Annex 32

Economical heating and cooling systems for low energy houses

Final Report – Part 6

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Preface

This project was carried out within the Technology Collaboration Programme on Heat Pumping Technologies (HPT TCP), which is a Technology Collaboration Programme within the International Energy Agency, IEA.

The IEA
The IEA was established in 1974 within the framework of the Organization for Economic Cooperation and Development (OECD) to implement an International Energy Programme. A basic aim of the IEA is to foster cooperation among the IEA participating countries to increase energy security through energy conservation, development of alternative energy sources, new energy technology and research and development (R&D). This is achieved, in part, through a programme of energy technology and R&D collaboration, currently within the framework of nearly 40 Technology Collaboration Programmes.

The Technology Collaboration Programme on Heat Pumping Technologies (HPT TCP)
The Technology Collaboration Programme on Heat Pumping Technologies (HPT TCP) forms the legal basis for the implementing agreement for a programme of research, development, demonstration, and promotion of heat pumping technologies. Signatories of the TCP are either governments or organizations designated by their respective governments to conduct programmes in the field of energy conservation.

Under the TCP, collaborative tasks, or “Annexes”, in the field of heat pumps are undertaken. These tasks are conducted on a cost-sharing and/or task-sharing basis by the participating countries. An Annex is in general coordinated by one country which acts as the Operating Agent (manager). Annexes have specific topics and work plans and operate for a specified period, usually several years. The objectives vary from information exchange to the development and implementation of technology. This report presents the results of one Annex.

The Programme is governed by an Executive Committee, which monitors existing projects and identifies new areas where collaborative effort may be beneficial.

Disclaimer
The HPT TCP is part of a network of autonomous collaborative partnerships focused on a wide range of energy technologies known as Technology Collaboration Programmes or TCPs. The TCPs are organized under the auspices of the International Energy Agency (IEA), but the TCPs are functionally and legally autonomous. Views, findings and publications of the HPT TCP do not necessarily represent the views or policies of the IEA Secretariat or its individual member countries.

The Heat Pump Centre
A central role within the HPT TCP is played by the Heat Pump Centre (HPC).

Consistent with the overall objective of the HPT TCP, the HPC seeks to accelerate the implementation of heat pump technologies and thereby optimize the use of energy resources for the benefit of the environment. This is achieved by offering a worldwide information service to support all those who can play a part in the implementation of heat pumping technology including researchers, engineers, manufacturers, installers, equipment users, and energy policy makers in utilities, government offices and other organizations. Activities of the HPC include the production of a Magazine with an additional newsletter 3 times per year, the HPT TCP webpage, the organization of workshops, an inquiry service and a promotion programme. The HPC also publishes selected results from other Annexes, and this publication is one result of this activity.

For further information about the Technology Collaboration Programme on Heat Pumping Technologies (HPT TCP) and for inquiries on heat pump issues in general contact the Heat Pump Centre at the following address:

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System Concepts IEA HPP Annex 32

IEA HPP Annex 32

Economical heating and cooling systems for low energy houses

Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra

Swiss Federal Office of Energy SFOE

System concepts

New developments of multifunctional heat pumps

Worked out by

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Imprint

IEA HPP Annex 32 " Economical heating and cooling systems for low energy houses"

The work presented here is a contribution to the Annex 32 in the Heat Pump Programme (HPP) Implementing Agreement of the International Energy Agency (IEA)

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PREFACE

Introduction to IEA HPP Annex 32

Since the mid of the nineties low energy buildings with a significantly reduced energy consumption down to ultra-low energy standard (typical space heating energy need of 15 kWh/(m^2a)) or even net zero energy consumption (on an annual basis by an integration of on-site renewable energy systems) have been realised.
These building concepts recently show strong market growth in different European countries. Many governments address the spread of low energy buildings as a major strategy to reach climate protection targets according to the Kyoto protocol. Heat pump markets are growing in many countries as well.
Low energy buildings have significantly different load characteristics compared to conventional existing buildings. This requires adapted system solutions to entirely use energy-efficiency potentials for the remaining energy needs.
Integrated heat pump solutions have favourable features for the use in low energy houses. The main advantages are the potential for internal heat recovery and simultaneous operation to cover different building needs at the same time as well as installation space and cost benefits. This leads to a significantly improved system performance in an adequate capacity range to reduce primary energy consumption and cut CO_2-emissions and costs.
However, in many countries, no adequate system solutions are available on the market or energy performance of available and newly-introduced low energy house technology is not yet approved by field experience. Therefore, system development and field approval of functionality and real-world operational performance of the systems are needed. These are the main working areas of IEA HPP Annex 32.

Main objectives of IEA HPP Annex 32

The main objectives of the IEA HPP Annex 32 are the further development and field monitoring of integrated heat pump systems for the use in low energy buildings, leading to the following objectives:

- To characterise the state-of-the-art in the different participating countries
- To assess and compare the energy performance of different system solutions for the residential low energy house sector
- To develop and lab-test new system solutions of integrated heat pumps in the low-energy-house capacity range including the use of natural refrigerants
- To accomplished field tests of new developments and marketable systems and to document best-practice examples
- To disseminate the results

Results of the IEA HPP Annex 32

The results of IEA HPP Annex 32 comprise:

- Overview of market system solutions of integrated heat pumps for low energy houses
- Design recommendations of the standard system solutions
- New system developments as prototypes including lab-test and simulation results
- Documentation of field monitoring results of new and marketable systems
- Dissemination of results by a website, workshop presentation and reports

1 SYSTEM CONCEPTS

In IEA HPP Annex 32 prototypes of multifunctional heat pump systems has been developed. However, in the time frame of the Annex 32, not all of the developments could be field tested, but work on the prototype developments continues. Field monitoring results of the prototype developments and an outline of field tests, which will be performed after the conclusion of the IEA HPP Annex 32 have been documented in 4-page System Concept Sheets. Moreover, some upcoming system concepts have been included in the sheets.

Tab. 1 gives an overview of System Concept Sheets. To go to the respective System Concept Sheet, just click on the description.

Tab. 1: Overview of documented System Concept Sheets in Annex 32

Country	Object	Description of heat pump system concept
CA		Concept EcoTerra EQuilibrium NZEB with BIPV/T and B/W-HP (Eastman, Québec)
CA		Concept Alstonvale NZEB with BIPV/T and L/W- HP (Hudson, Québec)
NL		Demand controlled V with B/W-HP for SH, DHW and SC (Ypenburg, Den Haag)
NL		B/W-Heat pumps for SFH with solar collectors (Delfgauw, Delft)
NL		B/W Heat pump for LE-appartments (De Tas, Biddinghuizen)
NO		Prototype 3 kW W/W propane-HP for SH, DHW in passive house (Flekkefjord)
US		B/A and A/A IHP-prototype for SH, DHW, V,SC , de-/humidification in NZEB (Oak Ridge)

EQuilibrium™ house with ground-coupled heat pump and BIPV/T-solar system (EcoTerra™ home)

CMHC SCHL — Equilibrium HEALTHY HOUSING FOR A HEALTHY ENVIRONMENT — ÉCOTERRA

Contribution of the Canadian national project

Summary

This System Concept Sheet gives an outline of the EcoTerra™ house, one of twelve winning house concepts of a Canadian nationwide contest under the EQuilibrium™ Housing Initiative run by the Canadian Mortgage and Housing Corporation. The initiative strives to realise Net Zero Energy Buildings with the additional criteria of occupant's health and comfort, resource conservation, affordability, and reproducibility all over Canada.
The EcoTerra™ House is a modular prefabricated house that can be assembled on-site in about one day. The building concept incorporates a high-performance thermal envelope, passive solar design, active heat recovery and integration of on-site renewable energy generation. Eliminated thermal bridges and triple-glazed windows guarantee a good envelope performance. An open design with sufficient thermal mass facilitates use of passive solar gains and reduced cooling needs in summertime. The system incorporates ventilation air and waste water heat recovery as well as a building-integrated solar PV/thermal (BIPV/T) system, which generates solar electricity and heat at the same time. The preheated air by the roof top PV/T-system is used as heat source for direct heating of a hollow concrete slab in the living room to the store heat energy in the concrete. The system is equipped with a ground-coupled heat pump for periods with little solar irradiation, which additionally enables passive ground-coupled cooling in summertime. The heat pump works on a thermal storage which is connected to the heating and DHW system.
The unoccupied house has been monitored for one year, and is continued to be monitored after occupation in Nov. 2009.

