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Norsk deltagelse i IEA Heat Pump Programme Annex 34 - sluttrapport

Institutt for energiteknikk

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Rapporttittel

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Sammendrag

Denne rapporten samler Norges bidrag i IEA HPP Annex 34 «Thermally driven Heat Pumps».

Termisk drevne varmepumper og kjølere er i liten grad anvendt i Norge. Norges unike vannkraftbaserte elektrisitetsproduksjon gir lave elektrisitetspriser, noe som gjør at termisk drevne varmepumper vanligvis ikke kan konkurrere med kompressordrevne varmepumper. Økt fokus på energieffektivisering og økt forståelse av begrepet energikvalitet gjør at det arbeides for å redusere bruken av elektrisitet til oppvarmings- og kjøleformål. Tiltak som reduserer elektrisitetsforbruket er mer aktuelle, og her kan termisk drevne systemer spille en rolle.

Forskning og utvikling på termisk drevne varmepumper over tid har ført til at det nå er kommersielt tilgjengelig systemer med kjøleeffekter fra 7.5-20kW fra en rekke leverandører. Dersom en ønsker å ta i bruk teknologien i Norge er informasjon og bevisstgjøring sentralt. Pilotanlegg for å gjøre teknologien kjent i Norge og for å øke kunnskapen rundt drift av slike anlegg større kan være veien å gå. Dette vil kreve subsidiering av teknologien.

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	Navn	Signatur
Utarbeidet av	Stein Rune Nordtvedt	Stein Rune Nordtvedt
Kontrollert av	Martin Kirkengen	[signature]
Godkjent av	Martin Kirkengen	[signature]

Elektronisk arkivkode

Institutt for energiteknikk

Postboks 40, NO-2027 Kjeller, Norge

Telefon: +47 63 80 60 00/Telefax: +47 63 81 63 56

http://www.ife.no / firmapost@ife.no

Innholdsfortegnelse

1 Introduksjon

Det internasjonale energibyråets (IEAs) varmepumpeprogram – IEA Heat Pump Programme (HPP) – er en allmennyttig organisasjon hvor deltakere fra en rekke land i Europa, Asia og Nord-Amerika arbeider med prosjekter knyttet til varmepumpeteknologi og tilgrensende fagområder. Programmet utvikler og formidler balansert informasjon av høy kvalitet for derigjennom å bidra til økt energieffektivisering og økt bruk av fornybar energi ved oppvarming og kjøling av bygninger og i industrielle prosesser. De 13 medlemslandene er Canada, Frankrike, Japan, Nederland, Norge, Spania, Storbritannia, Sveits, Sverige, Tyskland, USA, Italia og Østerrike.

De faglige samarbeidsprosjektene i Varmepumpeprogrammet kalles Annexer, og de har vanligvis en varighet på 2 til 3 år. Antall deltakerland ligger typisk mellom 3 til 8. I Annexene gjennomfører hvert deltakerland nasjonale studier på tilgjengelig teknologi samt egne forsknings- og utviklingsprosjekter.

1.1 Bakgrunn og målsetting

Norge har på ikke hatt tradisjon for å dekke varme- og kjølebehov med hjelp av termisk drevne varmepumper for oppvarming og kjøling på grunn av den unike tilgangen på elektrisk energi landet har. Endringer i forbruket av elektrisk kraft gjør behovet for bruk av utradisjonelle teknologier mer aktuelt. For å få tilgang til informasjon om termisk drevne varmepumper ble Norge med i IEA HPP Annex 34 «Thermally driven heat pumps for heating and cooling». Den overordnede målsettingen for IEA HPP Annex 34 har vært:

- Kartlegging og analyse av eksisterende termisk drevne varmepumpesystemer for oppvarming og kjøling
- Øke tilgjengeligheten av modellverktøy for analyse og forbedring av teknisk ytelse og totaløkonomi for termisk drevne varmepumpesystemer for oppvarming og kjøling
- Forbedring av systemintegrasjon, blant annet styrings- og reguleringssystemer/algoritmer
- Standardisering av informasjon for å øke konkurranseevne og kvalitet for systemene
- Analyse av økonomiske aspekter og markedsaspekter

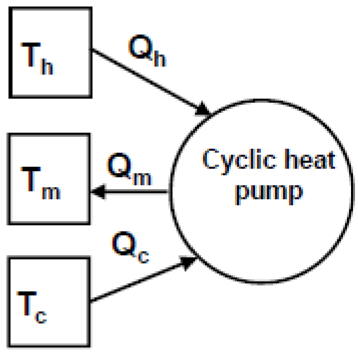
For Norges del er det også viktig å ha:

- Tilgang på markedsstudier fra deltakerlandene
- Tilgang på teknisk informasjon fra deltakerlandene vedrørende dimensjonering, utforming og drift av termisk drevne varmepumper for oppvarming og kjøling
- Tilgang på relevante forsknings- og utviklingsresultater fra deltakerlandene
- Tilgang til et internasjonalt nettverk mot sentrale aktører innen energieffektivisering og bruk av termisk drevne varmepumper

1.2 Teknologisk status for termisk drevne varmepumper

En termisk drevet varmepumpe/kjøler arbeider på tre temperaturnivåer: maskinen drives av en varmekilde med høy temperatur T_h, varme avgis ved middels temperatur T_m, og varme opptas ved lav temperatur T_c. Varmen som avgis ved middels temperatur T_m er den nyttbare varmen når maskinen kjøres som varmepumpe, og varmen som opptas ved den lave temperaturen T_c er den nyttbare varmen når maskinen kjøres som kjøler.

Termodynamikken setter grensene for ytelsen til termisk drevne varmepumper slik at COP er en funksjon av de tre temperaturnivåene; den øvre grensen for T_h=115 °C, T_m = 35 °C og T_c = 0 °C er 2.6. I praksis oppnås typisk halvparten av dette, dvs 1.3.



$$COP_{HP} = \frac{Q_m}{Q_h} \leq \frac{\frac{1}{T_c} - \frac{1}{T_h}}{\frac{1}{T_c} - \frac{1}{T_m}}$$

Figur 1 Den ideelle termodynamiske grense for termisk drevne varmepumper

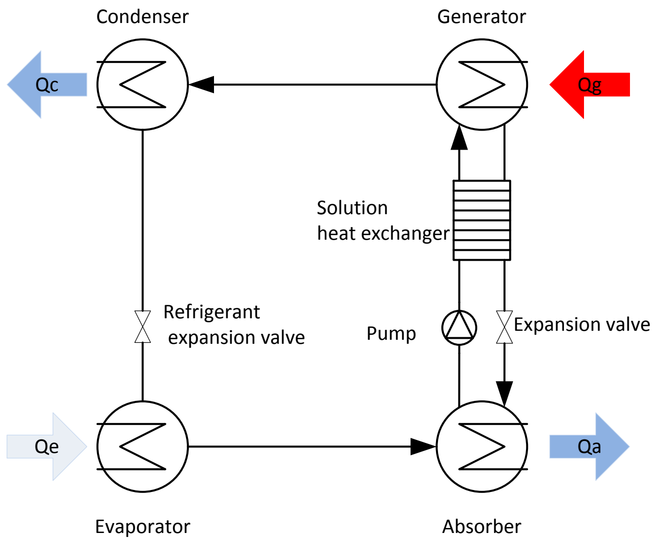
De viktigste termisk drevne varmepumpesystemene er lukkede absorpsjon- og adsorpsjonkretser. Sorpsjonssystemer finnes i effekter fra omtrent 10kW til flere MW og kan drives av mange forskjellige varmekilder, inklusive spillvarme og solvarme og direkte forbrenning av drivstoff. En annen fordel er at de er støysvake da de ikke bruker en mekanisk kompressor. En oversikt over termisk drevne systemer finnes i (Critoph and Zhong 2005), (Gluesenkamp and Radermacher 2011) og (Ziegler 2002).

Både absorpsjons- og adsorpsjonssystemene er basert på et arbeidsmediepar med et kuldemedium og et sorpsjonsmedium. I absorpsjonsenheter absorberes kuldemediet i en væske som endrer konsentrasjon. De mest vanlige arbeidsmedieparene er vann/litium bromid og ammoniakk/vann. I adsorpsjonsenheter adsorberes kuldemediet i porene i det faste adorpsjonsmediet. De mest vanlige arbeidsmedieparene er vann/zeolitt, vann/silikagal, ammonia/aktivert karbon og metanol/ aktivert karbon.

