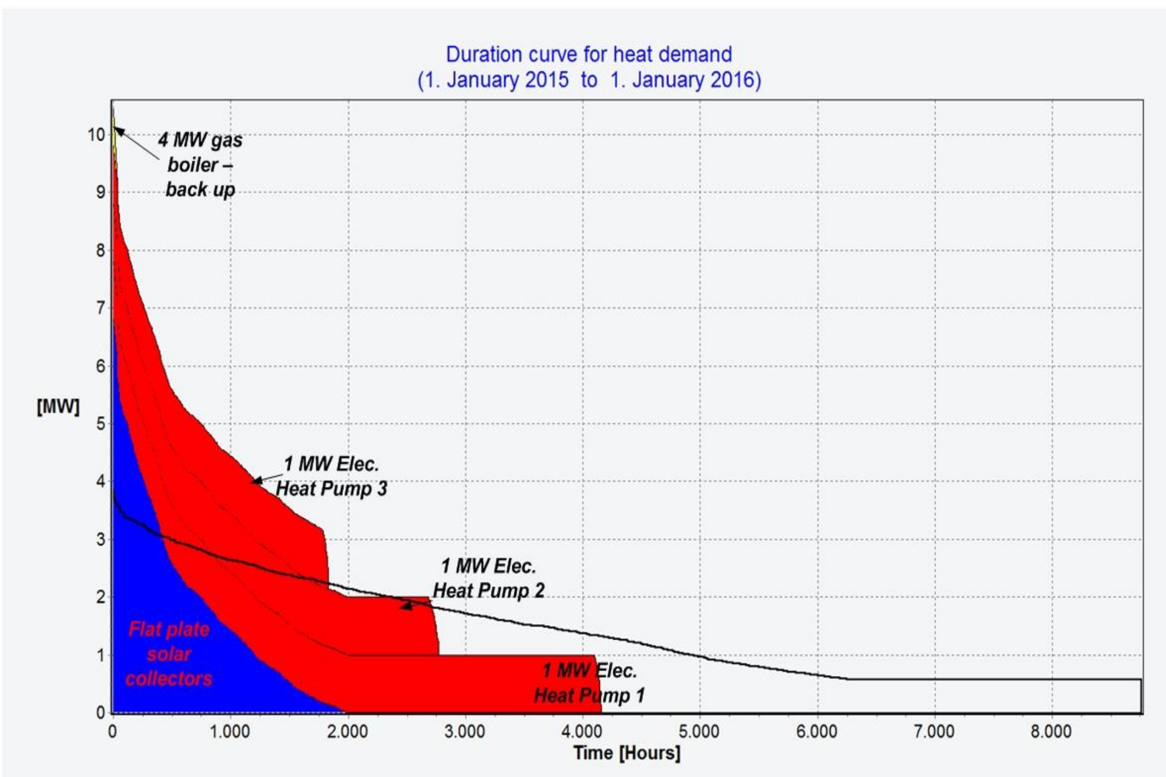

Figure 4 Heat Duration Curve with Productions from solar thermal, heat pumps and Ngas boiler

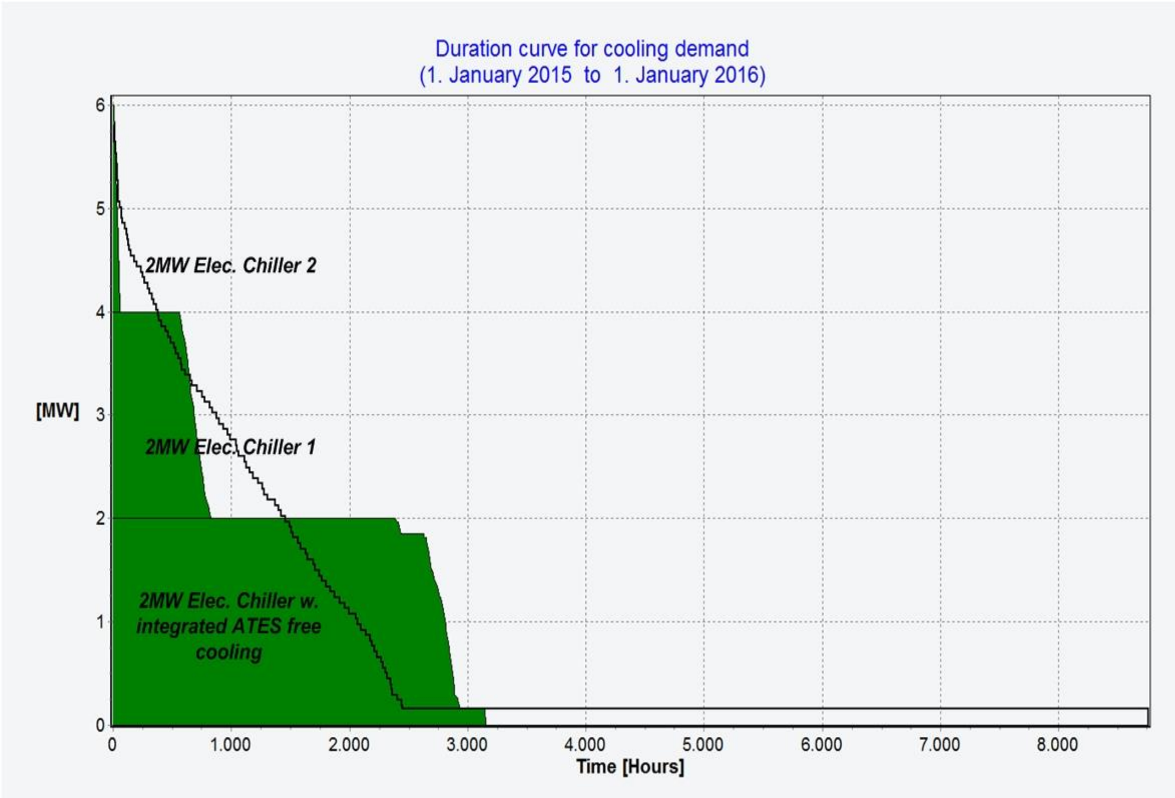

Figure 5 Cooling Duration Curve with Productions from ATES free cooling and chiller plants

The non-colored area is where demand is met by thermal storage.

The yield of the flat plate solar thermal is based on an actual irradiance model for the area of St Paul (and Ramboll's general experience).

Short-term thermal storages have been sized to optimize solar fraction in the system and to allow for economic optimization according to the day-ahead electricity market. The nighttime electricity tariff (between 9 pm and 9 am) is approx. 50% of the daytime tariff, making it favorable to operate heat pumps and chillers in the evening or nighttime.

Energy production will be on a modulated approach with smaller units added on as the site is built out to delay capital expenditure (CAPEX).

4.2.4 District Heating and Cooling (DHC) Network

Network dimensions have been chosen based on a hydraulic modeling of the proposed DHC concept. The district energy network is presented in Figure 6.

Figure 6 the district energy network

At this stage we envision that a low temperature DH network will be employed with the following design parameters:

Design temperature:	185 or 203°F (85 or 95°C)
Design Pressure:	87 or 145 psi (6 or 10 bars)

It should be noted that these temperatures require a different design to the secondary systems than is normally practiced in the United States.

Pre-insulated pipes have been assumed for both the heating and cooling network.

Pre-insulated pipes are a necessity in the DH network in terms of energy efficiency (large temperature difference to the ambient, meaning large heat losses). However, for the DC network un-insulated plastic pipes could be used instead because the temperature difference between the cooling water and the ambient is very small (low energy losses in general).

Plastic pipes incur a significantly lower investment in the piping network, however, it should be noted that using un-insulated pipes limits the options regarding leak detection.

If steel pipes are chosen for the DC network, insulation could be required to prevent condensation and resulting corrosion on the outside of the pipe.

For this high-level study, high-level assumptions have been used for the pipe investment costs. A concept design based study, will be able to look at these investment costs in more detail.

4.3 Concept 2: Individual Renewable Energy Supply

This concept is a further development of the BAU case described in concept 0. Heating and cooling production is individual (IND) for each building unit and close to 100% renewable energy supply (RES) integrated.

4.3.1 Energy Production

Individual heating and cooling by Heat Pumps and Chillers respectively, with immersion heaters installed as back up.

Solar photovoltaic (PV) panels are integrated into the building mass to increase RES in the overall concept. Solar PV is installed on a maximum of 40% of the individual building footprints with an additional constraint that the yield of the solar PV (MWh produced/year) must not exceed the total electricity consumption of the heat and cooling production in the individual building.

A net-meter arrangement is assumed, allowing excess production to be absorbed in the public electricity network and bought back at zero cost.

The specification for the Solar PV is taken from a report on the solar potential of the site, prepared by National Renewable Energy Laboratory (NREL) under direction of the Environmental Protection Agency "Integration of Rooftop Photovoltaic Systems in St. Paul Ford Site's Redevelopment Plans".

Alternatively, we propose the Solar PV panels could be located centrally at the concrete sealed area next to the river. A total of about 40% of this area (approximately 4 acres) of solar PV could be installed. This solution would probably be much cheaper that integrating it into the buildings.

The electricity produced by the PV-panels will be used for the heat pump and chillers in each building. It is assumed that the price of the supplied electricity corresponds to the industrial tariff.

Heat pumps are expensive and during peak hours, it would be necessary to install a high amount of capacity. An alternative to peak production for heat pumps is gas boilers, but to avoid establishing a natural gas network with little utilization and paying an increased price during peak hours, for this analysis an oil-fired boiler is assumed instead.

Table 14 Concept 2 Specifications

Individual Concept	Heating		Cooling	Electricity
Plant type	Heat Pump Individual or Common	Oil-fired boiler (as back-up)	Chiller Individual or Common	Solar PV + Grid
Plant size, MW	Depending on Building type and size		Depending on Building type and size	Depending on roof space
Plant efficiency, %	500%	85%	400%	-
Operating hours	1800		1200	1300[4]

[4] Assuming a little less than the maximum production (1400) mentioned in the EPA report.

5. FINANCIAL ASSUMPTIONS

5.1 Overall general assumptions

For the analysis, Ramboll has used the following financial inputs.

Parameter	Ramboll suggestion
Start year	2019
Inflation	2.75%
Discount rate (WACC)	7.3%

We consider the discount rate calculated in nominal terms (includes inflation) i.e. all calculation will be made on a nominal basis. All prices will therefore be inflated during the calculation period.

The technical lifetime has been assumed to be 20 years for most equipment, for pipes it has been assumed to be 40 years. The financial assessment period is 25 years and subsequently a scrap value after 25 years has been assumed.