Building data

- Location: Eastman, Québec, Canada
- Pre-fabricated wood frame modular housing concept
- Heated floor area/volume: 234 m^2/671 m^3
- Calculated space heating demand: 10 kWh/(m^2·a)
- R-37.5 walls, R-54.2 ceiling, R-22 basement walls, R-7 slab
- Windows: triple glazing

Background

The Canadian Mortgage and Housing Corporation (CMHC) has initiated a contest of 13 pilot and demonstration so-called EQuilibrium™ house projects, which refers to the Net Zero Energy building (NZEB) approach. EQuilibrium housing also incorporates the principles of occupant health and comfort, affordability, resource conservation and reduced environmental impacts. These significantly reduce greenhouse gas emissions and minimise the detrimental environmental impacts of housing on water, land and air. One winner of the contest was the concept of the Eco Terra™ house, which is a prefabricated house to be erected in one day. Field monitoring is ongoing since winter 2008.

Technical concept

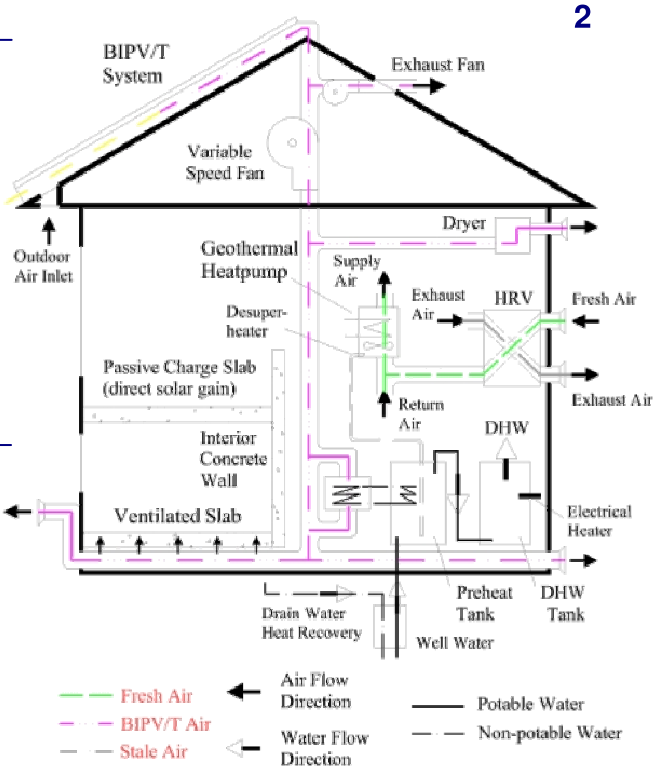
The technical concept of the EcoTerra™ house incorporates a highly efficient thermal envelope, the optimisation of passive solar gains, various energy recovery strategies, integrated renewable energy systems and sustainable building practices.

The EcoTerra™ house is a prefabricated house concept, which is delivered as six modules, which are assembled on-site in short time, including a technical pod in the basement and the PV/T system on the roof.

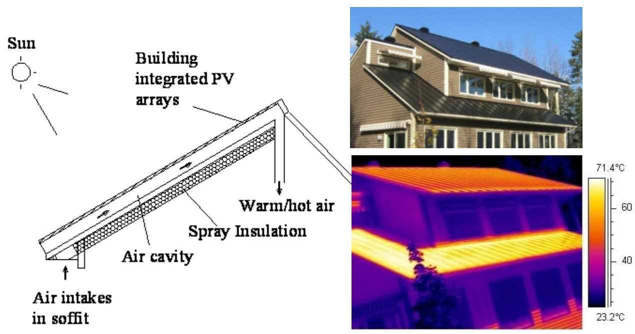
The high performance building envelope has a thorough thermal insulation avoiding thermal bridges and a triple glazing. The construction provides an open structure and massive concrete floor in order to store solar gains in the thermal mass and optimised for use of daylighting.

Energy recovery systems include a ventilation heat recovery integrated in the mechanical ventilation system, which is driven by EC motors and is controlled by the home automation system. Furthermore, a drain water heat recovery for preheating the fresh water is included.

The renewable energy systems consists of the core component is a 3 kW_p roof-integrated PV/Thermal (BIPV/T) array producing 3420 kWh annually, while the heat is used for clothes drying, for preheating the DHW and to heat-up the concrete slab for heating purpose. Moreover,



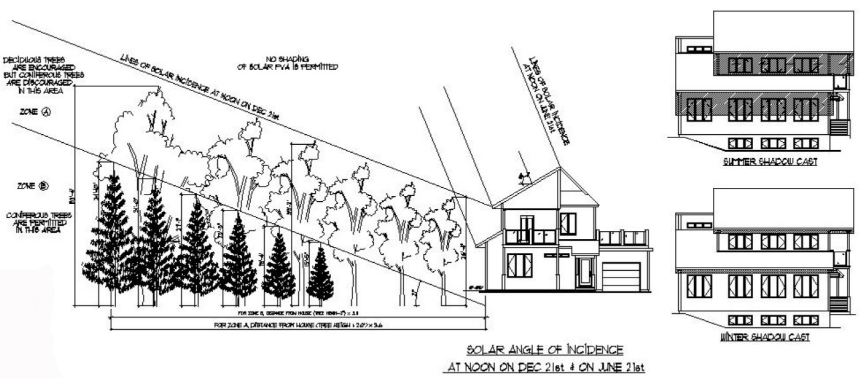
Components and layout of the system technology in the EcoTerra™ House



Principle and realisation of the Building Integrated Photovoltaic/Thermal (BIPV/T) system

State of market introduction

The house is sold by the Canadian home builder Alouette Home Ltd., so all components of the building and system technology are available on the market.



Planning of the shading of the EcoTerra™ house in Eastman

Technical components

Renewable energy systems

BIPV/T system:	**3 kW_p PV system, annual energy output 3420 kWh (calculated), Grid-connected with net metering system**
Heat pump	**3 ton, two-stage, ground-coupled heat pump**

Energy recovery systems

Ventilation	**mechanical ventilation system with EC motors and heat recovery, integrated in the home automation system**
Domestic Hot Water	**Drain water heat recovery**

Energy balance and field monitoring

Space heating represents the main part of annual energy consumption.

The annual gross space heating need of the house was estimated to 21795 kWh without the contributions of passive solar gains and renewable energies. With consideration of achievable passive solar gains of 9592 kWh/a and internal gains of 3491 kWh/a, the estimated net annual space heating need is reduced to 8712 kWh/a. The DHW need was approximated to 3353 kWh/a based on a DHW use of 150 l/d at 55°C.

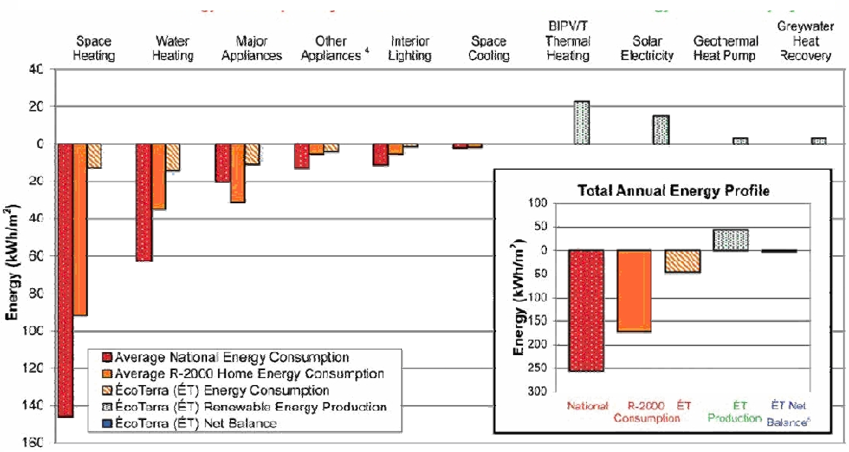
The annual electrical energy required for interior lighting, appliances and use electrical equipment (e.g. exterior lighting and dryer) was estimated to 3974 kWh/a and 617 kWh for mechanical ventilation. Thus, the total annual energy need of the house before the application of renewable energy technologies has been assessed to 16656 kWh/a.