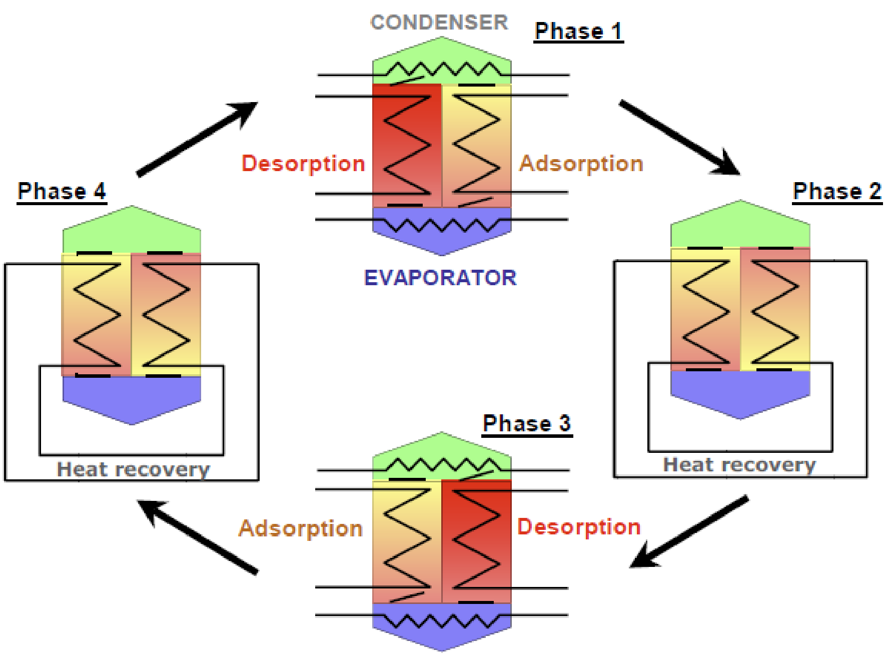
Teknologiene er like termodynamisk sett og har en lik basiskonfigurasjon, som består av fire hovedkomponenter: en reaktor kalt generator hvor sorpsjonsmediet (væske eller fast stoff) varmes opp ved høy temperatur, en kondensator hvor kuldemediet som kommer fra generatoren kondenseres til væske, en fordamper hvor kuldemediet fordampes og gir kjøleeffekten, og en reaktor kalt ab-/adsorber som mottar kuldemediedampen fra fordamperen og ab-/adsorberer denne i sorpsjonsmediet. I absorpsjonsenheter brukes en pumpe til å sirkulere den rike løsningen mellom absorber og generatoren og den svake løsningen tilbake til absorberen. De to reaktorene i en adsorpsjonsenhet driftes i motfase for å sikre en kontinuerlig kjøleeffekt og varmes opp for desorpsjon av kuldemedium ut av adsorpsjonsmediet og kjøles ned for adsorpsjon av kuldemedium.

Det er utviklet mer kompliserte konfigurasjoner for å øke virkningsgraden til termisk drevne varmepumper, som dobbel- og trippeleffekt absorpsjonsmaskiner og multi-reaktor maskiner. Kombinasjoner av enkel- og dobbel-effekt kjølemaskiner er også mulige. Disse mer avanserte konfigurasjonene har høyere virkningsgrad, men kan kreve en varmekilde med høyere temperatur og krever vanligvis en kompleks rørføring på vannsiden og en kompleks regulering.

En annen mulighet for å øke virkningsgraden for termisk drevne varmepumper er å senke kjølevannstemperaturen (middeltemperaturen T_m i Figur 1). Dette kan eksempelvis gjøres med bruk av faseskiftende materialer til å lagre kulde fra natt til dag.



Figur 2 Skjematisk skisse av Vann- LiBr absorptionskrets



Figur 3 Skjematisk skisse av adsorpsjonskrets med varmegjenvinning

Tabell 1 oppsummerer teknologiene, arbeidsmedieparene som brukes og gir en sammenlikning av de viktigste egenskapene og virkningsgradene til de vanligste termisk drevne varmepumpene.

Tabell 1 Tilgjengelige termisk drevne varmepumper (Fraunhofer-ISE 2012)

Process	Adsorption		Absorption		
Refrigerant/sorbent	water silica gel	water zeolite	water/LiBr Single-effect	water/LiBr double-effect	ammonia water
Temperature Heat source [°C]	60-90	75-150	75-110	135-200	100-180
Capacity [kW]	7.5-500	7-15	15-12000	200-6000	18-700
COP heat pumping	1.4-1.6	1.3-1.5	1.4-1.6	1.8-2.2	1.4-1.6
COP cooling	0.5-0.7	0.4-0.6	0.6-0.7	0.9-1.3	0.5-0.7

Et av de største hindrene for utbredelsen av termisk drevne varmepumper er de høye kapitalkostnadene, spesielt for småskala systemer. Tabell 2 gir en oversikt over maskinkostnader (kun) for kommersielt tilgjengelige maskiner. Driftskostnadene for en termisk drevet varmepumpe vil variere med varmekilden. Billig spillvarme vil gjøre driftskostnadene svært lave. Prisforholdet olje/gass og elektrisk kraft vil være avgjørende for sammenlikning med kompresjonsdrevne systemer.

Tabell 2 Oversikt over maskinkostnader for absorpsjon- og adsorpsjonsmaskiner (Fraunhofer-ISE 2012)

Operating conditions	Range of		
	machine costs in Euro	costs per kW-heat in Euro/kW	costs per kW-cold in Euro/kW
Absorption technology			
cold < 0°C, medium output 19,7 to 40°C and driving temperatures of 85 to 115°C. (valid for heating capacities of 45 to 145 kW)	21000 to 105000	476 to 868	1304 to 2625
cold < 0 °C, medium output 25 to 65°C (exceptions 70 to 80°C) and driving temperatures of approx. 200°C. (valid for heating capacities of 32 to 43 kW)	11030 to 22900	337 to 613	615 to 1355
cold > 0°C, medium output 27 to 45°C and driving temperatures of 70 to 110°C. (valid for heating capacities of 20 to 85,4 kW)	12500 to 30600	254 to 730	616 to 1703
Adsorption technology			
cold > 0°C , medium output 22 to 45°C and driving temperatures of 45 to 95°C. (valid for heating capacities of 22 to 40 kW)	10000 to 18000	446 to 542	1199 to 1446

1.3 Termisk drevne varmepumpesystemer i Norge

Absorpsjonskjøleskap fra Elektrolux var vanlig i Norge i 1950- og 60 årene i Norge. De ble etter hvert utkonkurrert av mer energieffektive kompresjonssystemer. I dag brukes mindre enheter som fritidskjølere om bord i båter og på hytter. Det er kun få termisk drevne varmepumpeinstallasjoner med større effekter i Norge i dag, og Tabell 3 gir en oversikt over kjente installasjoner.

Tabell 3 Kjente termisk drevne varmepumpesystemer for kjøling og/eller oppvarming i Norge per 2011

System	Kapasitet	Trinn	Varmekilde	Mediepar	Ferdigstilt
Fylkessykehuset i Haugesund	1.4 MW kjøling	1	Damp	Vann/LiBr	1974
Nedre Elvehavn Kjølesentral, Trondheim	3 MW kjøling	1	Fjernvarme	Vann/LiBr	2000
Øya Kjølesentral, Trondheim	2 x 1.5MW kjøling	1	Fjernvarme	Vann/LiBr	2004
Akershus Fjernvarmesentral, Lillestrøm	1.5 MW heating	2	Røygass	Vann/LiBr	2010
Veolia, Rogaland	40kW	1	Gass	NH3/vann	2011
Comfort, Mosjøen	40kW	1	Gass	NH3/vann	2011

2 Gjennomføring og resultater

Institutt for Energiteknikk har representert Norge i IEA HPP annex 34. IFEs forskningsaktivitet på termisk drevne varmepumper var et godt utgangspunkt i samarbeidet.