5.2 Concept 0: Business as Usual Financial assumptions

The financial assumption for concept 0 is presented in Table 15.

Table 15 Concept 0 Financial assumptions

Individual Concept	Heating	Cooling
Plant type	Natural gas boiler Individual or Common	AC unit Individual or Common
Plant efficiency, %	94% (HHV)	400% (COP = 4)
Equivalent Full Load Hours	1800	Retail, office, civic: 1500 Apartments: 1200
CAPEX	XX ($280/kW[5])	Apartment: $ 6.50 /MMBtu/h ($1,439/kW) Retail: $ 6.10 /MMBtu/h ($1,343/kW) Office: $ 9.30 /MMBtu/h ($2,048/kW)[6]
Service & Maintenance[7]		
Retail/Mixed use	$400 /unit/yr	$400 /unit/yr
Apartment/Condo-High Density	$400 /unit/yr	$400 /unit/yr
Official/Institutional	$500 /unit/yr	$500 /unit/yr
Civic	$400 /unit/yr	$400 /unit/yr
Apartment/Condo-Medium Density	$300 /unit/yr	$300 /unit/yr
Apartment/Condo-Low Density	$300 /unit/yr	$300 /unit/yr

The variable and fixed costs of maintenance are included in the service and maintenance costs.

A natural gas network is established throughout the new development area. The single consumer pays a price for the natural gas, which includes a natural gas network.

[5] Danish Energy Agency, Technology Data for Energy Plants, Individual Heating Plants and Energy, October 2013
[6] TAG committee comments Ken Smith email 8th of May 2015
[7] TAG committee comments Ken Smith email 8th of May 2015 + Ramboll assumption

Xcel Energy assumes that the loads will trigger the revenue justification formulas that would allow the natural gas ratepayers to absorb these costs. Hence, the investment for gas network will not be included in the financial model.

5.3 Concept 1: District Heating and Cooling Financial assumptions

A schematic overview of the system components can be found in Table 16.

Table 16 Concept 1 Specifications

District Energy Concept	District Heating				Combined heating/ cooling	District Cooling		
Plant type	**Solar thermal**	**Heat pump**	**Natural gas boiler**	**Thermal Store**	**Heat pump**	**ATES Free Cooling**	**Chiller**	**Cold Store**
Plant size	5250 m^2	3 x 1MW	1 x 4MW	600m^3	1 x 500 kW	1 x 2MW	3 x 2MW	1725m^3
Plant efficiency	Covers approx. 30% of yearly heat demand	600%	94%	-	800%	4000% (only pump)	500%	-
CAPEX/plant[8]	$375 /$m^3$	2.92 M$/MMBtu /h (0.85 M$/MW)	0.6 M$/MMBtu/h (0.175 M$/MW)	$200 /m3	4.75 M$/MMBtu /h (1.39 M$/MW)	$1,000,000	1.79 M$/MMBtu/h (0.52 M$/MW)[9]	$200 /$m^3$
OPEX		0,5% of CAPEX	0,05% of CAPEX	-	0,5% of CAPEX	0,1% of CAPEX	0,1% of CAPEX	-

Flat plate solar thermal is based on irradiance model for the area of St Paul and Ramboll's general experience.

Short-term thermal storages are sized to optimize solar fraction in the system and to allow for economic optimization according to the day-ahead electricity market. Nighttime electricity tariff (between 9 pm and 9 am) is approximately 50% of day time tariff making it favorable to operate heat pumps/chillers in the evening/night.

Energy production will be on a modulated approach with smaller units added on as the site is built out to delay CAPEX.

cooling and heating substation will be placed in each building. The CAPEX and OPEX are presented in Table 17.

Table 17 CAPEX and OPEX of District energy substations

Plant type	DH unit	DC unit
CAPEX/plant[10]	$0.76 /MMBtu/h ($224 /kW)	$0.76 /MMBtu/h ($224 /kW)
OPEX[11]	$134 /unit/year	$134 /unit/year

Installed district energy pipe prices are approximate for green field conditions as presented in Table 18.

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[8] TAG committee comments, 8th of May 2015

[9] Ramboll District Cooling feasibility studies

[10] Danish Energy Agency, Technology Data for Energy Plants, Individual Heating Plants and Energy, October 2013

[11] Danish Energy Agency, Technology Data for Energy Plants, Individual Heating Plants and Energy, October 2013

Table 18 Prices pipes installed

Pipes	DN (mm)	32	40	50	65	80	100	125	150	200	250	300
Heating/ Cooling	$/ft	350	375	425	500	525	550	575	600	730	920	1130
Heat loss	w/m	17.74	21.15	23.48	26.44	27.98	29.18	28.52	37.95	44.47		
Cooling loss	w/m				2.14	2.27	2.37	2.68	3.08	3.61	3.53	4.02

Above prices assume separate installation of heating and cooling pipes which increases the prices by $100/ft each. Simultaneous installation is assumed for the financial analysis.

It is estimated that coordination of installation with other infrastructure and utilities will save another 30% in installation cost. This is not assumed for the analysis, but investigated through a separate sensitivity analysis.

Operation and maintenance costs for the district energy networks including administration are presented in Table 19.

Table 19 overheads for the district energy network

Overhead	%
O&M	0.5
Power demand for network as pct. of heating and cooling demand	1.0

5.4 Concept 2: Individual Financial assumptions

The financial assumptions regarding concept 2 are presented in Table 20.

Table 20 Concept 2 Specifications

Individual Concept	Heating		Cooling	Electricity
Plant type	Heat Pump Individual or Common	Oil-fired boiler (as back-up)	Chiller Individual or Common	Solar PV + Grid
Plant size, MW	Depending on Building type and size		Depending on Building type and size	Depending on roof space
Plant efficiency, %	500%	95%	400%	-
Operating hours	1800		1200	1300[12]
CAPEX/plant, Installed effect	$2.73 /MMBtu/h (800$/kW)	$9,400 /unit[13]	$6.8-13.6/MMBtu/h ($ 2,000-4,000/kW)[14]	$6 /MMBtu/h ($2,000 /kW[15])
Maintenance	$450/unit/yr	$390 /unit/year[16]	$300/unit/yr	-

To the heat pump, CAPEX a cost of $150,000[17] per building is added to cover the expenses for ground source heating for the heat pump.

[12] Assuming a little less than the maximum production (1400) mentioned in the EPA report.
[13] Danish Energy Agency, Technology Data for Energy Plants, Individual Heating Plants and Energy, October 2013
[14] Depending on size, Ramboll District Cooling feasibility studies
[15] Assuming the average cost projections for 2019, p. 23 of the EPA report.
[16] Danish Energy Agency, Technology Data for Energy Plants, Individual Heating Plants and Energy, October 2013
[17] Based on Ramboll experience from similar project

5.5 Operational costs and tariffs

Several additional components are needed to complete price assumptions of the analysis.

5.6 Energy prices

The following energy prices are assumed for natural gas prices, for energy plants in DH Concept and for end users in BAU Concept. Three different price levels dependent on customer type are assumed (DH company, commercial/retail, residential). The price is for the base year (2016), and is adjusted annually by the chosen rate of inflation.

Flat rate prices are assumed for all utilities except electricity for the district energy company.

Table 21 Energy Prices ($/MWh)[18]

	Residential	Commercial/Retail	Industrial	District energy utility
Natural gas	23.5	21.5	16.5	16.5
Electricity	127	120	92	-
Oil	31	31	31	-

Commercial/retail prices are applied for electricity used for chillers, and heat pumps in concept 1 DHC.

The oil for the oil-burner peak load will be available for both residential and commercial at the same price, as a larger block central oil boiler is assumed rather than smaller individual oil boilers.

All energy prices presented in Table 21 have a price increase of 2.75% per year, corresponding to assumed inflation.

5.7 Electricity for the district energy utility

Basically, two demand charges appear, one for peak hours (9 a.m.-9 p.m. on weekdays) and one for off-peak hours.

The rates assumed are based on information from Xcel Energy and are as follows:

Rate,	Peak	Off-peak
$/MWh	76.31 (78.6)	40.94 (42.17)[19]

The share between Peak and Off-Peak hours are assumed at:
Peak: 35%
Off-peak: 65%
A 3.0% price increase per year.

Fixed charges are anticipated at about $14.39/MW/month and $10.28/MW/month for summer and winter periods respectively.

[18] Xcel Energy, John Marshall, May 7th 2015 by email

[19] Including 3,0% add on of May 2015 class rate increase

6. RESULTS

6.1 Concept 0, Business as Usual

The Business As Usual Concept is used as a reference Concept for comparison between the three Concepts. The assumptions regarding the BAU Concept are described in section 4.1.

In order to compare the BAU concept with the other two concepts, a weighted average price per MMBtu heating and cooling was calculated based on the total investment and all cost during the entire project lifetime. The share between heating and cooling are presented in Figure 7.

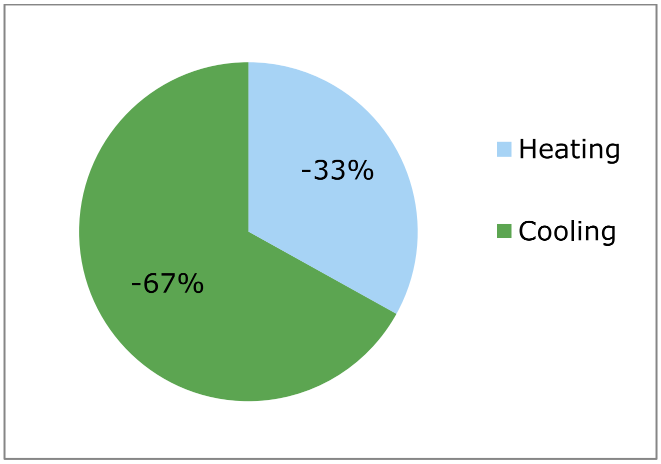

Figure 7 the share of costs and investment between heating and cooling in Concept 0

The reason that cooling is a larger share than heating is due to the high investment cost in chillers compared to the investment cost for gas boilers. The different costs and investment included when calculating the heating and cooling prices are as following:

- Gas for boilers
- Service and maintenance
- Electricity for chillers
- Network investment
- Gas boiler investment
- Chiller investment

The heating and cooling costs per MMBtu are presented in Table 22. The calculated costs of energy per MMBtu cooling and heating are the weighted costs the consumers will pay in order to be supplied with both heating and cooling seen over a lifespan of 25 years.