The annual electricity generation potential of the solar PV system was evaluated to about 3420 kWh for a slope of 30° by use of RETScreen software, which, however, does not take into account the cooling effect of the air flow behind the PV laminates. The BIPV/T system is an on-grid application accompanied with an inverter for the AC/DC conversion. The system allows for redirection of the locally generated electricity surpluses to the grid.

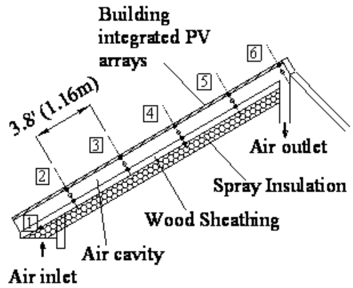
The PV/T heat recovery system of the EcoTerra™ house is estimated to provide 700 kWh/a of 900 kWh/a energy need for clothes drying. From November to March, the hollow core concrete thermal mass in the basement is heated by the warm air from the BIPV/T system. The BIPV/T system is therefore expected to reduce the space heating need by about 3800 kWh/a in the heating season. For the other 7 months, the BIPV/T is estimated to supply ≈1400 kWh/a of the annual DHW needs.

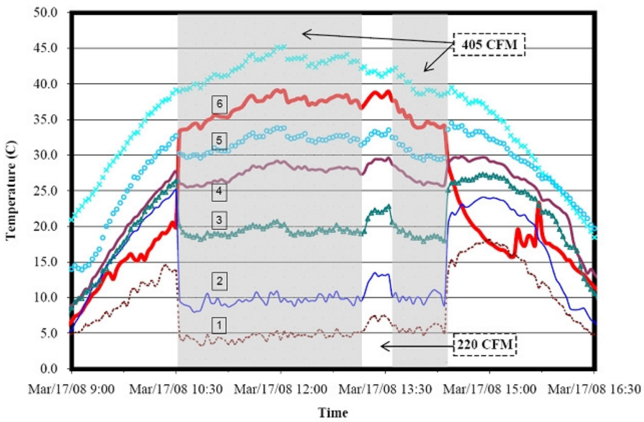
The electricity used for DHW could be reduced from 3353 kWh/a to 553 kWh/a by the heat pump desuperheater, BIPV/T system and a heat recovery of 21% of the drain-water depending on actual water consumption. If the storage volume is adequate, it can be heated further with the desuperheater. The energy consumption of indoor lighting, appliances and equipment was decreased to 3274 kWh/a with the reduced clothes dryer annual energy need. With the PV electricity generation of 3420 kWh/a, the annual energy consumption of the EcoTerra house can be re-estimated at 3856 kWh/a.

Field monitoring started in Nov. 2008 with the unoccupied home. and is intended to continue as long-term monitoring for about 3-5 years with occupants.

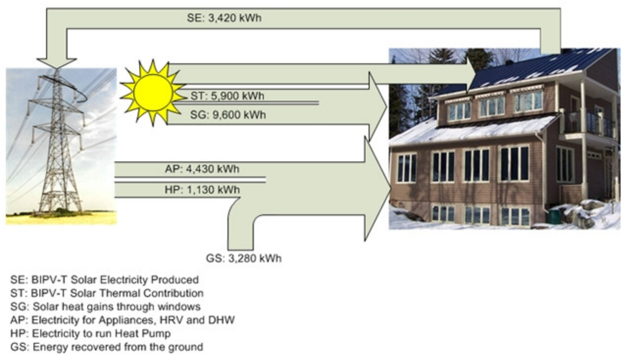


Calculated balance of the EcoTerra™ Equilibrium™ Net Zero Energy House





Measured air temperatures of the PV/T system



Simulated energy generation of the PV/T system

Calculated energies

Conventional home in Quebéc	
Annual consumption	**26000 kWh**
EcoTerra Home	
Gross space heating needs	**21795 kWh**
Passive solar gain	**9592 kWh**
Internal gains	**3491 kWh**
Net space heating needs	**8712 kWh**
Net DHW (incl. desuperheater)	**553 kWh**
Lighting, appliances, equipment	**3274 kWh**
Ventilation	**617 kWh**
Total need without renewable	**13156 kWh**
Generated electricity solar PV	**3420 kWh**
Clothes drying heat from the PV/T	**700 kWh**
Hollow floor slab heating	**3800 kWh**
Supply of DHW need in summer	**1400 kWh**
Net Energy demand	**3856 kWh**

Innovative concepts in Eco Terra NZEB

Building integrated PV/Thermal system (BIPV/T)
BIPV/T systems enable a double use of a solar PV system. While solar electricity is generated, PV panels heat-up by the solar irradiation, which deteriorates the efficiency of the cells. By cooling the PV-panels, heat can be recovered from the system, while the efficiency decrease can be avoided. In the EcoTerra™ House, the heat of the BIPV/T is used for drying clothes, as DHW preheating and is stored in a concrete slab for room heating purpose.

Modular prefabricated house concept with modular system technology
The EcoTerra™ house consists of prefabricated components, which can be assembled on the real estate in a short time. The building technology also follows a modular concept with the core components of the BIPV/T, the mechanical ventilation system and the ground-source heat pump.

Drain water heat recovery
90% of the energy used to heat water in a home is normally wasted out to the sewer. In the EcoTerra™ house a drain water heat recovery is installed to recover heat from the waste water. The unit called Power Pipe™ of a Canadian retailer consists of an inner copper drainpipe with soft copper tubes wrapped very tightly around the inner pipe. It is stated, that cold water temperature can be increased from 10 °C to 24 °C.

Economy, Ecology and Costs

Construction costs
The total construction cost add-up to ca. $350'000 (Canadian Dollar, excluding land) corresponding to about $230 per square foot, which is about $90'000 to $110'000 over the cost of a conventionally built home in Quebéc. The additional cost can be broken down to $20'000 - Building envelope, $50'000 for the energy recuperation, $5'000 for reduced electrical needs (lighting, appliances etc.), $5'000 for a reduced hot water consumption, $5'000 for the cost of the ventilation and $60'000 for the renewable energy installations (solar PV, solar thermal, geo-thermal, etc.)

Health
Reduced air leakage; balanced, fresh, filtered air to every room, uniform temperatures and humidity levels throughout the house, use of natural materials and finishes chosen to minimize indoor air pollution, optimization of natural lighting enhances the health of the inhabitants.

Sustainability
Wood frame, siding, flooring and cabinetry, use of recycled materials, off-site manufacturing and modular sections enable a more efficient use of materials, including extensive recycling Environmental covenants at building site, self contained water supply and waste water disposal and highly reduced carbon equivalent emissions contribute to the sustainability of the concept.

Imprint

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Alouette home Ltd.
E-mail:
Web: http://www.alouettehomes.ca

Field monitoring
Concordia University Montréal
Laboratoire des Technologie de l'Energie
Hydro-Quebéc, Shawinigan

Date of System Concept Sheet: June 2010

Literature

Bradley Berneche
Achieving Net Zero
Presentation National Marketing Committee, Canadian Home Builders Association, Ottawa, June 6, 2008

M. Noguchi, A. Athienitis, V. Delisle, J. Ayoub, B. Berneche
Net Zero Energy Homes of the Future - A Case Study of the ÉcoTerraTM House in Canada, Renewable Energy Congress, Glasgow, Scotland, July 19-25, 2008

Website of the EcoTerra™ house concept
http://www.maisonalouette.com/english/ecoterra2

EQuilibrium™ House with building integrated solar PV/T-system with heat pumps (Alstonvale Net Zero Energy House)

CMHC SCHL

EQuilibrium HEALTHY HOUSING FOR A HEALTHY ENVIRONMENT

Contribution of the Canadian national project

Summary

This System Concept Sheet outlines the technical concept of the Alstonvale Net Zero energy house (ANZEH) which is one of the winning house concepts in the EQuilibrium™ pilot and demonstration Initiative of the Canadian Mortgage and Housing Corporation. The house incorporates a passive solar design with large south-oriented windows and massive floor components to provide thermal mass to store solar gains. The main components of the technical building system are a roof-integrated 8.4 kW solar PV/thermal (BIPV/T) systems and two air-to-water heat pumps, which work on a 4500 l thermal energy storage. Outside air is used to cool the PV systems and serves as heat source for the heat pumps. Ventilated solar PV systems have higher efficiency, since a higher cell temperature decreases the efficiency by about 0.5%/K. Thus, the PV/T has a double effect, the preheated air as heat source and a higher electricity generation of the solar PV systems. To boost the outlet temperature, the air passes through 16 glass panes which serve as glazed air collector. For back-up operation in times without solar irradiation the heat pumps can be switched to a ground-source, as well.