2.1 Møter i ekspertgruppen

Det er holdt totalt 10 ekspertmøter inklusive oppstartsmøtet i IEA HPP Annex 34. Norge har deltatt på syv ekspertmøter. Møtene har vært nyttige for Norge da vi har kunnet høste av erfaringene andre land har gjort og fått innblikk i nyvinninger.

Tabell 4 Liste over Annex 34 møter med Norges deltagelse

Møte	By	Land
Oppstartsmøte	Freiburg	Tyskland
1.ekspertmøte	Alkmaar	Nederland
3.ekspertmøte	Wien	Østerrike
4.ekspertmøte + møte med IEA SHC Task38	Freiburg	Tyskland
6.ekspertmøte	München	Tyskland
7.ekspertmøte	Oslo	Norge
8.ekspertmøte	Padova	Italia

2.2 Nasjonale bidrag i IEA HPP Annex 34

Følgende bidrag er kommet fra Norge i IEA HPP Annex 34 samarbeidet:

- «Thermally driven heat pumps, Task A: State of the art analysis, Country Report Norway». Landrapporten er tilgjengelig for deltakerlandene via nettsiden til IEA HPP Annex 34 (www.annex34.org). Alle deltakerlandenes landrapporter er presentert der. Norges landrapport er inkludert i appendix 1.
- Institutt for Energiteknikk var vert for ekspertmøte nr 7 med 16 deltakere fra 7 land. Status for IFEs forskning på termisk drevne varmepumper ble presentert.

3 Videre arbeid og satsing i Norge

Det er per i dag få termisk drevne varmepumper installert i Norge. Lav elektrisitetspris gjør at termisk drevne varmepumper vanligvis ikke er konkurransedyktige med kompresjonsbasert teknologi på grunn av høye investeringskostnader. Økt fokus på energieffektivisering og økt forståelse av begrepet energikvalitet gjør at det arbeides for å redusere bruken av elektrisitet til oppvarmings- og kjøleformål. Behovet for termisk energi bør i større grad dekkes med bruk av termisk energi, helst med gjenbruk av spillvarme. Solvarme er også en varmekilde som bør utnyttes mer til oppvarmings- og kjøleformål. Termisk drevne varmepumper er fleksible med hensyn til drivvarme og kan drives av både spillvarme og solvarme.

Forskning og utvikling på termisk drevne varmepumper over tid har ført til at det nå er kommersielt tilgjengelig systemer med kjøleeffekter fra 7.5-20kW fra en rekke leverandører. Dersom en ønsker å ta i bruk teknologien i Norge er informasjon og bevisstgjøring sentralt. Pilotanlegg for å gjøre teknologien kjent i Norge og for å øke kunnskapen rundt drift av slike anlegg større kan være veien å gå. Dette vil kreve subsidiering av teknologien.

4 Referanser

Critoph, R. E. and Y. Zhong (2005). "Review of trends in solid sorption refrigeration and heat pumping technology." Proceedings of the Institution of Mechanical Engineers, Part E: Journal of Process Mechanical Engineering **219**(3): 285-300.

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Gluesenkamp, K. and R. Radermacher (2011). Heat-activated cooling technologies for small and micro combined heat and power (CHP) applications. Small and micro combined heat and power (CHP) systems: Advanced design, performance, materials and applications. R. Beith, Beith and Assocates Ltd, UK, Woodhead Publishing Limited.

Ziegler, F. (2002). "State of the art in sorption heat pumping and cooling technologies." International Journal of Refrigeration **25**(4): 450-459.

5 Appendix

A2 Country Report Norway

IEA Heat pump program

IEA HPP Annex 34

Thermally driven heat pumps

Task A: State-of-the-art analysis

Norway Team report

Submitted by

Institute for Energy Technology (IFE)

Department of Energy Systems

Instituttveien 18

NO-2007 Kjeller, Norway

Author: Stein Rune Nordtvedt (contact: stein.rune.nordtvedt@ife.no)

Summary

This report is the Norwegian team contribution to Task A within the IEA Heat Pumps Programme Annex 34 on “Thermally driven heat pumps”. It aims to give an overview of the thermally driven heat pump (TDHP) and chiller (TDC) market, recent developments in the area of TDHP and TDC, as well as to give an outlook of the progress of this technology.

There are no Norwegian manufacturers on the TDHP market.

There are only seven existing thermally driven absorption system installations in Norway. Three are district heat driven water/LiBr chillers, one is a steam driven water/LiBr chiller, one water/LiBr heat pump for flue gas condensation in a wood chip heating unit, and two gas driven ammonia-water chillers.

The future market for thermally driven heat pumps and chillers in Norway is expected to be in combination of biomass, district heat or waste heat.

Contents

INTRODUCTION

Annex 34 focuses on thermally driven heat pumps (ad-/absorption) for heating and cooling applications in residential and commercial buildings.

The purpose of this report is to give an overview of the Norwegian market, recent developments and progresses with respect to thermally driven heat pumps (TDHP) and chillers (TDC).

The following items are covered in this report:

- State of the art on TDHP and TDC
- Existing TDHP installations
- Engineering tools
- Market
- Regulatory framework
- Outlook

The state-of-the-art survey in Chapter 0 gives an overview of the state-of-the-art of thermally driven heat pumps and chillers in Norway.

A list of the presently known installed systems based on TDHPs and TDCs in Norway is presented in Chapter 3.

In Chapter 0 some of the software programs used for the design and the scientific investigation of TDHPs and TDCs are described.

Chapter 0 gives an overview of climatic conditions in Norway, building stock and key market players. The situation on the current HVAC market described and information on reference and competing technologies for TDHPs and TDCs are provided.

The outlook for TDHPs and TDCs in Norway is included in Chapter 6. The technical developments are described, and the trends in the Norwegian energy demand and production are provided. A SWOT analysis on the TDHPs and TDCs is included.

In Chapter 7 the existing and expected national legislation on TDHPs and TDCs are described.

TECHNICAL STATE OF THE ART

This chapter describes the technical state of the art of thermally driven cooling (TDC) and thermally driven heat pumps (TDHP) in Norway.

There are no Norwegian manufactures of traditional TDHPs and TDCs, and all existing thermally driven units in Norway are imported.

The company Hybrid Energy AS is the only manufacturer of absorption equipment in Norway. Hybrid Energy AS builds and delivers high temperature compression/absorption heat pumps for industrial purposes. Ammonia/water is used as working fluid. At present there are six hybrid heat pump installations in Norway.

Interested readers looking for TDC and TDHP products may refer to the following manufacturers: Carrier (USA), MacQuay (USA), Toshiba (Japan), Broad (China), Hitachi (Japan), Ebara (Japan), Trane (USA) , LG (Korea), Mitsubishi (Japan), York (USA), Yazaki (Japan), Nishiyodo (Japan), Mayekawa/Mycom (Japan), Robur (Italy), ClimateWell (Sweden), Stork-Colibri (Netherlands), Jiangsu Huineng New Energy Technology (China), Pink (Austria), Sorption Energy (UK), Thermax (India), SorTech AG (Germany), Viessmann (Germany), Invensor (Germany), Vaillant GmbH & Co (Germany), SolarNext (Germany), AbKM Klimatechnik GmbH (Germany), ECOPLUS Energy Systems (Austria) and EAW (Germany).

Table 5 gives an overview of recent TDC and TDHP products with less than 50kW cooling capacity. The table is not exhaustive.