Table 22 energy cost per MMBtu (MWh) heating and cooling in BAU Concept

Energy	Cost per energy unit
Heating	$184/MMBtu ($54/MWh)
Cooling	$647/MMBtu ($190/MWh)

With the calculated reference heating and cooling price, the results of the BAU Concept are as presented in Figure 8. Given the calculated average price of heating and cooling, the

BAU concept will, as expected, result in a Net Present Value (NPV) of $0 (accumulated discounted cash flow) and an Internal Rate of Return at 7.3%.

An overview of revenues, costs, investments, and the accumulated discounted cash flow is presented in in figure 8.

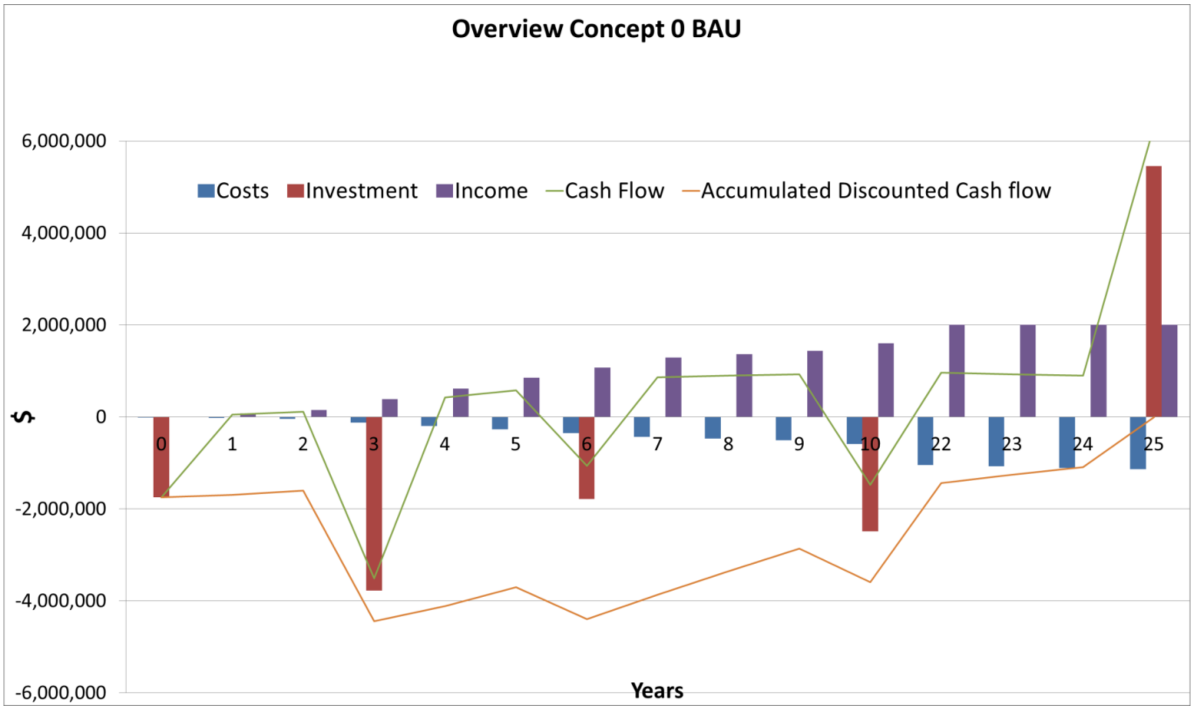

Figure 8 Overview concept 0 BAU

Depending on how well the individual system is looked after, reinvestment will need to be made in new boilers and/or chillers. A technical lifetime of 20 years has been assumed and as such there will be a scrap value at the end of the 25 year financial assessment.

The detailed cash flow is added in Appendix 8.2. From the cash flow it is evident that the largest costs are the investment in chillers, and the energy cost of gas of $6.5M and $3M respectively as net present value.

The net present value of the total investment for concept 0 BAU is $7.8M when scrap value is taken into account.

6.2 Concept 1, District Heating and Cooling

Previously mentioned, the heating and cooling $/MMBtu from Concept 0 BAU will be applied 1:1 as the actual heating and cooling price in the District Energy Concept.

By adding an income responding to the cost of energy per MMBtu (MWh) in the reference BAU Concept, a comparison between the two can be executed.

The overall results are presented in Table 23, with the net present value (NPV) and Internal Rate of Return (IRR).

Table 23 the result of concept 1

	NPV	IRR
Concept 1, DHC	$-12,3M	1.3%
Total investment	$ 23M	-

As the table indicate Concept 1 has an overall negative result of $-12.2M, which is largely caused by the investments of $23M, which also is presented in Table 23, while the shares of investments are illustrated in Figure 9. The figures are based on the assumption that district energy prices correspond to the calculated prices in the BAU scenario. Often it is a requirement that choosing a renewable energy based system should benefit its consumers with lower energy prices. If, for instance, the requirement is that the consumers should have a reduction on the energy price of 10%, then the NPV will further be reduced to approximately $-13.5M and the IRR will decrease to approximately 0.55 %.

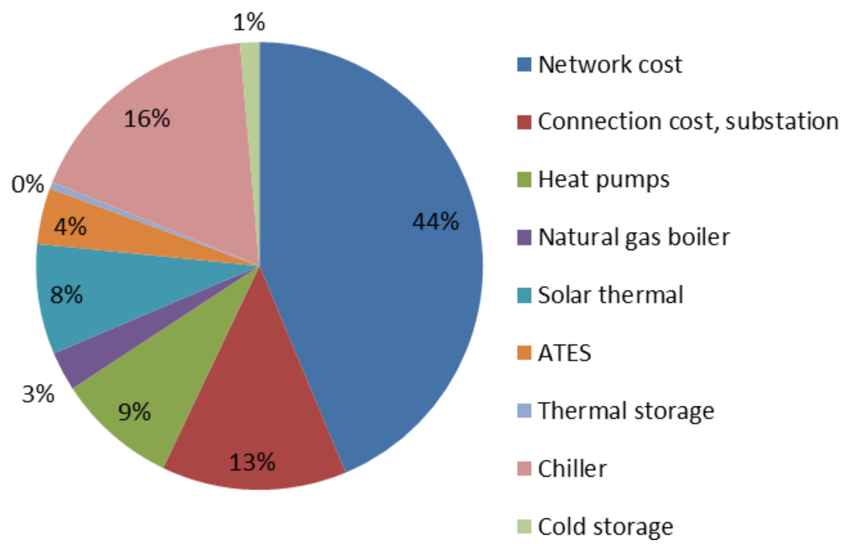

Figure 9 The share of investment for concept 1

The main contributor to the overall total investment is the network, comprising both the heating and cooling network. While the chillers and substations accounts for 16% and 13%, respectively.

The cash flow is included in Appendix 8.3.

As the cash indicates, the service and maintenance costs of all production units are rather low compared to the electricity costs of $0.8M.

The overview of concept 1 is illustrated in Figure 10.

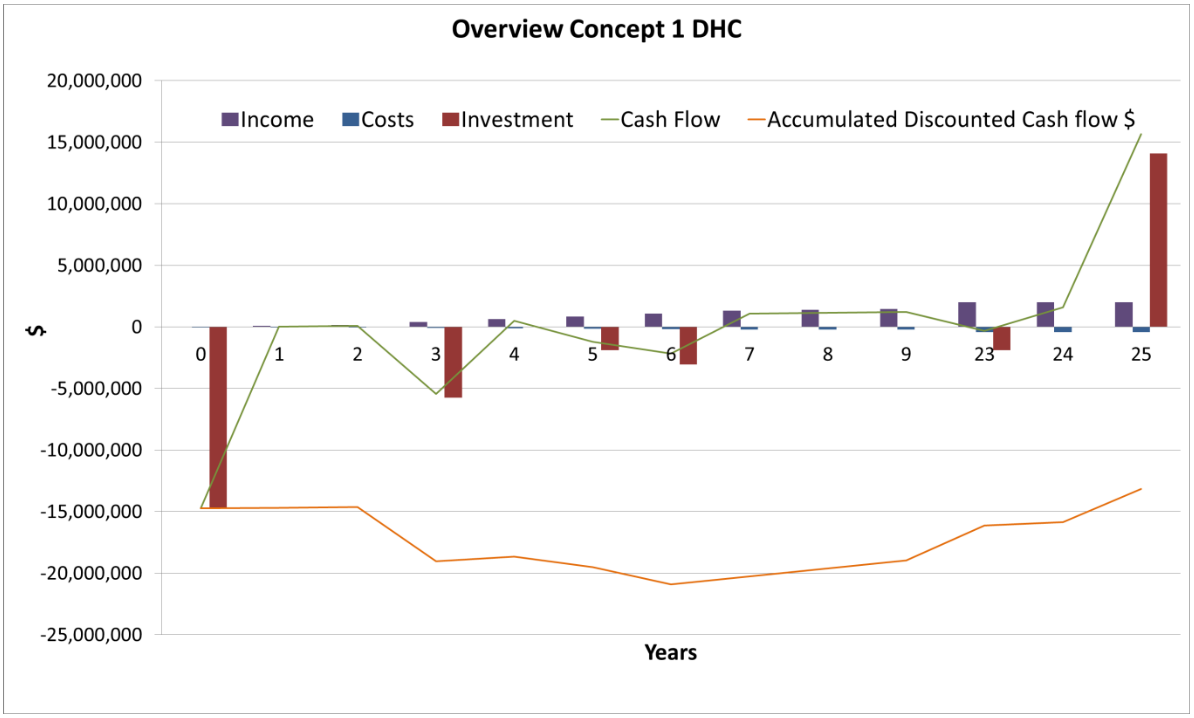

Figure 10 Overview of concept 1 DHC

As the figure indicates, the concept is slowly moving to a break even, with only a slightly higher annual income than costs, however it is not possible within the project evaluation time due to the value of the investments. Fortunately, the project lifetime is longer than the evaluation period. The high positive value at the end of the evaluation period is the remaining value of the investments incurred in the period.

6.3 Sensitivity analysis Concept 1 – District Heating and Cooling

A sensitivity analysis was carried out for concept 1, in order to analyze the different parameters and their influence on the final results. Table 24 presents the chosen factors and their corresponding interval. The intervals indicate how the parameters will be changed to see the effect on the result.