Besides the housing, other aspects of sustainability like mobility and local food production are included in the concept, too. To achieve the net zero energy balance, simulation results yielded a required installed power of the solar PV of 5.5 kW. Further 1.5 kW PV power are dedicated for mobility with a hybrid electrically-driven car. For optical and fallout reasons (snow cover), effectively 8.4 kW solar PV has been installed.

Building data

- Location: Hudson, Québec, Canada
- Heavyweight building (brick walls/massive concrete floors)
- Floor area: 230 m^2/volume 630 m^3
- 50m^2 south-oriented windows, 43% of south façade
- Solar chimney connected to the indoor space
- U-value walls: 0.18, roof: 0.08, floor: 0.22 W/(m^2·K)
- triple glazed low-e windows with argon-filling, g-value:0.46

Background

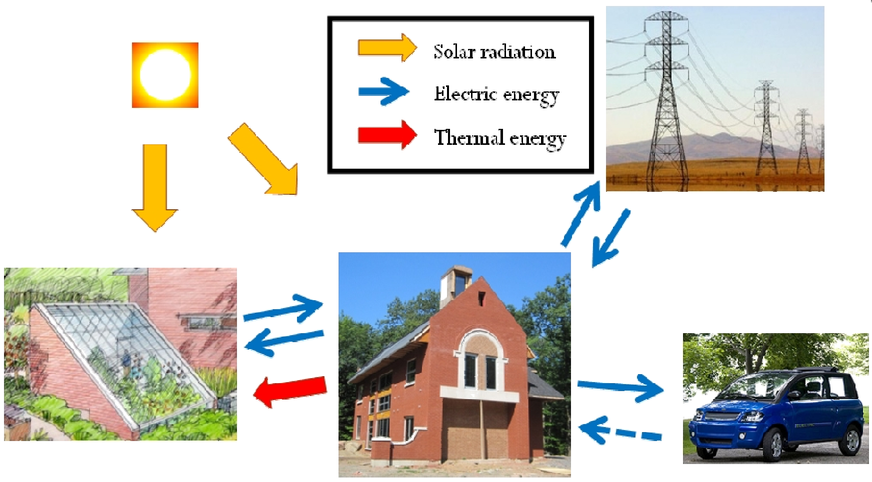
The Canadian Mortgage and Housing Corporation (CMHC) has initiated a contest of 13 pilot and demonstration so-called EQuilibrium™ house projects, which refers to the Net Zero Energy building (NZEB) approach. EQuilibrium housing also incorporates the principles of occupant health and comfort, affordability, resource conservation and reduced environmental impacts. This significantly reduces greenhouse gas emissions and minimises the detrimental environmental impacts of housing on water, land and air. One winner of the contest was the concept of the Alstonvale Net Zero Energy House, which is currently being finished. Field monitoring is scheduled to start in summer 2010.

Sustainability concept

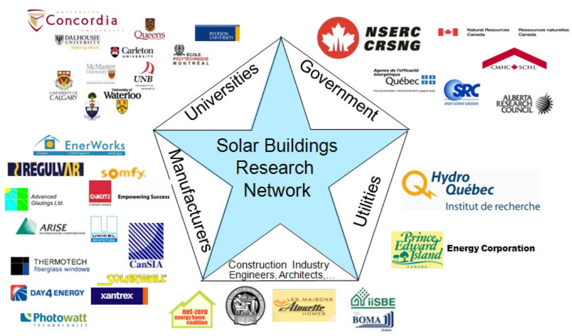
In addition to meeting the targets of the EQuilibrium™ Initiative, the Alstonvale Net Zero Energy House is proposing to go one step further as it strives towards a Net Zero Energy lifestyle by integrating efficient on-site mobility and food production methods to further reduce the household's energy footprint.
As key component the system incorporates an 8.4 kW building integrated photovoltaic/thermal system (BIPV/T) on its roof as the energy generation system for both electricity and thermal energy.
The thermal energy serves as heat source for a heat pump. Besides the electricity consumption of the house 1.5 kW of the generated electricity is dedicated to balancing the local transportation needs of the household, assuming an electric drive vehicle (EDV) as so-called plug-in hybrid-electric vehicle. Due to the volatile electricity generation, storage for the electricity is needed. Electric drive vehicle can provide local storage for the PV electricity. On the other hand, the EDV can back-up critical circuits of the house in case of emergency.
Industrial food production has become much more energy intensive by a factor of 25 compared to a local food production. Thus, a small greenhouse is also integrated in the concept.

State of market introduction

The concept of the Alstonvale Net Zero Energy house is a pilot and demonstration project, where both commercial and prototype technologies are applied.



Integrated systems to reach a Net Zero Energy lifestyle with the Alstonvale Net Zero energy house (Candanedo, 2009)



The project is supported by the Canadian Solar Buildings Research Network

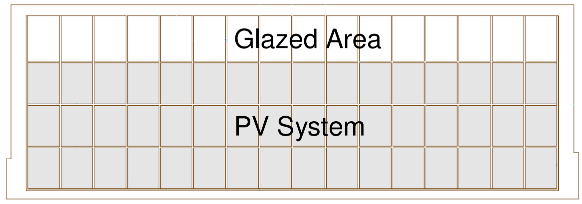
Development of energy consumption per produced calorie of food (SPD, 2009)

Technical installations

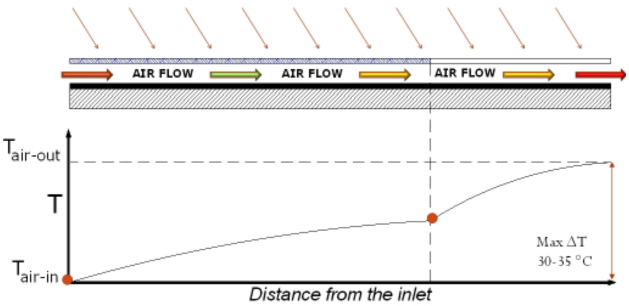
BIPV/T system:	**48 PV panel with 175 W_p**
	8.4 kW_p
Solar air collector:	**16 glass panels at the top of the PV panel array**
Heat pumps	**two heat pumps with 10.6 kW nominal capacity**
	Ground loop as back-up heat source for the heat pumps
Air-to-water HX	**8 rows of coils Cross section area 1.2 m^2**
Buffer storage volume	**4000 l**
Solar thermal collector	**6m^2 evacuated tube**
DHW storage volume	**400 l**

Technical concept

The field monitoring was planned for summer 2010, so results could not be covered in IEA HPP Annex 32.
The core component of the energy concept is a roof integrated solar PV/T system, which generates electricity and heats up outdoor air. The air is further reheated in an air collector, before it is led into the house by a duct. The hot air passes a heat exchanger, by which either a 4500 l water storage can be charged or the heat transferred is used as heat source for a heat pump. Due to changing volume flows and heat transfer rates depending on conditions a heat exchanger much larger as commonly used for domestic applications has been integrated.
For capacity control reasons two heat pumps of each 10.6 kW nominal capacity have been integrated. The configuration with two heat pumps offers, for instance, to work with very low flow rates and temperatures by operating only one heat pump and still deliver about 7 kW to the storage.
In times of low solar irradiation a ground-source is used as back-up heat source. This could be easily integrated by just additional piping and a 3-way valve and a pump.
The tank also has one additional coil permitting heat transfer between the buffer storage and the 400 l DHW tank. Two evacuated tube solar collectors (AP-20), each with about 3 m^2 of gross area and 20 tubes, are used for domestic hot water heating. Furthermore, a waste water heat recovery called "Power-pipe" is integrated to preheat the DHW. DHW is produced instantaneously using heated water from the DHW tank. Additionally, heat dissipater to release the excess heat, mainly in the summer months, is installed. In addition, a motorized canopy, which can be extended over the edge of the awnings to improve the shading of the windows in summer, will be used to cover the solar collector.
The Alstonvale Net Zero Energy house was equipped with over 200 measurement point. Unfortunately, the house was totally destroyed by a fire. Presently, it is not sure, if it will be re-built and monitoring will be accomplished as planned.