Table 5 Overview of recent TDC and TDHP products of less than 50kW cooling capacity

Manufacturer	**Type**	**Technology**	**Nominal capacity**
ECOPLUS Energy Systems	Helioplus	Gas fired, absorption, water-NH3	~40kW heating ~18kW cooling
Robur	GAHP line	Gas fired, absorption, water-NH3	~40kW heating ~18kW cooling
Vaillant	zeoTHERM	Gas-fired, adsorption, zeolite-water	10kW heating
AbKM Klimatechnik	Suninverse	Indirect fired, LiBr-water	~10kW cooling
Broad	BCT23	Indirect fired, LiBr-water	23kW cooling
ClimateWell	SolarChiller	Indirect fired, adsorption, LiCl-water	~10kW cooling
EAW	WEGRACAL 15, 30, 50	Indirect fired, absorption, LiBr-water	15, 30, 50kW cooling
Invensor	LTC09,HTC11	Indirect fired, adsorption, zeolite-water	9 and 11kW cooling
Jiansu Huineng	RXZ11,23,35 XRZ11,23,35	Direct or indirect fired, absorption, LiBr-water	11, 23, 35kW cooling
Pink	PC14, PC19	Indirect fired, absorption, water-NH3	14 and 19kW cooling
Robur	GA ACF series	Gas fired, absorption, water-NH3	~18kW cooling (~21kW heating)
SorTech	ACS8, ACS15	Indirect fired, adsorption, silica gel-water	8 and 15kW cooling
Thermax	Cogenie	Indirect fired, absorption, LiBr-water	35kW cooling

Tranter Solarice	XS30	Indirect fired, absorption, water-NH_3	40kW cooling
Yasaki	WFC-SC5 WFC-SC10	Indirect fired, absorption, LiBr-water	17.5, 35kW cooling (25, 50kW heating)

EXISTING TDHP INSTALLATIONS

This chapter gives an overview of the known thermally driven heat or cooling systems in Norway. There are only a few installations of absorption systems in Norway; all installed in the non-residential sector. The oldest unit still in operation is installed in a hospital in the town Haugesund, located at the western coast of Norway.

- *Table 6: Known thermally driven heat pump systems for heating and/or cooling installed in Norway until 2009*

System	Capacity	Stages	Drive heat	Remark	Completed
County hospital in Haugesund	1.4MW cooling	Single	Steam	Water/LiBr system	1974
Øya Cooling Central, Trondheim	3 MW cooling	Single	District heating	Water/LiBr system	2004
Nedre Elvehavn Cooling Central, Trondheim	2 x 1.5MW cooling	Single	District heating	Water/LiBr system	2000
Akershus district heating central, Lillestrøm	1.5MW heating	Two	Flue gas	Water/LiBr	2010
Veolia, Rogaland	40kW	Single	Gas	NH3/water	2011
Comfort, Mosjøen	40kW	Single	Gas	NH3/water	2011

Trondheim Energi has two cooling centrals, Øya and Nedre Elvehavn cooling central. The Øya Cooling Central has 7 MW cooling power installed, and currently includes one absorption chiller of 3MW cooling, one compression chiller of 4MW cooling and direct cooling by river water. The river water is used as the primary source for cooling. The river water is also used for heat rejection.

- *Table 7: Øya Cooling Central. Source: Trondheim Energi*

Project name	Øya Cooling Central	
Location	Øya, Trondheim, Norway	
In operation since	2004	
Project status	A commercial system	
Application	TDHP is used	
Heat pump system	Manufacturer	York by Johnson Controls
	Product type	YIA ES10E3 – HW, water/LiBr absorption, one unit
	Nominal capacity	3 MW cooling
	Driving energy	Hot water from Trondheim Energi's district heating network at 105°C.
	Recooling	Water from the River Nidelva

- *Figure 4: The absorption chiller at Øya Cooling Central. Source: Trondheim Energi*

Nedre Elvehavn cooling central started delivering cooling in October 2000, and currently has 5MW cooling power installed. The cooling central includes two absorption chillers of 1.5 MW cooling power, two compressor chillers of 1 MW cooling and direct cooling by river water. The river water is used as the primary source for cooling. The river water is also used for heat rejection.

- *Table 8: Nedre Elvehavn Cooling Central. Source: Trondheim Energi*

Project name	Nedre Elvehavn Cooling Central	
Location	Nedre Elvehavn, Trondheim, Norway	
In operation since	2000	
Project status	A commercial system	
Application	TDHP is used	
Heat pump system	Manufacturer	York by Johnson Controls
	Product type	YIA ES4C1– HW, water/LiBr absorption, 2 units
	Nominal capacity	1.5 MW cooling each
	Driving energy	Hot water from Trondheim Energi's district heating network at 105°C.
	Recooling	Water from the River Nidelva

Two gas-driven ammonia-water absorption heat pumps are installed in Norway. *Table 9*and *Table 10* show the details of these heat pumps.

Table 9: Veolia. Source: SGP Varmeteknikk AS

Project name	Veolia	
Location	Stavanger, Rogaland	
In operation since	2011	
Project status	A commercial system	
Application	TDHP is used	
Heat pump system	Manufacturer Product type Nominal capacity Driving energy Recooling	Robur GAHP 40kW Gas na

- *Table 10: Comfort Mosjøen, Source: SGP Varmeteknikk AS*

Project name	Comfort Mosjøen	
Location	Mosjøen, Nordland	
In operation since	2011	
Project status	A commercial system	
Application	TDHP is used	
Heat pump system	Manufacturer Product type Nominal capacity Driving energy Recooling	Robur GAHP 40kW Gas na

ENGINEERING TOOLS

This chapter gives a short overview of engineering tools used for the design and study of TDHPs, TDCs and systems at IFE. The list of tools includes:

- EES
- TRNSYS

- EES

EES, delivered by F-Chart Software, is an acronym for Engineering Equation Solver. The basic function provided by EES is the numerical solution of a set of algebraic equations. EES can also be used to solve differential and integral equations, do optimization, provide uncertainty analyses and linear and non-linear regression, convert units and check unit consistency and generate plots.

More information about EES can be found in the product overview at http://www.fchart.com/ees/eesoverview.shtml

- TRNSYS

TRNSYS is a transient systems simulation program with a modular structure. It recognizes a system description language in which the user specifies the components that constitute the system and the manner in which they are connected. The TRNSYS model library includes many of the components commonly found in thermal energy systems, as well as component routines to handle input of weather data or other time-dependent forcing functions and output of simulation results. The modular nature of TRNSYS gives the program flexibility, and facilitates the addition of mathematical models not included in the standard TRNSYS library to the programme. TRNSYS is well suited for detailed analyses of systems with time dependent behavior.

TRNSYS applications include:

- Solar systems (solar thermal and PV)
- Low energy buildings and HVAC systems with advanced design features (natural ventilation,
- Slab heating/cooling, double facade, etc.
- Renewable energy systems
- Cogeneration, fuel cells
- Anything that requires dynamic simulation

TRNSYS offers various models of thermally driven heat pumps. There is a variety of external model libraries available, both for internal usage and commercial. One of the commonly used libraries for HVAC system modeling is the TESS HVAC library, which contains a number of models of thermally driven heat pumps. Further information about TRNSYS is available at www.transolar.com

MARKET

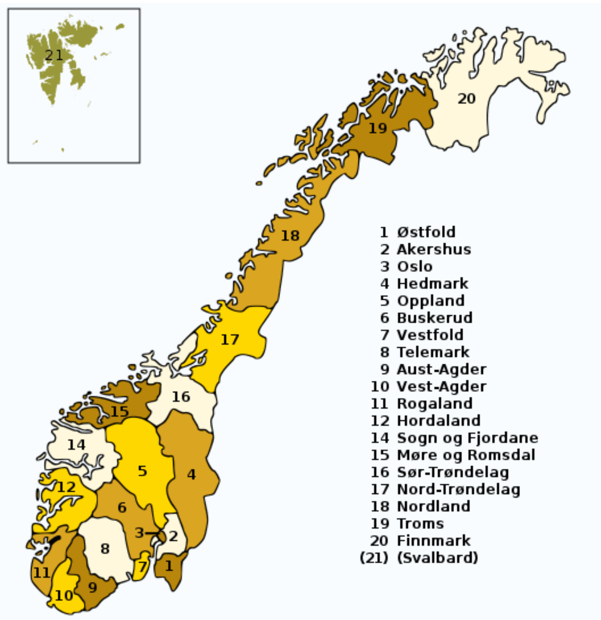
This chapter describes the Norwegian climate, building stock, HVAC market and the power production mix. The market for thermally driven heat pump and chillers in Norway, the key market players and the reference and competing technologies are also described.