Table 24 Parameters used in sensitivity analysis

Name	Start	High / low
Discount rate (WACC)	7,3%	10,0% / 3,0 %
Network investment	100%	±30 %
Substation costs	100%	±50 %
District Energy price	100%	±20 %
Residential, EqFLH	1200	±30%
Electricity on/off peak	70,0%	100%
Heat pump investment	100%	±20 %
Gas boiler investment	100%	±20 %
Chiller investment	100%	±20 %
Solar thermal investment	100%	±20 %
ATES investment	100%	±20 %
Electricity price increase	3,0 %	3,0 % / 0 %
Internal rate of return	7.3%	7.3% / 3,0 %

The results of the sensitivity analysis are presented in Figure 11. The parameters are examined one at a time, to see their individual effect on the result.

The figure should be read as follows: The overall NPV of concept 1 is represented by the reference line in the figure. The high and the low columns indicate the NPV if the given parameter was changed to the higher or lower value, as presented in Table 24. As an example, the NPV is around $ -12.3M now. If the network investment (initially around $4M) is increased with 30% the NPV would be around $-13M, and if the investment was decreased with 30% the NPV would be approx. $-11M.

The parameter with the largest sensitivity is the energy price, accounting for both the cooling and heating. If the heating and cooling prices are 20% higher than the current reference price, the concept will have an overall result of around $-9.6M.

As mentioned in the section about the network cost, we have included a sensitivity in which we vary the costs ± 30%. The influence on the net present value from changing the value of various parameters in the concept can be seen in the following figure.

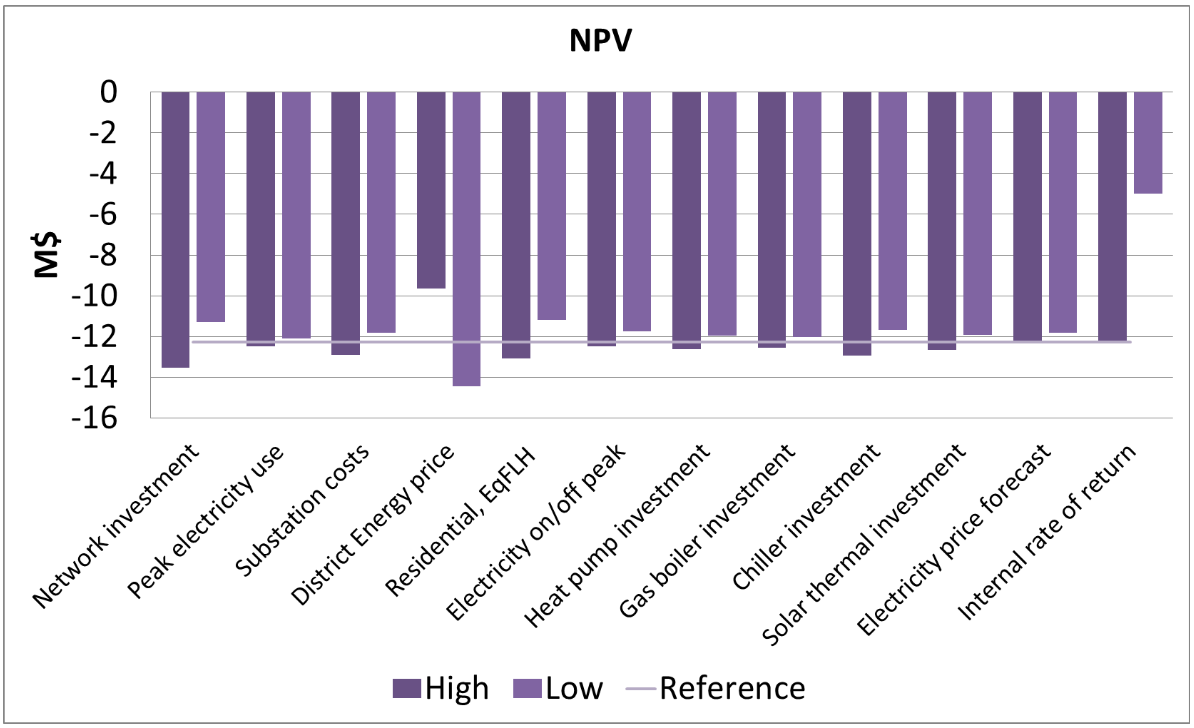

Figure 11 Results of sensitivity analysis of concept 1

The network investment cost and district energy price have a rather high impact on the result, as expected and outlined above.

The equivalent full load hours for residential buildings will also have a rather high impact on the viability of the concept - 1,200 hours are expected as the base and the sensitivity is calculated for 900 and 1550 hours respectively. The result varies between approximately -$11.1M and -$13.2M

The assumed investment for the different energy technologies has a relatively low impact on the result of the concept although varied ±20%.

6.4 Concept 2, Individual Renewables

The reference heating and cooling price from concept 0 is again used as the price the costumers will pay. However, since the Ford site will be developed from the ground, a price index of 1:1 is assumed. The overall results are presented in Table 25.

Table 25 result of concept 2

	NPV	IRR
Concept 2, IND	$-10.3 M	1.1%
Total investment	$21.6M	-

Concept 2 has a negative net present value of -$10.3M compared to concept 0 BAU. The main reason for that is the larger capital investment cost in concept 2.

The cash flow is added in Appendix 8.4.

As the cash flow indicates, the overall significant cost in the Individual concept is the investment in chillers with $12M.

Even though this analysis assumes that each building will have solar PV panels, some buildings are not able to produce enough energy to cover the electricity demand from the heat pump and chillers in the buildings. Hence, some electricity must be bought from the grid. As for the gas infrastructure the investment in an electric grid could be considered an expensive investment, but it is thought that it will be utilized more than the gas network would.

The shares of the investments are presented in Figure 12.

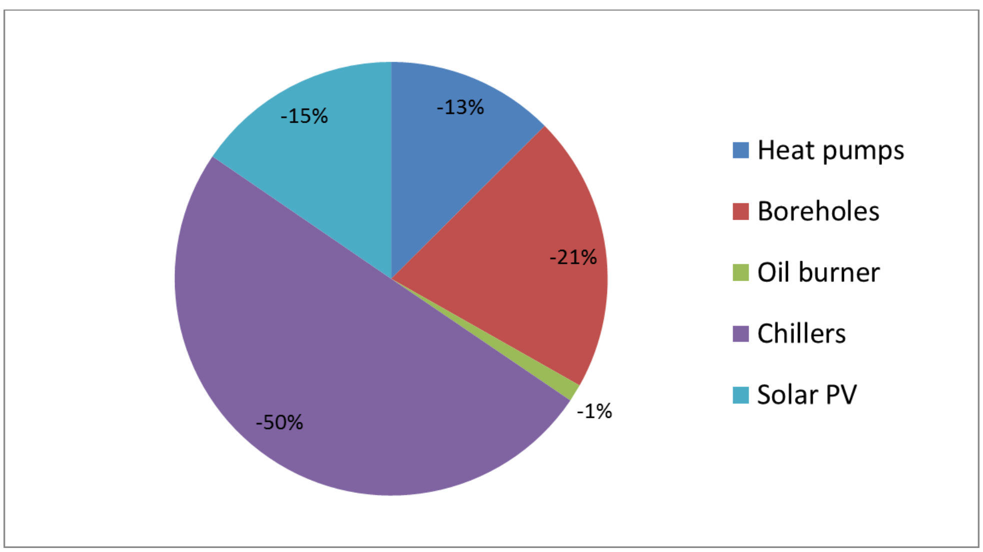

Figure 12 share of investment for concept 2

The main investment is the chillers, at approximately 50% of the total investment.

The overview of concept 2 is illustrated in Figure 13.

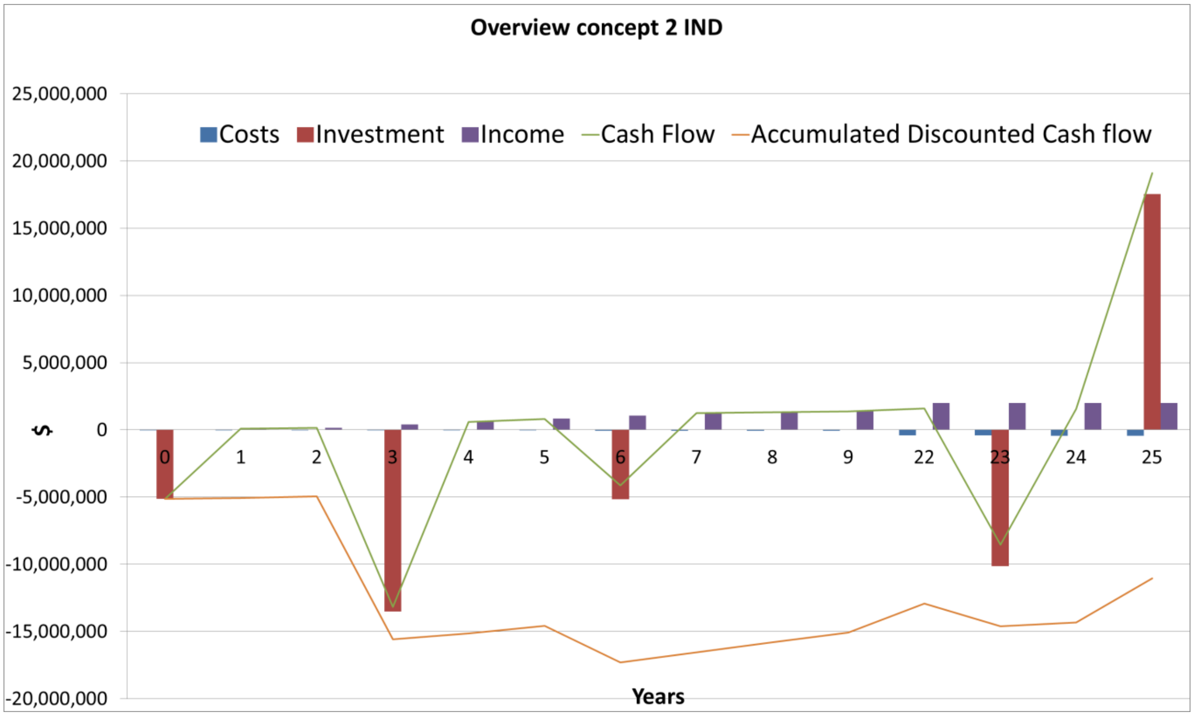

Figure 13 Overview Concept 2 Individual renewable energy supply

The figure indicates, that Concept 2 not viable within the lifetime of the project. However, as for the DHC option the concept is slowly moving to a break even.

6.5 Sensitivity analysis Concept 2 – Individual

The sensitivity analysis was also carried out for Concept 2. The chosen parameters are presented in Table 26 below.