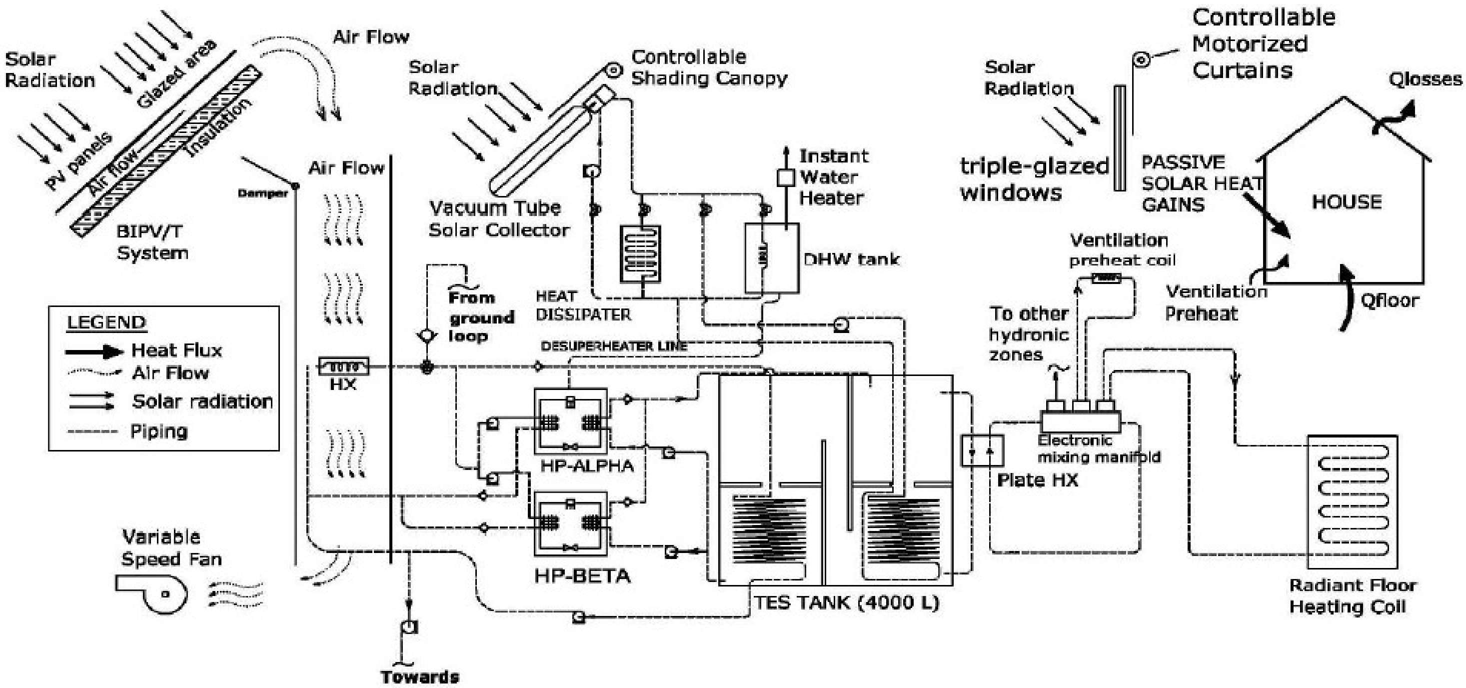


Realisation of the Building Integrated Photovoltaic/ Thermal (BIPV/T) system with air collector above



Example of the air temperature in the BIPV/T and the subsequent glazed air collector

Integrated concrete thermal energy storage for space heating and DHW preheating



Building energy systems of the Alstonvale Net Zero EQuilibium^{TM} House

Major technical innovations

Building integrated PV/Thermal system (BIPV/T)
PV/thermal (PV/T) systems enable a double use of a solar PV system. While solar electricity is generated, PV panels heat-up by the solar irradiation, which deteriorates the efficiency of the cells. By cooling the PV-panels, heat can be recovered from the system, while the efficiency decrease can be avoided.

Solar air-collector as booster for the BIPV/T
In order to boost the outlet temperatures of the solar PV/T system air collectors are integrated at the top of the solar PV system, where the preheated outlet air of the PV/T system is further reheated. Thereby, higher inlet temperatures as source of a heat pump or other applications are achieved.

Predictive weather forecast system control
The amount of solar irradiation is not constant by volatile depending on the local weather conditions. Thus, predictive control anticipating the available solar irradiation of the next day for the control of the system can hold efficiency gains, in particular for optimisation of the storage operation of the system.

Virtual storage by an electric drive vehicle
Many electrical drive vehicles (EDV) can collectively be used as virtual storage (vehicle-to-grid V2G), where the electricity stored in the vehicle batteries in off-peak hours or by household PV is used for peak shaving of the utility. Further on, a voltage and frequency stabilisation can be achieved as well as a stabilisation for large scale wind power.

Calculated energy balance

In order to prove the net zero energy balance, simulations of the PV system have been accomplished in the Canadian software RetScreen. The consumption per charge of a hybrid-electric vehicle has been estimated to be 9 kWh, allowing the user to drive for 40 km.

Calculated energy consumption

Annual consumption	
Heat pumps	2500 kWh
Fans and pumps	800 kWh
Domestic hot water	50 kWh
Ventilation	800 kWh
Lighting	350 kWh
Domestic appliances	3000 kWh
Electric plug-in vehicle	1600 kWh
Total	9000 kWh
Electricity generated (PV)	10000 kWh
Surplus electricity generation	1000 kWh

Conclusions

"A house is not just a home.
If designed intelligently, a house is the enabling backbone that supports a household's need for shelter, mobility, and food solely through a reliance on solar energy and without any associated GHG emissions."
(Sevag Pogharian Design)

Imprint

Architecture and Design
Sevag Pogharian Design (SPD)
Web: http://www.spd.ca

Field monitoring
Concordia University Montréal
José Candanedo, Prof. Andreas Athienitis

Laboratoire des Technologie de l'Energie
Hydro-Quebéc
Shawinigan

Date of Best practice sheet: June 2010

Literature

Sevag Pogharian, Josef Ayoub, Jose Candanedo et al.
Getting to a net zero energy lifestyle in Canada: the Alstonvale Net Zero Energy house, Conference paper 23th PV solar conference, Valencia, Sept. 2008, Download: http://www.spd.ca/

Further publications can be found on the
Alstonvale Net Zero Energy House project website
http://www.montrealzero.ca

System concept

Economical heating and cooling systems for low energy houses

Seasonal storage integrated heat pump concept with individual ground sources and demand controlled ventilation for the low energy homes

Agentschap NL
Ministerie van Economische Zaken

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Contribution of the Dutch national project

Summary

Individual seasonal storage systems can be effective in low energy houses, even in densely populated areas, because of the availability of very energy efficient cooling and the possible integration with solar thermal energy systems, offering a seasonal performance on primary energy of up to 2.5.

The demand controlled ventilation system automatically reduces the ventilation rate in separate rooms on the basis of CO_2 and humidity measurements. This greatly reduces thermal losses. In houses in a row and apartments, an energy performance up to the 2015 level can be reached even without ventilation heat recovery. In detached and semi-detached houses, a solar collector or shower heat exchanger can be added to achieve the same performance.