- Climate

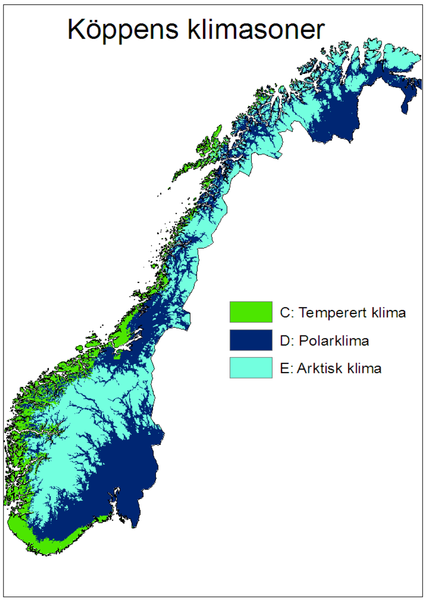
Norway has a total area of 385252 km^2 (including Svalbard and Jan Mayen) and approximately 5.0 million inhabitants.

The mainland experiences four distinct seasons, with colder winters and less precipitation inland. The northernmost part has a mostly maritime subarctic climate, while Svalbard has an Arctic tundra climate. The southern and western parts of Norway experience more precipitation, and have milder winters than the south-eastern part. The lowlands around the capital Oslo have the warmest and sunniest summers, but also cold weather and snow in wintertime (especially inland).

Norway comes under more of the climate zones in the Köppen's climate classification, mainly in the temperate and continental climate zones. Coastal areas from the west side of the outer Oslo fjord and the far north to Troms has maritime climate (group C). Inner areas of Eastern Norway, Southern Norway and Trøndelag has continental climate with hot summers, while the southern parts of Finnmark have continental polar climate (group D). Mountain areas and Svalbard have almost Arctic climate (group E).

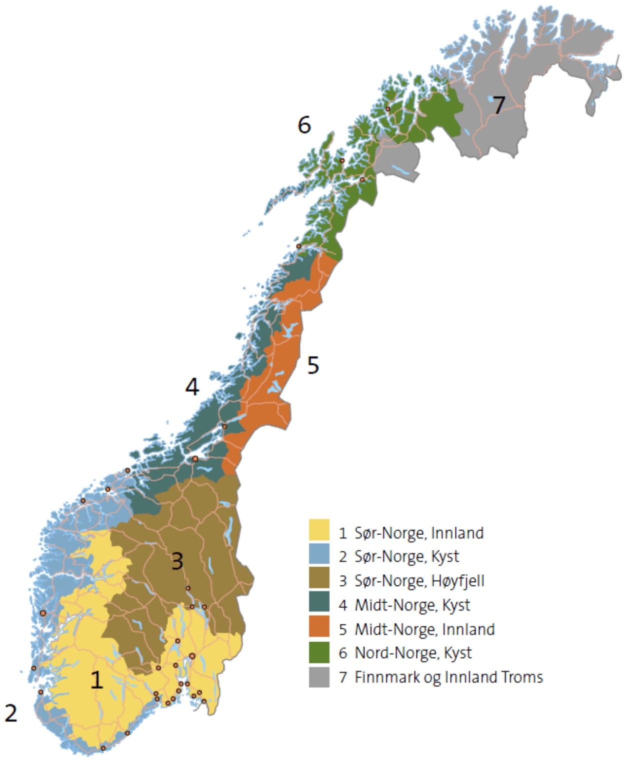


- *Figure 5 Map of Norway, with counties.*



- *Figure 6 Climatic zones in Norway*

The energy for building heating can be roughly split in a part that is virtually unchanged over the year, and a part that is dependent on climatic factors such as outside temperature, wind and sun. The climate-dependent requirements are space heating and ventilation of the building. To be able to say something about the total energy to space heating and ventilation for the building premises in the Norway, it is appropriate to divide the country into zones that have the most internally consistent climate. *Figure 7* shows the seven climatic zones defined in Norway [1].



- *Figure 7: Climatic zones in Norway [1]*

Heating degree days is a measurement designed to reflect the demand for energy needed to heat a building. It is derived from measurements of outside air temperature. The heating requirements for a given structure at a specific location are considered to be directly proportional to the number of HDD at that location. *Table 11* shows the annual heating degree days for the seven climatic zones in Norway. The reference temperature is 17°C.

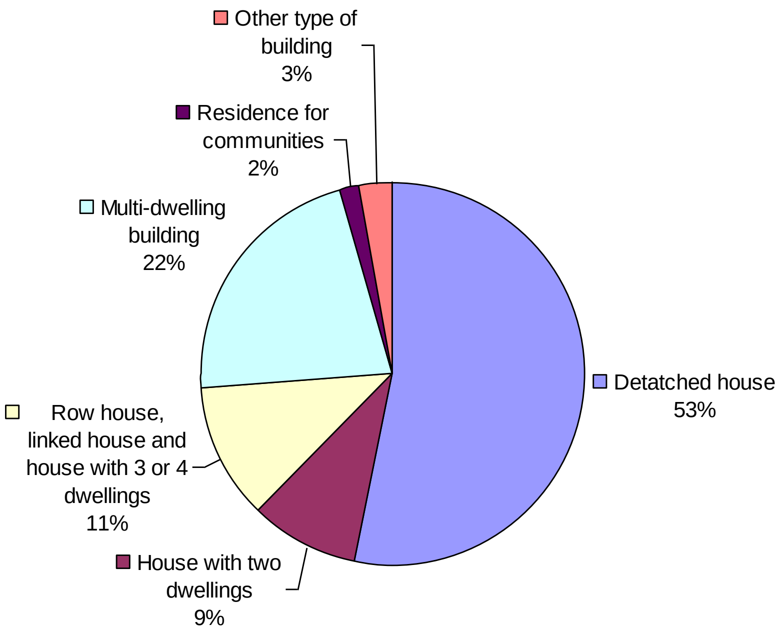
- *Table 11 Annual Heating Degree Days for the 7 climatic zones in Norway, averaged over the period 1971 to 2000.*

Climatic zone	**Normal 1971-2000**
1. Sør-Norge, Inland	4183
2. Sør-Norge, Coast	3670
3. Sør-Norge, Highlands	5203
4. Midt-Norge, Coast	4282
5. Midt-Norge, Inland	5155
6. Nord-Norge, Coast	4875
7. Finnmark and Inland of Troms county	5749

- Building stock

Number and age of buildings

In January 2008, the number of buildings in Norway was 3.8 million, of which 1.44 million or 38% were residential buildings. There were a total of 2274362 dwellings in Norway at the first of January 2008, with 53% being detached houses. Flats in multi-dwelling buildings followed at 22%, while dwellings in row houses, linked houses and houses with three or four dwellings accounted for 11%. Dwellings in houses with two dwellings accounted for 9% and dwellings in residences for communities accounted for 2% of all dwellings. The last 3% of the dwellings are registered in buildings where the main part of the floor space is used for other purposes than dwellings, mainly industrial buildings.



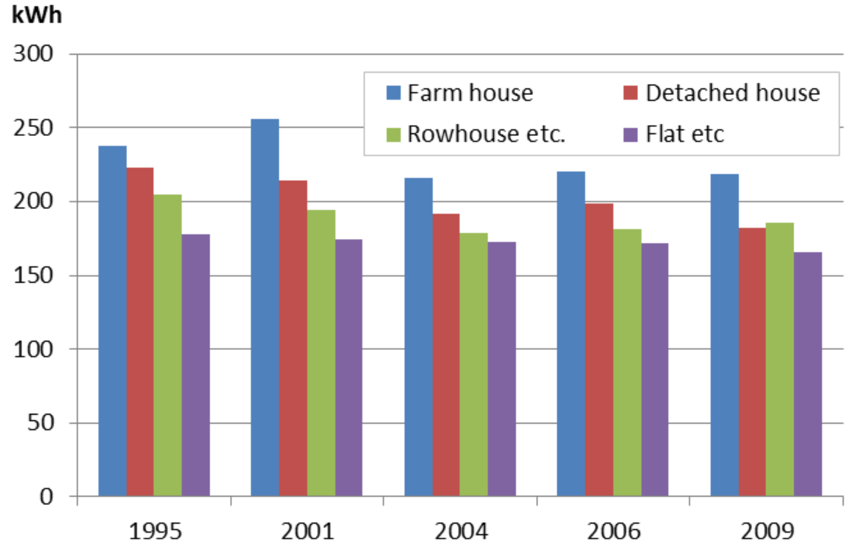
- *Figure 8 Distribution of Norway's 2274362 dwellings by 1st of January 2008 [2]*

78% of the dwellings in Norway are located in densely built-up areas. In Oslo, 99.8% of the dwellings are in densely built-up areas, whereas 88.2% of the dwellings in Akershus are located in such an area. At the other end of the scale are Hedmark, Sogn and Fjordane, Oppland and Nord-Trøndelag - all with approximately 55% of the dwellings in densely built-up areas.