Table 26 Parameters used in sensitivity analysis

Name	Start	High / low
Residential, EqFLH	1200	±30 %
Heat pump investment costs	100%	±20 %
Service heat pump	100%	±20 %
PV panel investment costs	100%	±20 %
Chiller investment costs	10%	±20 %
Service chillers	100%	±20 %
Electricity price forecast	100%	±2 % pa.
Internal rate of return	7.3%	7.3%

Figure 14 below illustrates the results of the sensitivity analysis. As expected, the viability of Concept 2 is rather sensitive to changes in the investment cost of the chillers. Other relevant parameters are the investment cost of the PV panels and heat pumps, whereas, the service and maintenance cost for the heat pump and chiller does not have significant influence.

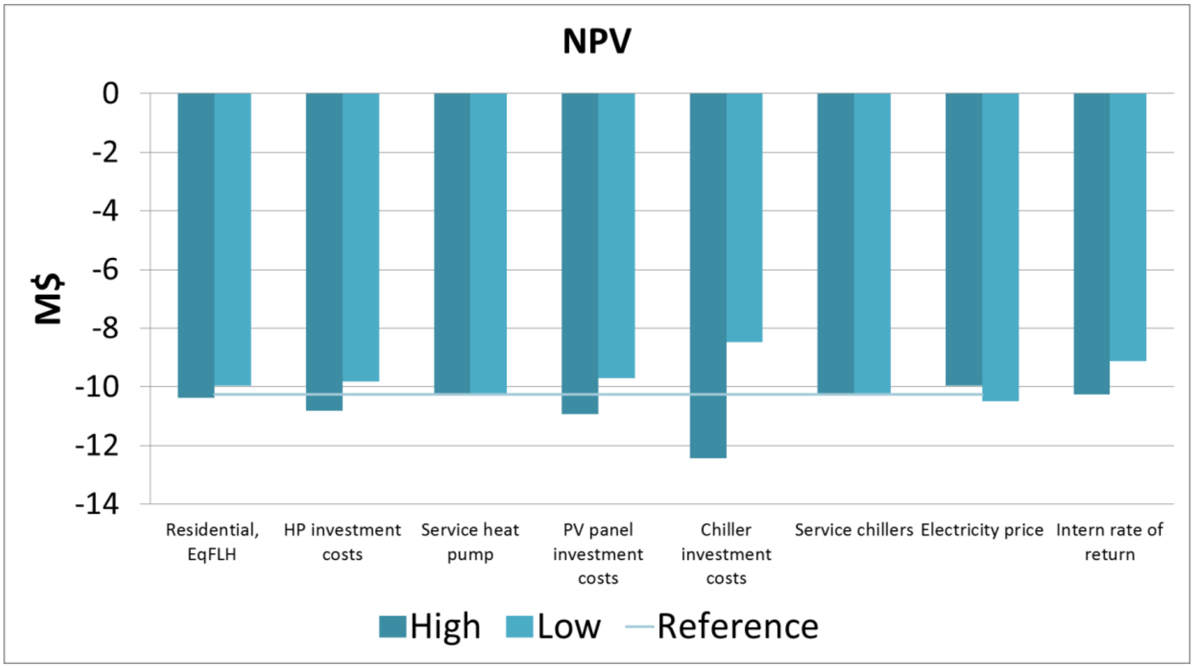

Figure 14 Results of sensitivity analysis

The amount of electricity produced from the PV panel was not included in the sensitivity analysis, however it is expected to have a significant influence on the viability of the concept, hence more electricity must be purchased from the grid and the cost will increase.

6.6 CO_2 calculations

The CO_2 accounts for each concept are calculated and presented in Figure 15. The kg CO_2 equivalents used for the calculations are included in Table 27. The Electricity provided from the grid has the highest contents of CO_2, while the content of natural gas is somewhat smaller than the oil.

Table 27 CO_2 equivalents for electricity, oil and gas

Natural gas[20]	450	lbs CO_2 eq./MWh	204	kg CO_2 eq./MWh
Electricity, Grid[21]	1,054	lbs CO_2 eq./MWh	586	kg CO_2 eq./MWh
Oil[22]	620	lbs CO_2 eq./MWh	281	kg CO_2 eq./MWh

It is evident from the results of the calculations that the BAU concept has the highest CO_2 emission during the project evaluation period. Emissions in the concepts DHC and IND are very close. with no clear conclusion about which is the lowest emission.

If taking a cost of CO_2 emission per kg into consideration in this project, it will influence the overall results of each concept.

[20] www.Energinet.dk – Danish Energy Angency, http://www.energinet.dk/DA/KLIMA-OG-MILJOE/Energi-og-klima/Naturgas-og-klimaet/Sider/default.aspx
[21] Xcel Energy, 2014 Carbon Dioxide (CO_2) from Xcel Corporate Responsibility Report, Upper Midwest. Reduced gradually to 720 lbs/MWh in 2030.
[22] www.Energinet.dk – Danish Energy Angency, http://www.energinet.dk/DA/KLIMA-OG-MILJOE/Energi-og-klima/Naturgas-og-klimaet/Sider/default.aspx

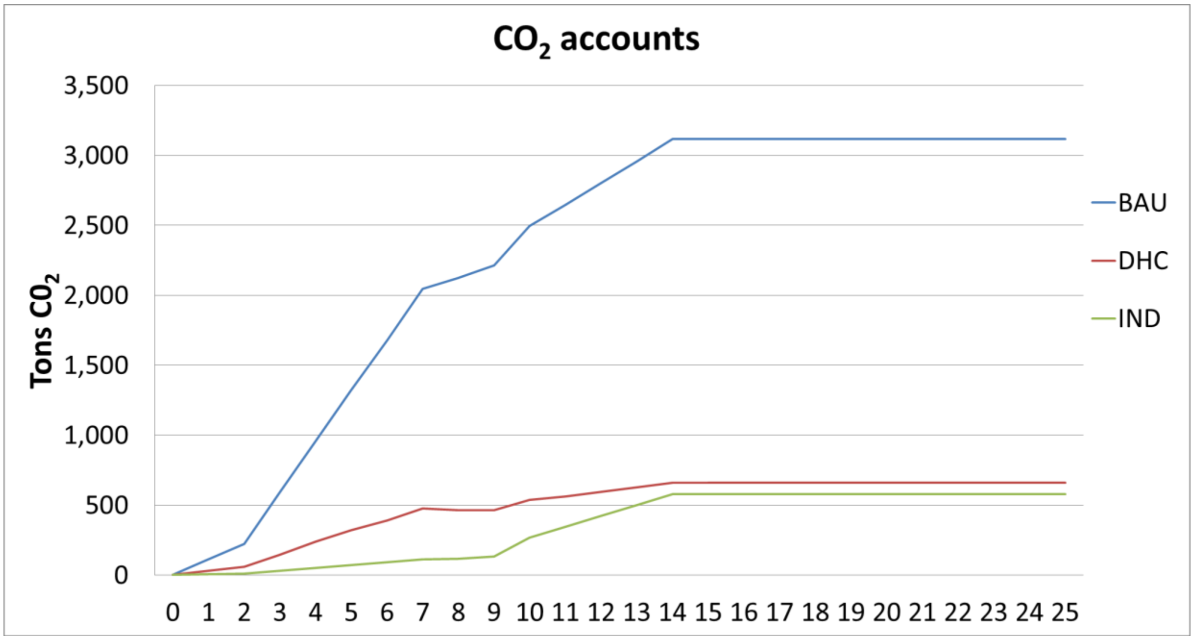

Figure 15 CO_2 accounts for all three concepts

6.7 Share of renewables

The share of renewables in each concept is calculated based on the demand for heating and cooling for all buildings.

With regard to electricity from the grid, the production composition is presented in Figure 16. The CO_2 neutral electricity is equal to 34%. Energy supplied from gas and oil is assumed to be 0% renewable. Electricity from the local PV panels is assumed to be 100% renewable, as accounts for the heat produced from the solar thermal plant.

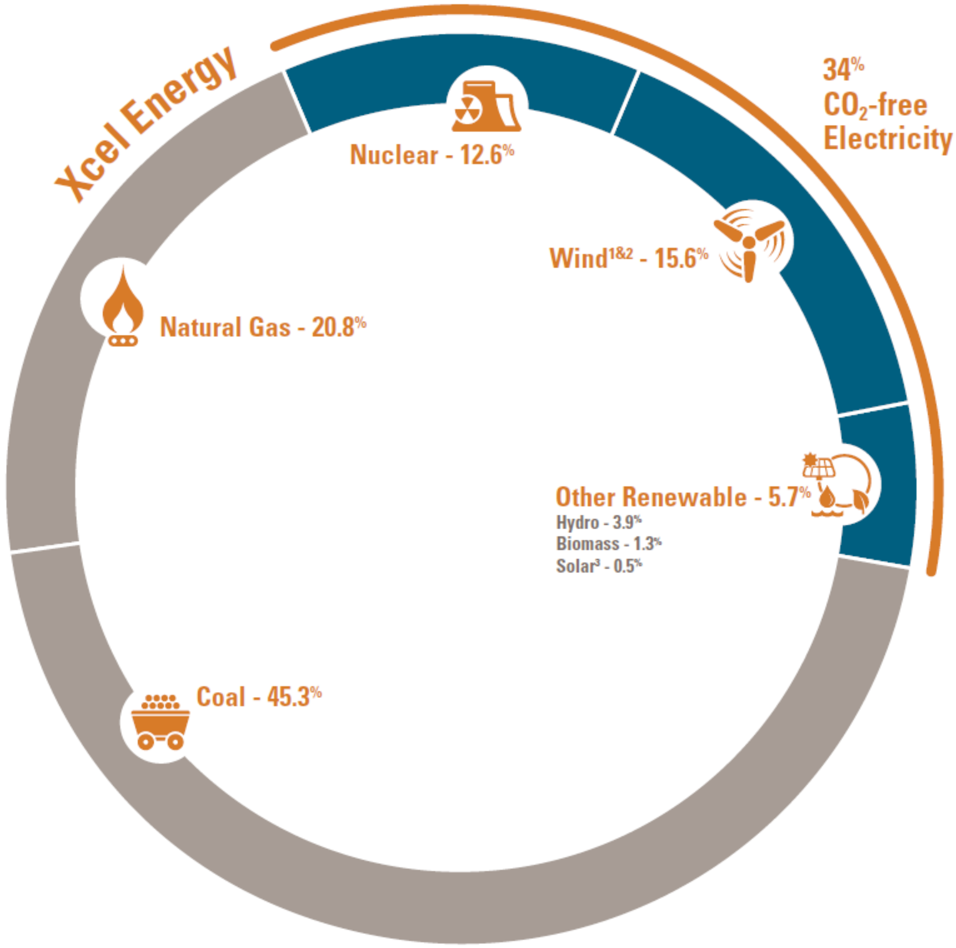

Figure 16[23] Share of renewables in electricity from the grid

With the mentioned assumptions, the share of renewables for each concept can be calculated. This is done by using the energy demand, the Coefficient of Performance (COP) of both heat pumps and chillers, and efficiency of gas boilers and oil-burners. The numbers are presented in Table 28.