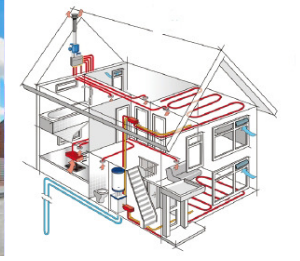
The system concept consists of:

- Heat pump 3.5 to 5 kW_{th}, floor heating, vertical closed ground source (brine or water) 60-90 m, hot water storage tank 150 – 200 l
- Demand regulated ventilation system 300 m^3/h
- Several options are possible

Building outline for the concept

Application:

- Single family homes, detached and semi-detached houses, apartments (collective source).
- The low temperature floor heating system avoids turbulence of the room air, which is beneficial for people with allergies, respiratory diseases or elderly inhabitants.
- Annual heating primary energy 8.7 $kWh_{prim}/(m^2 \cdot a)$
- Annual total energy ex user equipment: 50.3 $kWh_{prim}/(m^2 \cdot a)$
- User energy incl. cooking : 21.6 $kWh_{prim}/(m^2 \cdot a)$
- Functions: Heating, cooling, hot water, ventilation
- Identified optimisation potentials: capacity reduction, integration with ventilation system and building
- Costs € 14.000 (heat pump and source, balanced ventilation with heat recovery)


Background

In the EU, all buildings commissioned after January 1st, 2019 will be required to be net zero, meaning that a building's carbon emissions are offset by the generation of energy through non-carbon-emitting means. In the Netherlands some local goals are more ambitious and are set to reach net zero for projects commissioned after 2015 or even 2010, for a part of the volume. In 2011, the national energy performance requirement for dwellings will be changed from the present energy performance coefficient (EPC) of 0.8 to 0.6, comparable to passive house level plus 50%, bringing it to an effective low energy level. This includes room heating, cooling, hot water, lighting, ventilation and auxiliary energy, but not the energy consumption for consumer appliances such as washing, drying, computers and audio/video equipment.

This heat pump concept has been developed recently, originally in a reaction to the public concern on balanced ventilation systems, but has proven to be viable in its own right, reaching an excellent energy performance at acceptable costs. One of the first applications is in a development project in the city of Ypenburg by a consortium of developer / builder Dura Vermeer, Nieman installation consultants, Van der Giessen-de Graaf installation engineers and producer Itho. These parties have worked together to develop the concept and continue to further improve the concept, the integration in the building and the building process. By rethinking the specifications of building parts, a further energy performance improvement in the Ypenburg project from 0.43 to 0.37 (15%) has been achieved at virtually no cost. This is also partly achieved by improved air tightness of the shell.

The system can be extended by a thermal solar collector and a shower heat recovery system, leading to lower energy consumption, but also to higher initial costs. Market research in the Ypenburg project has shown that most buyers are willing to pay more for a house with this heat pump concept as compared to the alternative, a house with heat distribution, but up to a limit of € 5.000 to € 7.000, as financing may become problematic. For this reason, no solar collector and shower heat recovery system have been implemented.

Technical concept

Heat pump systems are still relatively new to the Dutch housing market, the standard technology being natural gas heating with condensing boilers. The higher cost of heat pump systems has slowed down the market penetration.

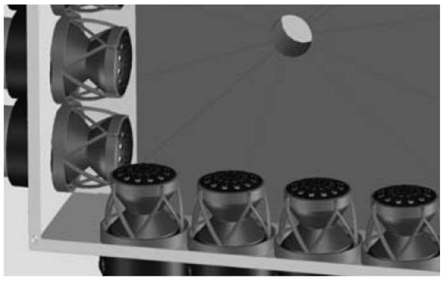
The next change in the energy performance requirement can still be met by gas systems, combined with ventilation heat recovery, solar energy and reduction of losses. From 2011, fuel cells systems using natural gas will be available suitable for heating and electricity production for individual houses. This will probably be a competitor, but also a partner for heat pump systems, using the smart grid concept.

To reduce building costs, and to be able to meet the increasing demands on building performance in the field of energy, acoustic insulation, fire safety and recycling of materials, the building industry switches more and more to prefabricated parts and components. Prefabricated floors and walls can come with a low temperature heating system already built-in.

A closed ground heat exchanger offers good working conditions for a heat pump in heating mode. The relatively cold water from the ground source can be used directly for cooling in summer, with only very little auxiliary energy consumption.

Several producers have developed advanced demand controlled ventilation systems and integrated these with heat pump systems. Demand controlled ventilation systems measure CO_2 and humidity in each room and adjust the ventilation rate accordingly, ensuring a good climate, avoiding user error, reducing the energy loss through ventilation and perceived ventilation noise. The sensors and the valves can be located in a central plenum box, and the air from each room is sampled sequentially. This system is self adapting and needs no tuning. It will do this automatically.

Demand Flow plenum box and controller (Itho)



Plenum box valves (Itho)

Pressure controlled vent

Technical data of the unit

3.44 kW$_{th}$ brine-to-water heat pump R407C

COP room heating 6.0 (exclusive well pump)

COP hot water 2.65

Demand regulated ventilation system, 300 m^3/h max

Pressure operated vents

Backup: resistance heater

Noise emissions
38 dB (A) (heat pump)

Storage volume 200 l

Demand regulated ventilation system,
365 m^3/h max (@ 100 Pa)

Field monitoring

Project: De Caaien, Ypenburg

Location: near The Hague

Type: single family terraced (row-)houses

Monitored house:
floor area: 107 m^2, house in a row

Walls	R_c = 3.5 m^2K/W
Roof	R_c = 5.0 m^2K/W
Ground floor	R_c = 3.0 m^2K/W
Glazing	U_c = 1.2 (1.7) $W/(m^2K)$
Infiltration	0.625 $l/(s \cdot m^2)$
EPC	0.40- 0.45
CO_2-emission annual	1346 kg (building related energy)

Number of units to be monitored: more than 250

Variables monitored:
- room temperature
- temperature setting,
- ground source temperature
- hot water temperature
- operating mode of heat pump
- floor heating temperature