Average energy consumption in Norwegian dwellings

Figure 9 gives an overview of the average energy consumption in Norwegian dwellings. The specific energy consumption per m^2 can be seen in *Figure 10*.

- *Figure 9 Average energy consumption by house type. kWh of supply energy. Source: SSB 2011*



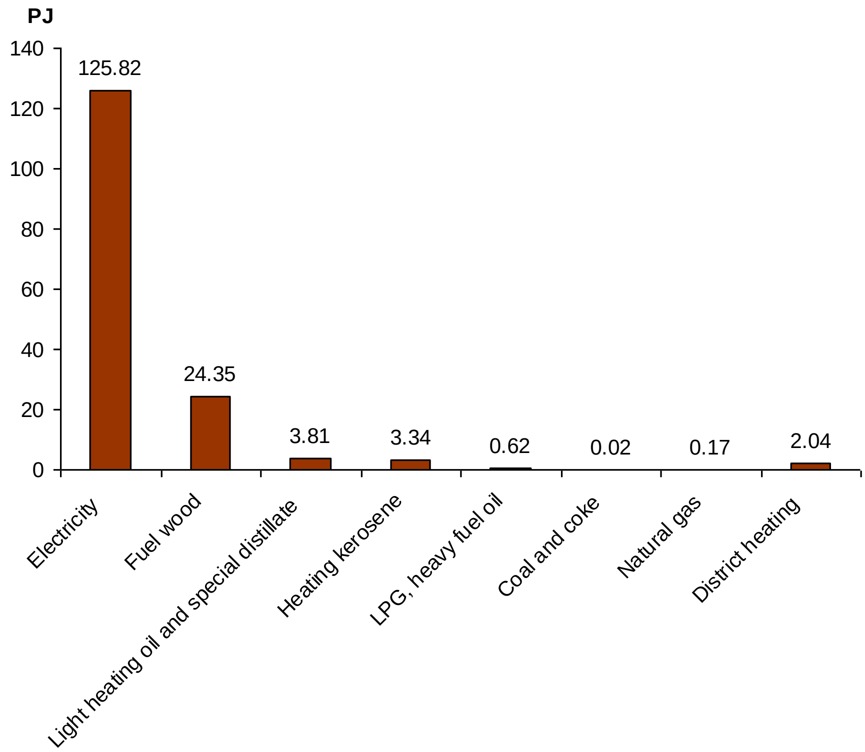
- *Figure 10 Energy consumption per m^2 dwelling area, by house type, 1995 - 2009. Source: SSB 2011*

Energy sources for heating and hot water production

Electric heating is the most common heating equipment in Norwegian households. 98% of all households have electrical space heating and/or floor heating, while stove for fire wood is the second most common heating equipment. According to Statistics Norway [2] 69% of all households have stove for fire wood, but often in combination with electrical space heaters. About 43% has this combination, while 4.5% has heat pump in addition to stove for fire wood and electrical space heaters. Stove for pellets is still very seldom. 13% has open fire place that is less efficient than stove for fire wood, but then often in combination with closed stove for fire wood.

Current energy use for the built environment

The energy consumption in households in Norway in 2008 was 160.9 PJ. Most of the energy for space heating and hot water preparation comes from electricity and fuel wood. *Figure 11* shows the energy consumption of the Norwegian households in 2008, divided between different energy sources.



- *Figure 11 Distribution of the energy consumption by Norwegian households in 2008 by energy source [2]*

- Key market players

Norway has no manufacturers of conventional thermally driven systems for heating or cooling, and all of the equipment in the existing installations is imported.

The main actors in the heat pump market in Norway are:

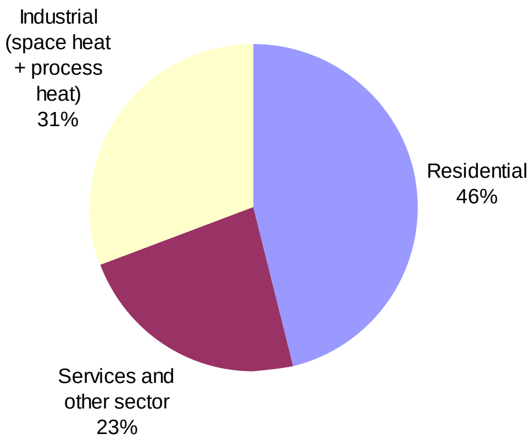
- Installers
- NOVAP (Norwegian Heat Pump Association)
- ENOVA (a public enterprise owned by the Ministry of Petroleum and Energy)

Other significant organizations include Kulde og varmepumpeentreprenørenes Landsforening, KELF (National Organization of Cooling and Heat Pump Entrepreneurs)

- Current HVAC market

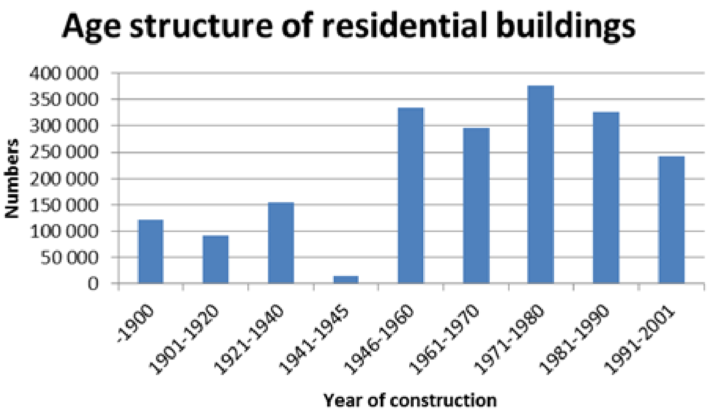
Heating and cooling market

The total heat demand in Norway was 233812 TJ in 2007. 46% of the heat was used in the residential sector, 31% in the industrial sector and 23% in the services and other sectors.



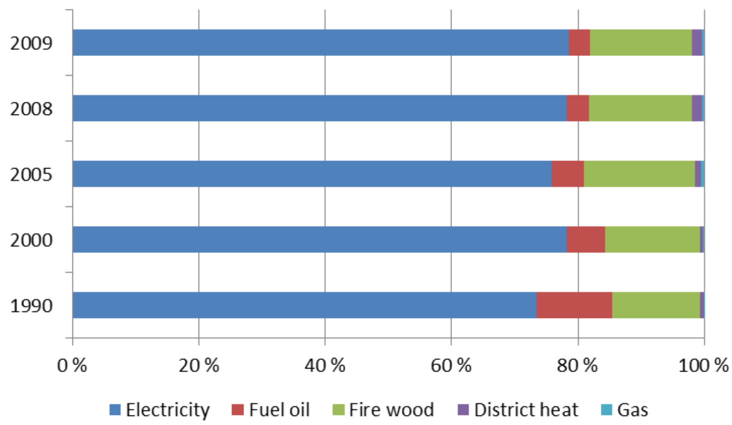
- *Figure 12 Total heat demand for 2007 by sector [3]*

The market for TDHPs and TDCs can be divided into existing buildings (retrofitting) and new buildings. *Figure 13* shows the age structure of residential buildings in Norway.