Table 28 share of renewables for each concept

Concept	Share of renewable
BAU	27%
DHC	90%
IND	84%

The calculation is carried out for 2014. Gradually, as the percentage of renewable energy in the overall electricity supply increases, the total share of renewable energy will increase for concept BAU as well as for IND.

The share of renewables is highest for concept 1 DHC with 90%. This is due to the use of solar energy for heating and high COP for both the heat pumps and the chillers, hence when 1 unit of energy is used in the heat pump 5 units are produced.

[23] Xcel Energy, 2014 Carbon Dioxide (CO_2) Reporting Worksheet. The figures are presumable based on average content of renewable energy but the electricity consumption in the DHC scenario is predominantly used in off peak hours in which the share is expected to be higher

Concept 2 IND also has a rather high share of renewables, 84%, due to the use of PV panels for electricity production, a COP of 5 for the heat pump and the use of free cooling.

With regards to the share of renewable in energy production, concept 1 DHC clearly provides the best result.

6.8 Potential Renewable Energy Certificate sales[24]

Although sales of Renewable Energy Certificates were not included in the economic analysis, there is great potential to offset costs in the DHC and IND concepts through the sale of Renewable Energy Certificates (RECs).

These credits are equivalent to 1 MWh of renewable energy. The sale of RECs in both compliance and voluntary markets for the state is done through the Midwest Renewable Energy Certification System (M-RETS). Minnesota has adopted one of the highest standards in increasing renewable energy through a Renewable Portfolio Standard (RPS), 25% by 2020. Xcel Energy, Minnesota's largest utility company and the energy and gas supplier for St. Paul, is required to source 30% of energy from renewables by 2020. Furthermore, the voluntary REC market is expanding with customer purchases of "green energy" and Minnesota is one of the top states in terms of sales (Heeter 2010). Thus, there is a huge potential for future demand for RECs in both compliance and voluntary markets. Including the sale of RECs in future analyses could alter results of the feasibility study.

7. SUMMARY, COMPARISON AND FURTHER RECOMMENDATIONS

The main goal of activity 1.7 was to outline the concept design for three technical solutions and to compare their financial viability. With a reference energy price for the customers, a comparison between the three concepts was carried out.

Both Concept 1 DHC and Concept 2 IND require significant capital investments. Renewable energy solutions, whether through a DHC concept or an Individual concept, are often thought to be a good, short-term investment and business opportunity, but they are very rarely that. Renewable energy solutions area long-term investment with long paybacks, generally implemented for the good of the community and/or the environment and not to make a profit.

Someone has to pay for the additional cost compared to conventional individual heating. As the results section presents, Concept 1 DHC has a net present value of -$12.3M and Concept 2 IND -$10.3M. Both results are based on the reference heating and cooling price from concept 0. However, both results have a positive internal rate of return.

Many parameters and assumptions will influence the result. Furthermore, commitment to renewable energy solutions should be considered. The most sensitive assumptions included in the analysis are the district energy prices (based on the BAU concept) and the network investment cost for Concept 1 DHC. For Concept 2 IND, the most sensitive assumptions are the investment costs of chillers and solar PV panels.

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[24] Status and Trends in U.S. Compliance and Voluntary Renewable Energy Certificate Markets (2010 Data), Jenny Heeter and Lori Bord, National Renewable Energy Laboratory, October 2011

Investments in energy producing units are the most significant parameters influencing the result for Concepts 1 DHC and 2 IND. For Concept 1, the network costs are the largest investment with around $10M, based on the pipe price assumptions. Several things should be kept in mind when designing the network such as choice of pipe material (plastic or pre-insulated steel pipes), and dimensions with regards to pressure drops and spare capacity. With that in mind, it could be possible to accomplish a reduction of CAPEX for Concept 1.

It is also important to mention the reference prices for heating and cooling. Currently they are used 1:1 in Concepts 1 and 2. Normally when an energy source is changed for a specific area, it is expected that the customers need an incentive to change from one source to another (e.g. from gas to district heating). Usually the incentive is a reduction in energy costs.

In the calculation, it is assumed that all investments (excluding piping) have a lifetime of 20 years. For piping, a lifetime of 40 years is expected. By the end of the evaluation period, the remaining value of all investments based on linear depreciation (scrap value) is accounted for.

As mentioned earlier, the potential of selling of renewable energy certificates can affect the price of energy considerably.

A value of some kind could be added, corresponding to the share of renewables, as credit to Concept 1 and 2 for their share of renewables and low CO_2 emissions.

Use of subsidies tariff and similar are not included the project since they are not constant and will change over time due to political decisions. Ramboll feels that all fiscal support is an additional uncertainty/risk added to a project if the viability and decision to proceed is directly or indirectly dependent on such measures. However, potential subsidies, grants or similar tools could be included when deciding which concept(s) to include in further investigations.

7.1 Comparison against Objectives

Comparing the three concepts against the objectives set for the site is likely to vary depending on whose view the evaluation is based on. Is it the end building owner/tenant, the City, a utility, or developer? A clear decision on this has not been given by the City or the Ford Energy Study Technical Advisory Group. Trying to perform an evaluation based on a purely technical view could look as follows:

<u>Cost effectiveness:</u> The technologies should be evaluated primarily on the expected levelized cost of energy (LCOE) over the technical lifetime. As such, Concept 1 DHC seems to have advantages over the BAU and IND concepts, although based on the selected assumptions; However the BAU is in simple terms the most cost effective but is only used as a reference scenarios as it does not offer the best solution overall.

<u>Energy efficiency:</u> Energy efficiency is evaluated on the conversion efficiencies and energy losses for the technologies. Solutions built around larger scale, such as the DHC concept, offer higher energy efficiency than the BAU and IND concepts.

<u>Net Zero:</u> Net Zero concerns the CO_2 emissions and primary energy use of the technology. With the selected assumptions, the DHC or IND concepts are very close and outperform the BAU concept.

Resilience: Resilience is understood as the security for energy supply that the technology delivers, in particular in the case of power grid failures or failing fuel supply. The local, large scale DHC concept is valued highest as there is redundancy and back up in the system. Storages will furthermore reduce the risks of being without heating and/or cooling. Resiliency also relates to equipment reliability - maintenance and operations, the need for equipment reinvestment equipment will come sooner in the individual solutions than for district energy.

Legacy/Innovation: Both the DHC and IND concepts offer some innovation relative to energy solutions typically seen in U.S. cities. The ATES solution in particular would be of great interest to many and be seen as an innovative approach.

Using the same scoring from 1 to 5 as used in the original technology screening (1 being the lowest) the overall assessment of the scenarios against the objectives can be summarized as outlined below:

OVERALL ASSESSMENT AGAINST OBJECTIVES

Scenario	(net zero) CO_2	Resilience	Legacy / Innovation	Energy Efficiency	Cost effective	Total Score
0. BAU	3	3	1	3	3	13
1. DHC	5	4	5	5	3	22
2. IND	4	3	3	4	3	17

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7.2 Recommendations

To reach a decision on the energy concept for the Ford Site, a clearer direction on delivery and objectives is needed.

The economic analysis is particularly sensitive to:

- Prices – capital and operational
- Assumptions on annual demand
- Design consideration and the associated capital investment for both the DHC and the IND related equipment

This study identifies the performance and potential price of three energy system concepts based on various assumptions and objectives. A conclusion on the preferred concept is dependent on a couple of key decisions:

- The priority and weighting of the energy system objectives.

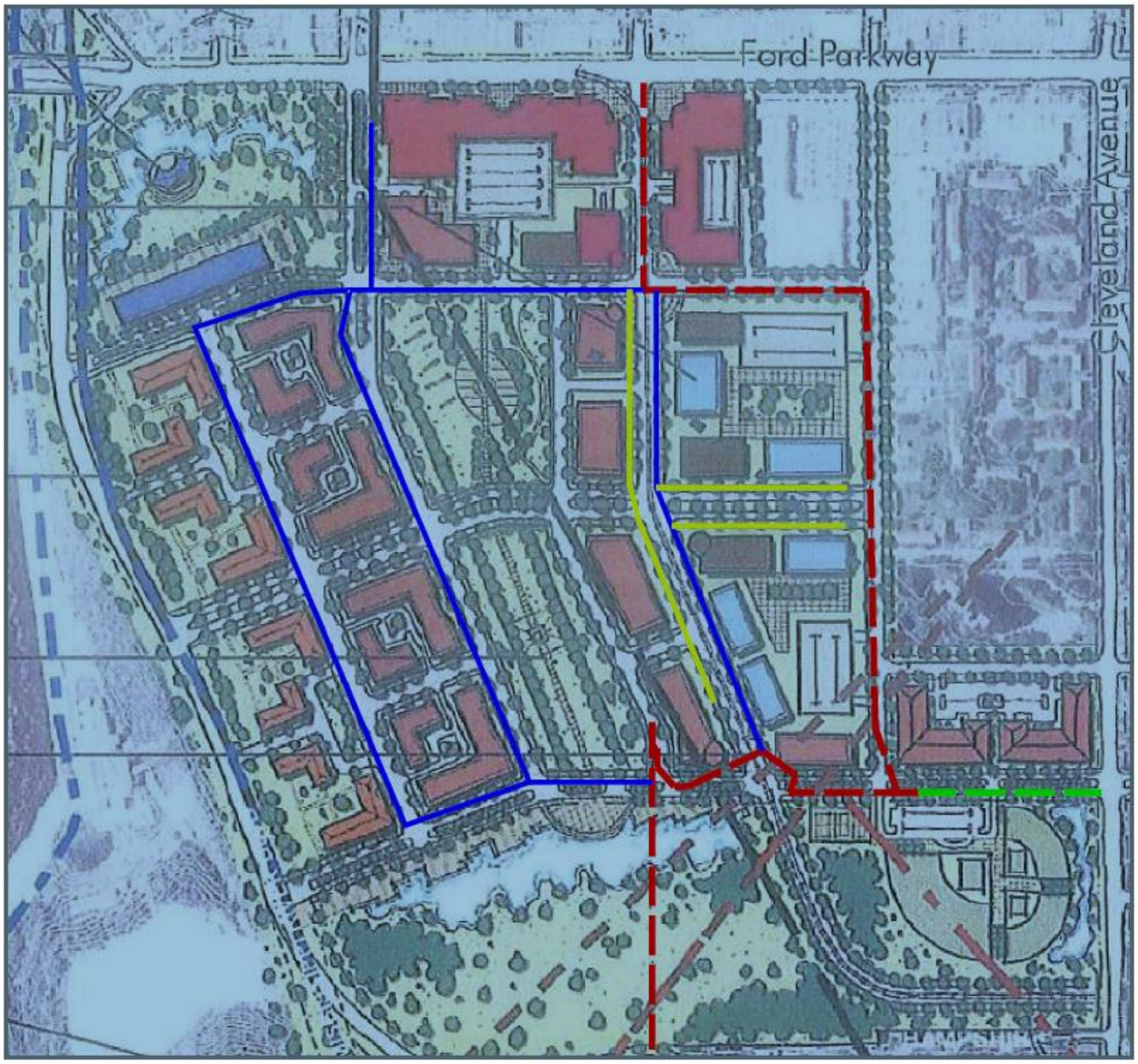
- Who will deliver the energy services on the site, - Xcel Energy; District Energy St Paul; a site developer; or some combination of parties.