Monitoring will start later in 2010

Expected Performance indicator

CO_2-emission reduction

CO_2 reduction building energy compared to conventional: 46%

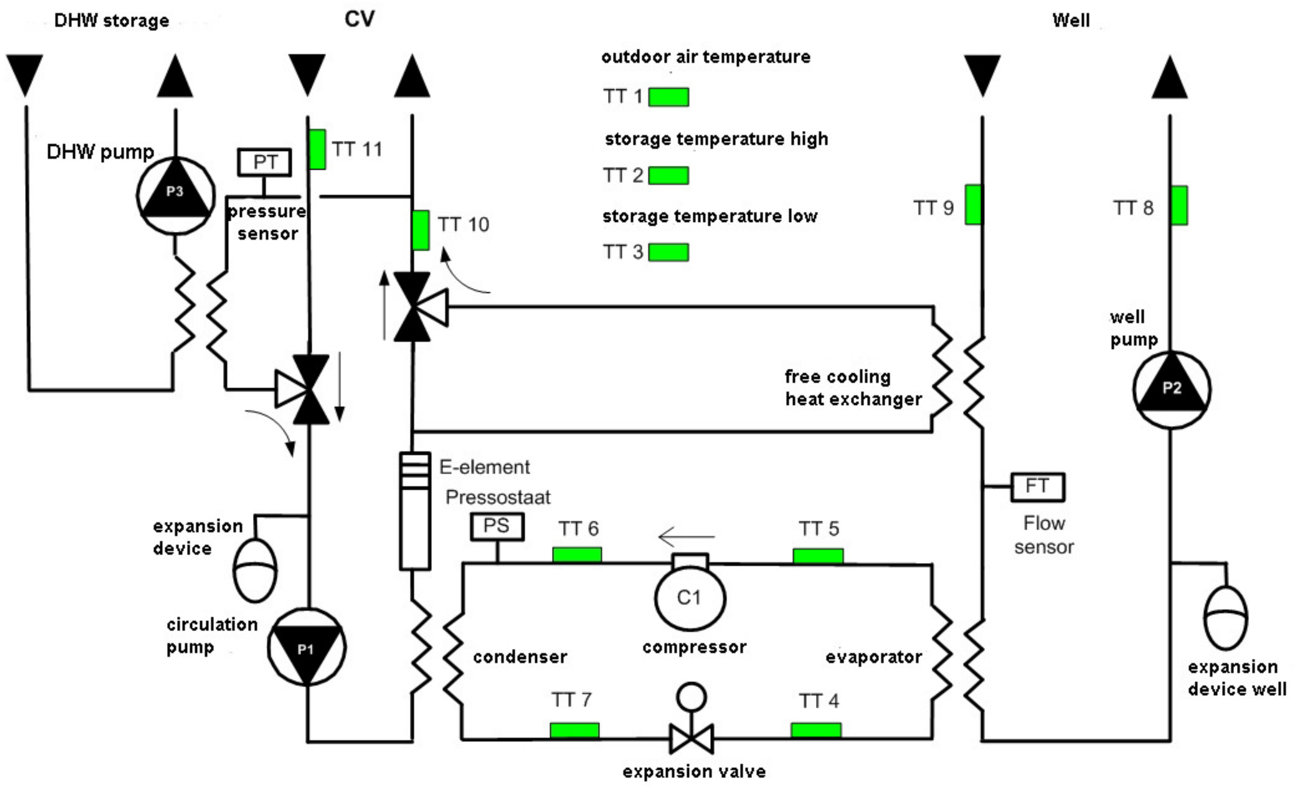
CO_2-reduction incl. user energy: 28%

Seasonal performance primary energy

Tap water primary performance including losses: 118 %

Back-up system: not needed during normal operation

Heating primary performance including auxiliaries and losses : 240%



Monitoring set-up (remote monitoring data acquisition)

Technical innovations system concept

A recent development is the demand controlled natural ventilation system. In this system, the ventilation air is allowed to enter the room directly from the outside through a heating unit, only when necessary. The necessity can be determined by a time schedule or by measuring the CO_2 concentration and humidity of the room air. An actuator automatically regulates the air flow accordingly. As a result, the heat loss due to ventilation is greatly reduced and a good energy performance can be reached without the need for an ventilation air heat recovery system. This system is combined with a ground source heat pump for floor heating and hot water production. The source is regenerated by subtracting thermal energy from the floor during warm periods in the summer, when cooling is needed. The thermal balance is achieved by a careful design of the building and dimensioning of windows.
Several producers have developed advanced demand controlled ventilation systems and integrated these with heat pump systems. Demand controlled ventilation systems measure CO_2 and humidity in each room and adjust the ventilation rate accordingly, ensuring a good climate, avoiding user error, reducing the energy loss through ventilation and perceived ventilation noise. The sensors and the valves can be located in a central plenum box, and the air from each room is sampled sequentially. This system is self-adapting and needs no tuning. It will do this automatically.
In order to achieve energy neutrality, the system can be further improved by adding a solar collector, a charge boiler at tap points and hot fill connections washing equipment.

Economy, Ecology and Cost Aspects

A heat pump with ground source will produce heating, cooling and hot water.
A gas boiler can only produce heating and hot water. In order to achieve cooling, an additional investment is necessary and operating costs will occur.
When this and the lower energy bill are taken into account, a ground source heat pump is an attractive option.

Ecology
Heat pump systems are the best performers on CO_2-emission reduction. This will even improve as more sustainable electricity is fed on the grid. The CO_2-emission can be reduced further by integrating sustainable energy systems such as a solar collector or photovoltaic cells.

Other environmental benefit
In homes, the internal space is important. Heat pump systems can appear to take o lot of room, but this does not take into account that no flue channel and radiators are necessary. The room requirement is actually less than for a conventional system, providing the building is optimized for the heat pump system

Adaptable buildings
Demand-controlled ventilation systems will adapt to changes in the way a room or a building is used. This creates some flexibility for the user, as no costly retuning is necessary. It is also possible to take away or relocate internal walls, as long as the ventilation vents remain clear.

Imprint

Developer:
Mr D. Broekhuizen
PCS Concept: Dura Vermeer,
Leidschendam

Development:
Itho, Schiedam
Nieman installation consultants
Van der Giessen-de Graaf installation engineers
Link: www.itho.nl

Date of System concept sheet: June 2010

Literature

Monitoring results will be available through Dura Vermeer

Technical reports: upon request (in Dutch)

Seasonal storage and solar collector integrated heat pump concept with individual ground sources for the application in low energy homes

Agentschap NL
Ministerie van Economische Zaken

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Contribution of the Dutch national project

Summary

Individual seasonal storage systems can be effective in low energy houses, even in densely populated areas, because of the availability of very energy efficient cooling and the integration with solar thermal energy systems, offering a seasonal performance based on primary energy of 2.5 and better.

The system concept consists of:

- Individual heat pump (7-9 kW_{th}) and vertical ground sources (brine or water, 150 m)
- Solar collector 2.8 m^2 with 150 l storage tank
- Floor or wall heating
- Ventilation system with heat recovery 300 m^3/h

Building outline for the system concept

Application:
Single family homes, detached and semi-detached houses, apartments, where heating and space cooling is required. Homes adapted to people with allergies or respiratory diseases, homes for the elderly, homes in smog risk areas.

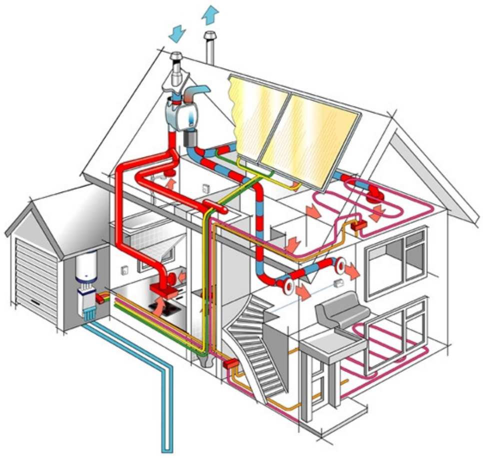
- Heat pump 3.5 to 9 kW_{th}, floor heating, solar collector 2.8 m^2, vertical closed ground source (brine or water)
- Functions: Heating, cooling, hot water, dehumidification, ventilation
- SPF on primary energy: 2.5 (heating and hot water)
- Identified optimisation potentials: capacity reduction, integration with ventilation system and building
- Costs € 18.000 (2003 prices for heat pump and source, solar boiler, ventilation with heat recovery)

Background

In the EU, all buildings commissioned after January 1st, 2019 will be required to be net zero, meaning that a building's carbon emissions are offset by the generation of energy through non-carbon-emitting means. In the Netherlands some local goals are more ambitious and are set to reach net zero for projects commissioned after 2015 or even 2010, for a part of the volume. In 2011, the national energy performance requirement for dwellings will be changed from the present 0.8 to 0.6, comparable to passive house level plus 50%, bringing it to an effective low energy level. This includes room heating, cooling, hot water, lighting, ventilation and auxiliary energy, but not the energy consumption for consumer appliances such as washing, drying, computers and audio/video equipment.

While not obligatory, several parties have already developed and built projects with an energy performance that meets the low energy level. This performance is obtained by a combination of improved insulation quality of the building, south orientation and an efficient energy system, at least partly based on sustainable energy and thermal storage.

Thermal storage in the underground or in aquifers can be considered a standard technique in the Netherlands and is widely applied for utility buildings. Several collective heat pump systems are operational in the housing sector. Also a limited number of projects using individual heat pumps are operational. Proposed new low energy housing projects frequently use individual heat pumps.



Concept with integrated solar collector

Technical concept

Heat pump systems are still relatively new to the Dutch housing market, the standard technology being natural gas heating with condensing boilers. The higher cost of heat pump systems has slowed down the market penetration.

The next change in the energy performance requirement can still be met by gas systems, combined with ventilation heat recovery, solar energy and reduction of losses.

To reduce building costs, and to be able to meet the increasing demands on building performance in the field of energy, acoustic insulation, fire safety and recycling of materials, the building industry switches more and more to prefabricated parts and components. Prefabricated floors and walls can come a with low temperature heating system already built in.

A closed ground heat exchanger offers good working conditions for a heat pump in heating mode. The relatively cold water from the ground source can be used directly for cooling and dehumidification in summer, with only very little auxiliary energy consumption.

Balanced ventilation systems offer the possibility to effectively use the heat from the exhaust air to heat the incoming air through a ventilation heat exchanger, with a recovery rate of up to 95%, leading to a reduction in energy demand for room heating (and in principle, cooling). A solar collector of 2.8 m2 with a storage tank will normally produce all the hot water needed for a family during the summer months and for regenerating the ground source, in addition to the heat obtained by the cooling system. In colder and less sunny periods, the heat pump will process the water further the required temperature.