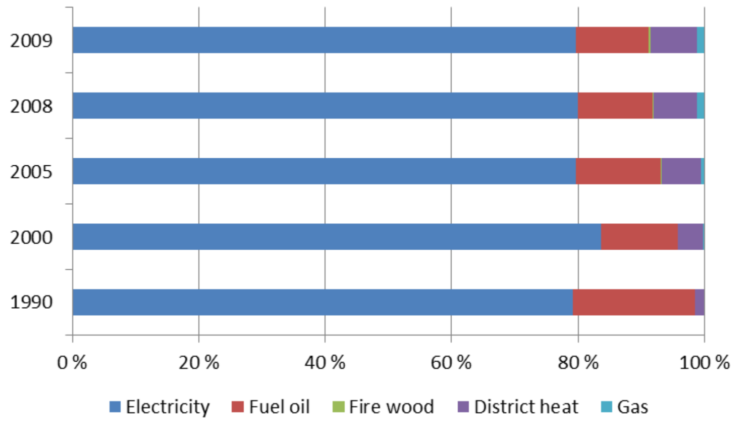


- *Figure 13 The age structure of residential buildings in Norway. Source: SSB*

The distribution of the total energy use between different energy sources in existing buildings are shown in *Figure 14* for household and in *Figure 15* for private and public services and defense. Approximately 70-75% of the total energy is used for hot water and space heating.



- *Figure 14 Distribution of energy sources in existing households. Source: SSB*



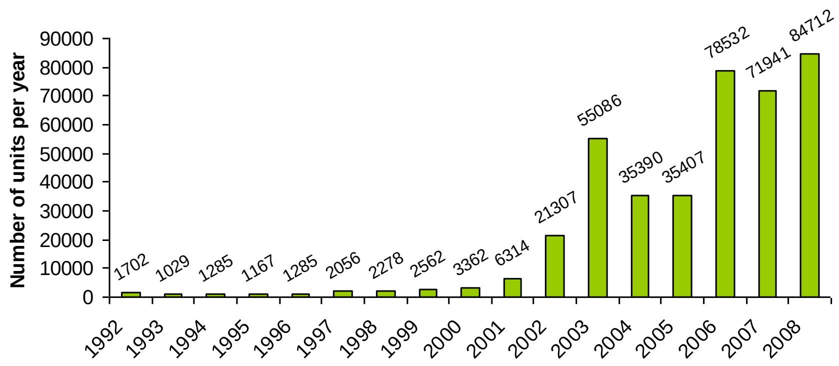
- *Figure 15 Distribution of energy source in private and public services and defense. Source: SSB*

Current market for electrical heat pumps

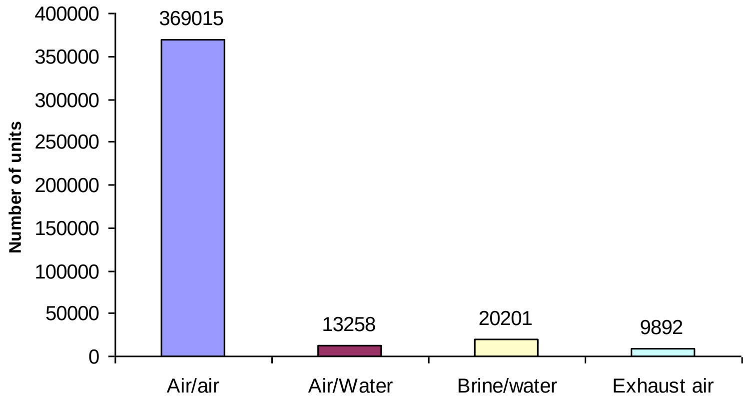
After a minimal Norwegian heat pump market during the 1990'ies, the annual installation rate has now stabilized at much higher level. The main reasons for this are:

- Increasing electricity prices
- Relatively low interest rate
- Establishment of Enova SF, which is owned by the Norwegian Ministry of Petroleum and Energy. Enova SF offers subsidies for water-to-water heat pumps, brine-to-water, air-to-water and ventilation air-to-water heat pumps.
- Installation of hydronic floor heating systems
- Increasing awareness of the economical, technical and global environmental benefits of heat pump systems among end-users.

Figure 16 shows the annual installation rate for heat pumps in Norway during the period 1992 to 2008, and *Figure 17* shows the total number of heat pump installations in Norway by 2008. The total number of heat pumps in households has surpassed 600000 units. The data are based on information from the Norwegian Heat Pump Association, NOVAP [4].



- *Figure 16 The annual installation rate for heat pumps in Norway, 1992-2008 [4]*



- *Figure 17 Total number of heat pumps installed in Norway by 2008 [4]*

Power production mix

The energy situation in Norway is quite special compared to most other countries, as the annual production of energy is approximately ten times the domestic use, and more than 99% of the electricity production is hydropower. As Norway is a part of the international energy market, the energy costs in Norway reflect the international market.

and *Table 13* show the production of important forms of energy and the final energy consumption in Norway by 2008. The total energy consumption in Norway in 2008 was 819 PJ, excluding offshore industry and international shipping. Almost all electricity production, 98.5%, originates from renewable hydropower. The remaining 1.5% is produced in thermal power stations (0.9%) and by wind power (0.5%).

- *Table 12 Production of important forms of energy in Norway in 2008[2]*

Energy form	**Unit**	**2008**
Coal	1000 tonnes	3282
Crude oil	Mill Sm3	122673
Natural gas	Mill Sm3	99233
Electricity	GWh	142667

- *Table 13 Final energy consumption[1] in 2008 [2]. In PJ*

	2008
Coal and coke	50
Wood and black liquor	43
Gases	28
Petroleum products	286
Electricity	401
District heating	10
Total	819

- Reference technologies

The reference technologies for heating and cooling in Norway are:

- for heating: electric resistance heating, fuel wood, mechanical compression heat pumps, district heating, biomass
- for cooling: mechanical compression chillers

Electric resistance heating

Electricity is the main energy source used to satisfy heating demands in Norway and has a share of almost 50%.

Mechanical compression heat pumps

The market for mechanical compression heat pumps has increased as a response to governmental incentives and increasing electricity prices. Air-to-air heat pumps dominate the residential market.

District heating

District heating accounts for 4.8% of the energy sources used to satisfy the heat demand in the residential, services and other sectors. In total 11312 TJ of district heating is delivered and the industrial sector has the highest share of district heating delivery (64%). The most common energy resources for production of district heating are waste (33%), electricity (20%) and combustible renewables (15%).

The total installed district cooling capacity in Norway amounts to 75.2 MW_{th} and from 2002 to 2007 district cooling increased by more than 200%.

Norway has 55 district heating utilities with a total capacity of 1400 MWth installed. 900km of district heating piping is installed.

[1] Consumption by energy producing industries, consumption for non-energy purposes and losses in transportation and distribution are not included in the figures.

- *Table 14 District heating delivered, by sector [3]*

Sector	In TJ	Percent
Residential	1907	17
Services and other sectors	2212.2	19
Industrial sector	7194.2	64
Total	**11312.9**	**100**

Bioenergy and industrial surplus heat are increasingly used for the base load renewable energy sources. Heat from CHP generated through coal is also increasing. Gas, electricity and oil, depending on the energy price, are used for the peak load.

- *Table 15 Production sources for district heating [3]*

	2002		**2007**	
	In TJ	Per cent	In TJ	Per cent
Cogeneration from coal and coal products	146	2	198	2
Combustible renewables	756.8	10	1852.5	15
Waste	3230.5	41	4041	33
Heat pumps	527	7	925.2	8
Industrial surplus heat	471.6	6	1271.9	11
Natural gas	205.6	3	614.4	5
Oil and petroleum products	1289.2	17	781.3	6
Electricity (hydropower)	1177.7	15	2379.9	20
Total	**7804**	**100**	**12064**	**100**

Solar heat

The commercial market on solar heating in Norway has been limited. The market is increasing, but compared to the neighboring countries, it is still immature. By the end of 2006, the total installed solar heating systems in Norway were approximately 9MW_{th}.

Biomass

The use of bioenergy is estimated to 14 TWh. Norwegian households used about 6.7TWh bioenergy in 2007. Corrected for efficiency factors this corresponds to about 3.5TWh net energy consumption. Higher electricity prices have led to increased use of biomass in industry. The consumption of wood residues was 2699 GWh in 2007, an increase of 531 GWh since 2006.

REGULATORY FRAMEWORK

In this chapter the relevant Norwegian legislation concerning design, production and safety maintenance of TDHPs is presented.