Other important parameters that Ramboll suggests further investigation of are:

1. Identify delivery vehicle for the energy on site.
2. ATES is included in Concept 1. There are however many parameters which should be thoroughly examined to achieve a higher probability that ATES is actually possible and viable. Very important are the local hydrogeological conditions. The certainty can be achieved within a few weeks desktop study. This is highly recommended.
3. Investments in piping network – more detailed work will be required to further develop the network design and assess investments costs and opportunities for lowering capital costs.
4. Possible selling of renewable energy credits or other grants
5. Getting closer to the actual investments in small and large scale chillers

8. APPENDIX

8.1 Gas network



Existing 12" Main
Existing 16" Main
Proposed 4" Main
Proposed 2" Main

Proposed 4" Main Footage: 6500'
Proposed 2" Main Footage: 2500'

8.2 Concept 0 – BAU

			Sequence	0	1	2	3	4	5	6	7	8	9	10	22	23	24	25
	unit	Base	Year	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2041	2042	2043	2044
		2.75%	price index	1.00	1.03	1.06	1.08	1.11	1.15	1.18	1.21	1.24	1.28	1.31	1.82	1.87	1.92	1.97
		NPV																
Heat demand		80,050		-	401	803	2,219	3,635	5,051	6,506	7,961	8,400	8,840	9,909	12,427	12,427	12,427	12,427
Cooling demand		46,117		-	299	598	1,417	2,236	3,055	3,821	4,586	4,831	5,075	5,662	7,031	7,031	7,031	7,031
Electricity demand		84,111		-	467	934	2,424	3,914	5,405	6,884	8,364	8,821	9,277	10,381	12,972	12,972	12,972	12,972
Energy total		210,277		-	1,167	2,334	6,060	9,786	13,511	17,211	20,911	22,052	23,193	25,953	32,429	32,429	32,429	32,429
Cashflow BAU																		
Income			**NPV**															
Heating	$		4,316,974	-	21,647	43,294	119,667	196,039	272,412	350,856	429,301	453,020	476,739	534,397	670,150	670,150	670,150	670,150
Cooling	$		8,740,046	-	56,627	113,254	268,527	423,801	579,075	724,101	869,128	915,508	961,888	1,073,114	1,332,497	1,332,497	1,332,497	1,332,497
Sum	$		38,329,397	-	78,274	156,548	388,194	619,841	851,487	1,074,958	1,298,429	1,368,528	1,438,627	1,607,510	2,002,647	2,002,647	2,002,647	2,002,647
			Sequence	0	1	2	3	4	5	6	7	8	9	10	22	23	24	25
	unit	Base	Year	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2041	2042	2043	2044
		3%	price index	1.00	1.03	1.06	1.08	1.11	1.15	1.18	1.21	1.24	1.28	1.31	1.82	1.87	1.92	1.97
Costs			**NPV**															
Gas costs	$		-															
Retail/Mixed use			-282,119	-	-4,622	-9,520	-14,709	-20,200	-26,008	-26,788	-27,592	-28,420	-29,272	-30,151	-42,987	-44,277	-45,605	-46,974
Apartment/Condo-High Density			-575,422	-	-2,685	-5,531	-8,545	-11,736	-15,109	-23,256	-31,878	-40,996	-50,632	-66,384	-126,434	-130,227	-134,134	-138,158
Official/Institutional			-88,915	-	-	-	-	-	-	-1,355	-2,792	-4,313	-5,923	-9,316	-22,924	-23,612	-24,320	-25,050
Civic			-32,880	-	-	-	-656	-1,351	-2,087	-2,867	-3,691	-3,801	-3,915	-4,033	-5,750	-5,922	-6,100	-6,283
Apartment/Condo-Medium Density			-1,324,186	-	-2,600	-5,356	-22,282	-40,220	-59,214	-80,252	-102,499	-109,770	-117,385	-139,080	-276,554	-284,851	-293,397	-302,198
Apartment/Condo-Low Density			-651,594	-	-	-	-12,997	-26,774	-41,365	-56,808	-73,141	-75,335	-77,595	-79,923	-113,951	-117,369	-120,890	-124,517
O&M, fixed, heating, cooling	$		-278,669	-3,800	-3,905	-4,012	-15,404	-15,828	-16,263	-22,359	-22,973	-23,605	-24,254	-33,841	-46,862	-48,151	-49,475	-50,835
Electricity for chillers	$		-2,060,506	-	-9,233	-19,019	-46,448	-75,505	-106,264	-136,863	-169,203	-183,580	-198,666	-228,288	-404,157	-416,281	-428,770	-441,633
Administration etc.	$		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Sum	$		-5,294,291	-3,800	-23,043	-43,438	-121,041	-191,613	-266,310	-350,548	-433,769	-469,820	-507,643	-591,015	-1,039,619	-1,070,691	-1,102,691	-1,135,648
Total Investments		**Lifetime (yr)**	**NPV**															
Network cost	$		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Units costs, chillers		20	-7,611,493	-1,493,171	-	-	-3,141,827	-	-	-1,507,952	-	-	-	-2,096,469	-	-	-	-2,096,469
Unit costs, gas boiler,	$	20	-1,423,839	-249,763	-	-	-631,415	-	-	-273,669	-	-	-	-391,576	-	-	-	-391,576
Scrap value from "Scrap values final year"			1,272,603															-
Total investment	$		-7,762,730	-1,742,934	-	-	-3,773,242	-	-	-1,781,621	-	-	-	-2,488,045	-	-	-	-2,488,045
Scrap values final year																		
Chillers										-75,398				-524,117	-	-	-	-2,096,469
Gas boilers										-13,683				-97,894	-	-	-	-391,576
TOTAL Scrap value as NPV value			1,272,603	-	-	-	-	-	-	-	-	-	-	-	-	-	-	7,948,509
Simple Cash Flow and payback			**NPV**															
Income	$		13,057,021	-	78,274	156,548	388,194	619,841	851,487	1,074,958	1,298,429	1,368,528	1,438,627	1,607,510	2,002,647	2,002,647	2,002,647	2,002,647
Costs	$		-5,294,291	-3,800	-23,043	-43,438	-121,041	-191,613	-266,310	-350,548	-433,769	-469,820	-507,643	-591,015	-1,039,619	-1,070,691	-1,102,691	-1,135,648
Investment	$		-7,762,730	-1,742,934	-	-	-3,773,242	-	-	-1,781,621	-	-	-	-2,488,045	-	-	-	5,460,464
Cash Flow	$		-0	-1,746,734	55,231	113,110	-3,506,089	428,227	585,176	-1,057,212	864,660	898,708	930,984	-1,471,550	963,028	931,957	899,956	6,327,463
Accumulated Cash flow		**IRR**	**7.30%**	-1,746,734	-1,691,503	-1,578,393	-5,084,482	-4,656,255	-4,071,078	-5,128,290	-4,263,630	-3,364,921	-2,433,938	-3,905,487	1,790,165	2,722,122	3,622,078	9,949,541
Discounted Cash flow (NPV)	$	7.3%	**-0**	-1,746,734	51,473	98,243	-2,838,074	323,054	411,423	-692,729	528,017	511,471	493,793	-727,407	204,383	184,333	165,893	1,087,018
Accumulated Discounted Cash flow	$	7.3%		-1,746,734	-1,695,261	-1,597,018	-4,435,092	-4,112,038	-3,700,615	-4,393,345	-3,865,328	-3,353,857	-2,860,064	-3,587,472	-1,437,243	-1,252,911	-1,087,018	-0
Payback		Years	15	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1