- Framework for TDHP products

The main normative document for heat pumps in Norway is the Norwegian Refrigeration Norm. The Norwegian Refrigeration Norm reflects the requirements and instructions in Norwegian regulations and relevant standards. In addition many practical suggestions and recommendations, data for the current refrigerants, etc., are provided. Norwegian Refrigeration Norm should always be based on the construction of heat pumps. Installation, operation and maintenance should always be in accordance with Norwegian Refrigeration Norm.

As a member of the EEA, Norway is in principle obliged to accept the EU / EEA's so-called harmonized standards. The special feature of these standards is that they function as directives to the EU legislation or directives. The following directives will be applicable in connection with the delivery of heat pumps:

- Machinery Directive (active from January 1,1995)
- Low Voltage Directive (active from January 1, 1997)
- Directive concerning the requirements for immunity and emissions in the electric and electronic circuits (EMC Directive, active from January 1,1996)
- Pressure Directive (active from 2002)

When it comes to heat pumps (and refrigeration), the selected parts of a new refrigeration standard in Europe (new refrigeration CEN-standard) function as a harmonized standard under the machine and pressure directives.

“NS-EN-378 Refrigerating systems and heat pumps. Safety and environmental requirements” is the guideline for the construction of secure refrigeration and heat pump in accordance with the EU machine directive.

- Heat pumps in building performance codes

The EU Energy Performance of Buildings Directive was implemented in Norway in 2010.

- Fiscal and financial incentives

Enova was established in 2001 as a public enterprise owned by OED. Its main mission is to contribute to environmentally sound and rational production and use of energy, relying on financial instruments and incentives to stimulate market actors and mechanisms to achieve national energy policy goals.

ENOVA have grants for household for installations of pellet boilers, pellets, air-to-water heat pumps, liquid-to-water heat pumps, and solar thermal collectors. The grant for solar thermal collectors is 20% of the installation costs, with a maximum funding of 1300 Euro. The solar thermal collector solution has to be integrated with the dwelling’s tap water heating system and possibly the space heating system. Private households can receive grants of up to 1300 Euro for air-to-water and liquid-to-water heat pumps.

ENOVA does not have any grants for thermally driven heat pumps today.

OUTLOOK

In this chapter the perspectives for thermally driven heat pumps in Norway are described.

- New technological developments

The TDHP equipment installed in Norway is imported and new products already on the international market may become commercially available on the Norwegian market if they gain the confidence of the customers.

General research and development of absorption systems on component and system level is ongoing at Institute for Energy Technology – Kjeller. On system level focus has been and still is on the development of ammonia-water compression/ absorption heat pumps and absorption heat pumps. On the component level focus is currently on heat exchanger design and new heat exchanger concepts for ammonia-water systems.

- National trends

Hydropower, oil, gas and solid fuels are the most important energy carriers today. In the future, an increase in the share of renewable energy is requested. In the Norwegian Public Study from 1998 [5], the growth potentials for renewable energy with an energy price to the consumer below 70 øre/kWh (before value added tax) was estimated.

- *Table 16 1998 estimates for future energy production in Norway. In TWh [5]*

	2001	**2020**
Hydro power	122	126
Wind power	0.03	6
Bioenergy/ energy from waste	15	22
Heat pumps	4.5	10
Solar energy	0.01	8
Geothermal energy	0	0.1
Wave/tidal	0	0.5

The energy act of 1991 deregulated the Norwegian electricity market. An overinvestment in the energy sector was the reason for low energy prices up to the year 2008. The years 1993, 1996, and 2004 were exceptions, due to little inflow of water into the storages. 98% of the electricity is provided by hydropower, while wind power accounts for 2%.

Electricity prices were expected to rise in 2009, but due to the financial crisis and a decrease in the industrial production, this development did so far not take place. Regarding the final consumption of energy, Norway has a share of 60% from renewable sources, but as a result of the new RES directive this share will increase to 67.5% by 2020. In order to reduce its GHG emissions Norway will need to reduce the use of electricity in the heating sector and replace it with renewable heating sources.

The current use of absorption systems in Norway is quite limited, due to the low electricity prices. The increasing use of district heating and cooling might change this. Air-conditioning has usually not been demanded in Norway due to the climate. However, the demand for comfort cooling during the summer is increasing especially in the commercial sector. The potential for absorption technology in Norway depends strongly on the price of the heat demanded to operate the systems. Mechanical compression technology will still be the most important competitor as long as the electricity prices are low.

- SWOT analysis

Strengths:

- Lower running costs
- Gas-fired heat pumps needs only 25% of the electrical heat source

Weaknesses:

- High investment costs

Opportunities:

- Low electrical consumption give relief of power grid in peak hours
- Increased use of district heating and cooling
- TDHPs can be used in a large number of applications, and can cover the heating and cooling needs from a few kW to several 100 MW
- Increased focus of the utilization of excess heat

Threats:

- Higher heat rejection for recooling
- Relatively limited resources for research, analysis and investigations

CONCLUSIONS

There are no current Norwegian manufacturers of traditional thermally driven heat pumps and chillers. The company Hybrid Energy AS designs and builds compression/absorption heat pumps for the industrial market.

The market for TDHPs and TDC in Norway has been quite limited. The thermally driven systems are mainly installed for district cooling. There is one example of an application for flue gas condensation in a biomass-fired energy central. The development of the Norwegian market will depend on the understanding of the technology and its opportunities, the availability of the driving energy sources and the electricity prices.

Air-conditioning has usually not been demanded in Norway due to the relatively moderate climate. The demand for comfort cooling is increasing, especially in the commercial sector. The current use of thermally driven systems in Norway is quite limited, as a consequence of low electricity prices and a limited activity on district heating and cooling. The installed capacity in district heating has increased in recent years, increasing the potential for introducing TDC systems driven by surplus heat in summer. As long as the electricity prices are low, vapor compression technology will still be a strong competitor to TDC.

The residential marked has probably small potential for thermally driven systems as there are no existing gas distribution grid.

The regulatory framework is the general framework specific for all the HVAC&R applications.

Reference technologies in Norway for TDHPs are mechanical compression heat pumps, fuel wood stoves, biomass, solar heat and district heating.

NOMENCLATURE

Abbreviations

PJ	PetaJoule = 10^{15} Joule
RES	Renewable Energy Sources
SWOT	Strengths, Weaknesses, Opportunities and Threats
TDHP	Thermally Driven Heat Pump
TDC	Thermally Driven Chiller

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5. *Energi- og kraftbalansen mot 2020: utredning fra et utvalg oppnevnt ved kongelig resolusjon 16. april 1997: avgitt til Olje- og energidepartementet 3. juli 1998*, A.-G. Strøm-Erichsen, Editor. 1998, Statens forvaltningstjeneste, Statens trykning: Oslo. p. 425 s.

APPENDIX

- National stakeholders

Suppliers (import / manufacturing)

Johnson Controls Norway, www.johnsoncontrols.no

Assocations and interest groups

NOVAP – The Norwegiean Heat Pump Association, www.novap.no

FOKU – Forum of refrigeration users, www.foku.org

NKF – The Norwegian Society of Refrigeration, www.nkf-norge.no

VKE - Association for ventilation, cooling and energy, www.norskteknologi.no

BKTF - Bergen Kjøletekniske Forening, www.bktf.no

Certification bodies

Norsk Teknologis Godkjenningsordning, www.norskteknologi.no, voluntary approbation body for refrigeration and heat pump contractors

Consultants & engineering companies

Hybrid Energy AS, www.hybridenergy.no

Norconsult AS, www.norconsult.no

Sweco Grøner AS, www.sweco.no

Hjellnes Consult AS, www.hjellnesconsult.no

COWI AS, www.cowi.no

Norsk Energi, www.energi.no

End users

Hospitals, office buildings, mall buildings

Research institutes & Developers

Institute for Energy Technology – IFE, www.ife.no, ammonia/water absorption systems

SINTEF Energy Research, www.sintef.no, vapor compression heat pumps

NTNU – Norwegian University of Science and Technology, Faculty of Engineering Science and Technology, Department of Energy and Process Engineering, www.ntnu.no/ept

Institutt for energiteknikk

Institutt for energiteknikk
Postboks 40
NO-2027 Kjeller, Norge
Telefon: (+47) 63 80 60 00
Telefax: (+47) 63 81 63 56
www.ife.no