8.3 Concept 1 - DHC

			Sequence	0	1	2	3	4	5	6	7	8	9	23	24	25
	unit	Base	Year	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2042	2043	2044
		2.75%	price index	1.00	1.03	1.06	1.08	1.11	1.15	1.18	1.21	1.24	1.28	1.87	1.92	1.97
Total heat demand					401	803	2,219	3,635	5,051	6,506	7,961	8,400	8,840	12,427	12,427	12,427
Income			**NPV**													
Heat Sales	$		4,328,973	-	29,270	43,402	119,829	196,255	272,682	351,180	429,678	453,452	477,225	671,390	671,444	671,498
Cooling sales	$		8,740,046	-	56,627	113,254	268,527	423,801	579,075	724,101	869,128	915,508	961,888	1,332,497	1,332,497	1,332,497
Sum	$		38,354,492	-	85,897	156,656	388,356	620,056	851,756	1,075,281	1,298,807	1,368,959	1,439,112	2,003,887	2,003,941	2,003,995
Costs			**NPV**													
Network oparation costs	$		-	-	-	-	-	-	-	-	-	-	-	-	-	-
Network, O&M incl. administration	$		-593,396	-31,576	-31,576	-31,576	-42,115	-42,115	-42,115	-52,716	-52,716	-52,716	-52,716	-66,794	-66,794	-66,794
Maintenance network	$		-	-	-	-	-	-	-	-	-	-	-	-	-	-
Fixed demand charge, power	$		-1,357	-0	-6	-11	-30	-49	-69	-91	-113	-122	-132	-270	-278	-285
O&M heat pumps	$		-160,676	-4,273	-4,391	-4,511	-9,271	-9,526	-14,681	-15,085	-15,500	-15,926	-16,364	-23,924	-24,582	-25,258
O&M natural gas boilers	$		-5,199	-350	-360	-370	-380	-390	-401	-412	-423	-435	-447	-653	-671	-690
O&M chillers	$		-322,732	-13,715	-14,092	-14,480	-20,553	-21,118	-27,691	-28,452	-29,235	-30,039	-30,865	-45,124	-46,365	-47,640
Service and maintenance thermal storage	$		-	-	-	-	-	-	-	-	-	-	-	-	-	-
Service and maintenance cold storage	$		-	-	-	-	-	-	-	-	-	-	-	-	-	-
Energy costs, electricity process	$		-1,359,805	-	-5,237	-10,788	-28,747	-47,773	-67,915	-89,048	-111,388	-120,984	-131,056	-277,092	-285,405	-293,967
Energy costs, gas for gas boiler	$		-2,797	-184	-189	-195	-201	-207	-213	-219	-226	-233	-240	-363	-373	-385
Reduction of building space	$		-	-	-	-	-	-	-	-	-	-	-	-	-	-
Sum	$		-2,445,962	-50,098	-55,850	-61,930	-101,295	-121,178	-153,085	-186,024	-209,601	-220,455	-231,820	-414,220	-424,468	-435,018
Total Investments			**NPV**													
Network cost	$		-10,067,473	-6,315,152	-	-	-2,107,768	-	-	-2,120,342	-	-	-	-	-	-
Connection cost, substation	$		-3,088,411	-639,095	-	-	-1,730,727	-	-	-938,798	-	-	-	-	-	-
Heat pumps	$		-2,490,144	-854,612	-	-	-854,612	-	-854,612	-	-	-	-	-854,612	-	-854,612
Natural gas boiler	$		-811,782	-700,000	-	-	-	-	-	-	-	-	-	-	-	-
Solar thermal	$		-2,283,138	-1,968,750	-	-	-	-	-	-	-	-	-	-	-	-
ATES	$		-1,159,689	-1,000,000	-	-	-	-	-	-	-	-	-	-	-	-
Thermal storage	$		-139,163	-120,000	-	-	-	-	-	-	-	-	-	-	-	-
Chiller	$		-5,016,368	-2,743,028	-	-	-1,046,308	-	-1,046,308	-	-	-	-	-1,046,308	-	-1,046,308
Cold storage	$		-400,093	-345,000	-	-	-	-	-	-	-	-	-	-	-	-
Scrap value from "Scrap values final year"			2,558,473													-
Total investment	$		-22,897,788	-14,685,638	-	-	-5,739,415	-	-1,900,920	-3,059,140	-	-	-	-1,900,920	-	-1,900,920
Scrap values final year		**Lifetime**														
Network cost		40		-2,368,182	-	-	-948,496	-	-	-1,113,180	-	-	-	-	-	-
Connection cost, substation		20								-46,940	-	-	-	-	-	-
Heat pumps		20								-	-	-	-	-769,151	-	-854,612
Natural gas boiler		20								-	-	-	-	-	-	-
Solar thermal		20								-	-	-	-	-	-	-
ATES		20								-	-	-	-	-	-	-
Thermal storage		20								-	-	-	-	-	-	-
Chiller		20								-	-	-	-	-941,677	-	-1,046,308
Cold storage		20								-	-	-	-	-	-	-
TOTAL Scrap value as NPV value			**2,558,473**	-	-	-	-	-	-	-	-	-	-	-	-	15,979,886
Simple Cash Flow and payback			**NPV**													
Income	$		13,069,019	-	85,897	156,656	388,356	620,056	851,756	1,075,281	1,298,807	1,368,959	1,439,112	2,003,887	2,003,941	2,003,995
Costs	$		-2,445,962	-50,098	-55,850	-61,930	-101,295	-121,178	-153,085	-186,024	-209,601	-220,455	-231,820	-414,220	-424,468	-435,018
Investment	$		-22,897,788	-14,685,638	-	-	-5,739,415	-	-1,900,920	-3,059,140	-	-	-	-1,900,920	-	14,078,965
Cash Flow	$		-12,274,730	-14,735,736	30,047	94,725	-5,452,355	498,879	-1,202,249	-2,169,883	1,089,206	1,148,504	1,207,292	-311,253	1,579,474	15,647,942
Accumulated Cash flow		**IRR**	**1.29%**	-14,735,736	-14,705,689	-14,610,963	-20,063,318	-19,564,439	-20,766,689	-22,936,571	-21,847,366	-20,698,862	-19,491,570	-11,102,515	-9,523,041	6,124,901
Discounted Cash flow (NPV)	$	7.3%	**-12,274,730**	-14,735,736	28,003	82,275	-4,413,518	376,353	-845,271	-1,421,798	665,138	653,634	640,346	-61,563	291,152	2,688,216
Accumulated Discounted Cash flow	$	7.3%		-14,735,736	-14,707,733	-14,625,458	-19,038,976	-18,662,623	-19,507,894	-20,929,692	-20,264,554	-19,610,920	-18,970,573	-16,150,153	-15,859,002	-13,170,786
Payback		Years	26	0	0	0	0	0	0	0	0	0	0	0	0	1

8.4 Concept 2 - IND

	unit	Base															
			Sequence	0	1	2	3	4	5	6	7	8	9	22	23	24	25
	unit	Base	Year	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2041	2042	2043	2044
		2.75%	price index	1.00	1.03	1.06	1.08	1.11	1.15	1.18	1.21	1.24	1.28	1.82	1.87	1.92	1.97
Income			**NPV**														
1 Heating	$		4,328,973	-	29,270	43,402	119,829	196,255	272,682	351,180	429,678	453,452	477,225	671,336	671,390	671,444	671,498
Cooling	$		8,740,046	-	56,627	113,254	268,527	423,801	579,075	724,101	869,128	915,508	961,888	1,332,497	1,332,497	1,332,497	1,332,497
Sum	$		13,069,019	-	85,897	156,656	388,356	620,056	851,756	1,075,281	1,298,807	1,368,959	1,439,112	2,003,833	2,003,887	2,003,941	2,003,995
Costs			**NPV**														
O&M Heat pump + oil burner	$		-363,073	-4,490	-4,613	-4,740	-21,431	-22,020	-22,626	-29,589	-30,402	-31,238	-32,097	-60,350	-62,010	-63,715	-65,467
O&M Chiller	$		-121,294	-1,500	-1,541	-1,584	-7,160	-7,357	-7,559	-9,885	-10,157	-10,436	-10,723	-20,162	-20,716	-21,286	-21,871
Net electricity	$		-950,689	-	-	-	-	-	-	-	-	-	-4,482	-283,918	-292,435	-301,208	-310,245
Energy cost, Oil	$		-216,665	-	-748	-1,542	-4,389	-7,405	-10,599	-14,061	-17,720	-19,260	-20,877	-43,096	-44,389	-45,721	-47,092
Sum	$		-1,651,721	-5,990	-6,903	-7,866	-32,979	-36,782	-40,784	-53,534	-58,279	-60,935	-68,180	-407,526	-419,550	-431,930	-444,675
Total Investments		**Lifetime (yr**	**NPV**														
Heat pumps	$	20	-3,074,724	-624,407	-	-	-1,578,537	-	-	-684,172	-	-	-	-	-1,578,537	-	-
Boreholes	$	40	-5,058,950	-1,000,000	-	-	-3,400,000	-	-	-1,200,000	-	-	-	-	-	-	-
Oil burner	$	20	-317,905	-53,760	-	-	-182,784	-	-	-64,512	-	-	-	-	-182,784	-	-
Chillers	$	20	-12,269,016	-2,480,325	-	-	-6,514,268	-	-	-2,574,826	-	-	-	-	-6,514,268	-	-
Solar PV	$	20	-3,788,565	-968,960	-	-	-1,846,263	-	-	-643,879	-	-	-	-	-1,846,263	-	-
Scrap value from "Scrap value final year"	$		2,809,875	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Total investment	$		-21,699,285	-5,127,453	-	-	-13,521,851	-	-	-5,167,388	-	-	-	-	-10,121,851	-	-
Scrap values final year																	
Heat pumps		20								-34,209	-	-	-	-	-1,420,683	-	-
Boreholes		40		-375,000	-	-	-1,530,000	-	-	-630,000	-	-	-	-	-	-	-
Oil burner		20								-3,226	-	-	-	-	-164,506	-	-
Chillers		20								-128,741	-	-	-	-	-5,862,841	-	-
Solar PV		20								-32,194	-	-	-	-	-1,661,637	-	-
TOTAL Scrap value as NPV value			**2,809,875**	-	-	-	-	-	-	-	-	-	-	-	-	-	17,550,104
Simple Cash Flow and payback			**NPV**														
Income	$		13,069,019	-	85,897	156,656	388,356	620,056	851,756	1,075,281	1,298,807	1,368,959	1,439,112	2,003,833	2,003,887	2,003,941	2,003,995
Costs	$		-1,651,721	-5,990	-6,903	-7,866	-32,979	-36,782	-40,784	-53,534	-58,279	-60,935	-68,180	-407,526	-419,550	-431,930	-444,675
Investment	$		-21,699,285	-5,127,453	-	-	-13,521,851	-	-	-5,167,388	-	-	-	-	-10,121,851	-	17,550,104
Cash Flow	$		-10,281,987	-5,133,443	78,994	148,790	-13,166,475	583,274	810,973	-4,145,641	1,240,527	1,308,025	1,370,933	1,596,308	-8,537,514	1,572,011	19,109,424
Accumulated Cash flow		**IRR**	**1.05%**	-5,133,443	-5,054,449	-4,905,659	-18,072,133	-17,488,859	-16,677,887	-20,823,527	-19,583,000	-18,274,975	-16,904,043	-7,828,671	-16,366,186	-14,794,174	4,315,250
Discounted Cash flow (NPV)	$	7.3%	**-10,281,987**	-5,133,443	73,620	129,234	-10,657,868	440,021	570,174	-2,716,398	757,545	744,420	727,141	338,784	-1,688,643	289,776	3,282,877
Accumulated Discounted Cash flow	$	7.3%		-5,133,443	-5,059,823	-4,930,590	-15,588,458	-15,148,436	-14,578,262	-17,294,660	-16,537,115	-15,792,695	-15,065,554	-12,916,582	-14,605,225	-14,315,449	-11,032,572
Payback		Years	26	0	0	0	0	0	0	0	0	0	0	0	0	0	1