A solar collector is used for both hot water production on sunny days and for ground source regeneration on colder days. This way, the solar panel has the highest possible performance: even with an outside temperature of 10 degrees and lower the solar panel are used to regenerate the ground source.

Technical data of the unit

Heat pump	**2 compressors**
	3kW+5kW
COP	**6 (heating)**
	3 (hot water)
Storage tank	**150 l hot water**
Refrigerant	**R134A**
Elec. backup	**5 kW**
Noise	**45 dB(A)**
Storage volume	**2 m^3**
Ventilation	**300m^3/hr**
	95% recovery

Figures apply to current units

State of market introduction

The technology has been applied in several low energy projects and is actively co-marketed by producers and project developers.

Market state

The technology has been applied in several projects and is actively co-marketed by Itho and project developers.

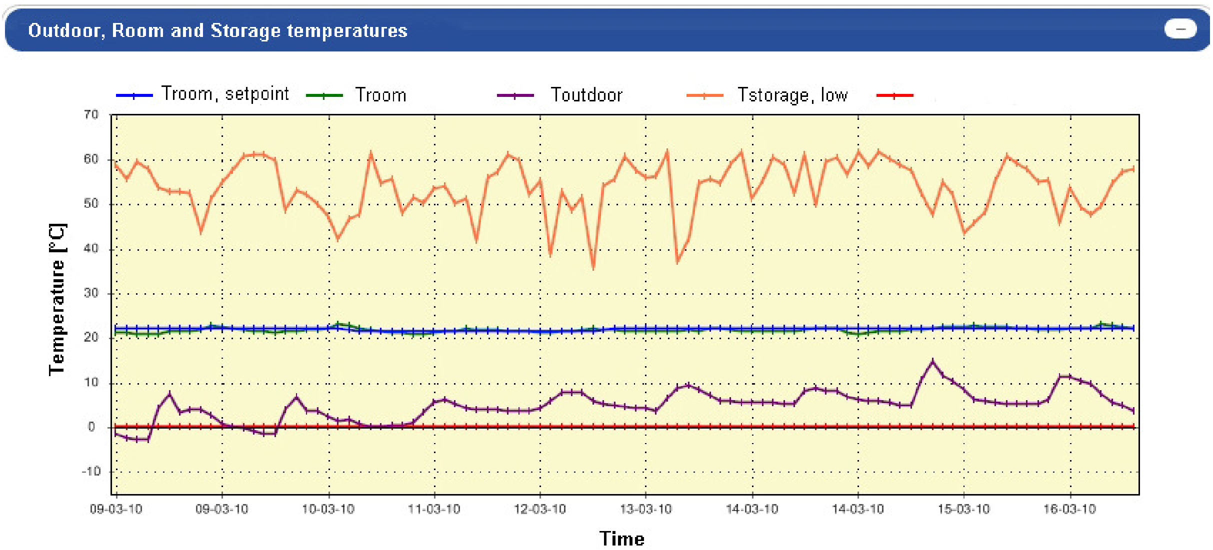
Field monitoring

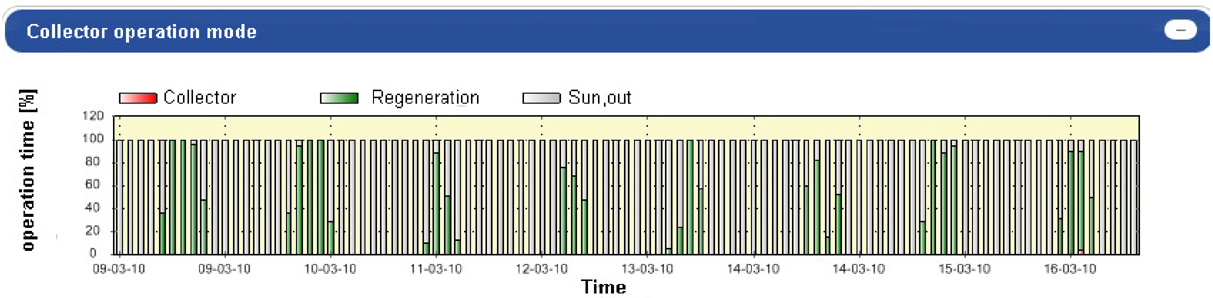
Project: Carré, Delfgauw
(ground source heat pump, balanced ventilation, solar collector)

Location:	Delfgauw, near Delft
Type:	single family terraced (row-)houses
Monitored house:	floor area: 90 m^2
Walls	R_c = 3.5 m^2·K/W
Roof	R_c = 4.0 m^2·K/W
Ground floor	R_c = 3.5 m^2·K/W
Glazing	U_c = 1.2 W/m^2·K
Infiltration	0.625 l/s·m^2
EPC	0.6

Number of units monitored: 1
Variables monitored: inside/outside temperature, solar regeneration, floor temperature
Occupant influence: the occupants use large quantities of hot water, approx double the expected volume

Results:
Energy consumption: system runs on approximately 5 kW_{th} on cold days, 40% lower than expected. This can be explained by the regeneration of the source by the solar collector. The ground source temperature has risen 5° C, including the cold winter of 2009/2010, after 5 years.
The solar panel contributes even at exterior temperatures below 10°C. While contribution of the collector to the hot water production under these circumstances is limited to a few hours per day, the temperature outside these hours will still be enough to store the energy in the (closed) ground source. The higher source temperature leads to better heating-COP of the heat pump.





Field monitoring values of the described system concept

Technical innovations in system concepts

The presented system was used in dwellings designed in 2001 and built in 2002. Thanks to improved isolation quality, the solar panels are no longer necessary in this concept. The power necessary for room heating, and the energy supplied by the ground source, currently are 40% lower than in 2002. Therefore the solar panel, which is an expensive component to produce and install, is not used in current projects.

In Eindhoven, Berckelbosch, Ballast Nedam is developing energy neutral (net-zero) single family terraced houses with the described concept without the solar panel.

Monitoring of these heat pumps has not started, yet.

Economy, Ecology and Costs

A heat pump with ground source will produce heating, cooling and hot water. A gas boiler can only produce heating and hot water. To achieve cooling, an additional investment is necessary and operating costs will occur. When this and the lower energy bill is taken into account, a ground source heat pump is an attractive option.

Ecology
Heat pump systems are the best performers on CO_2-emission reduction. This will even improve as more sustainable electricity is fed on the grid. The CO_2-emission can be reduced further by integrating sustainable energy systems such as a solar collector or photovoltaic cells.

Other environmental benefit
In homes, the internal space is important. Heat pump systems can appear to take a lot of room, but this does not take into account that no smoke channel and radiators are necessary. The room requirement is actually less than for a conventional system, providing the building is optimized for the heat pump system.

Imprint

Company
Woningcorporatie Rondom Wonen, Delfgauw
Energy concept: Itho, Schiedam
Consultans: W/E Adviseurs, Utrecht

Development
Itho, Schiedam

Date of System concept sheet: June 2010

Literature

Evaluation report available through AgentschapNL

System concept

Economical heating and cooling systems for low energy houses

Seasonal storage with collective ground source system for low energy apartments

Agentschap NL
Ministerie van Economische Zaken

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Contribution of the Dutch national project

Summary

By distributing water at ground source temperature, very energy efficient free cooling is available in all apartments. Individual heat pumps use the same source for the heating and hot water. Hot water is produced at night, when no room heating is required, and stored for use during the day. The low temperature of the two-pipe system avoids thermal distribution losses.
The source consists of several vertical heat exchangers, connected in parallel. The flow of all sources is matched by tuning the flow resistance. Thermal energy from the floor cooling system is fed into the system in the summer, regenerating the source. The heat capacity of the underground will level out variations in the energy balance from year to year. An overall balance is achieved by careful dimensioning of windows and openings.
The system concept consists of:

- Individual heat pump (3.5 kW_{th}) and collective vertical ground source system (33 closed loop sources, 120 m depth)
- Floor or wall heating
- Ventilation system with heat recovery 300 m^3/h

Building outline for the system concept

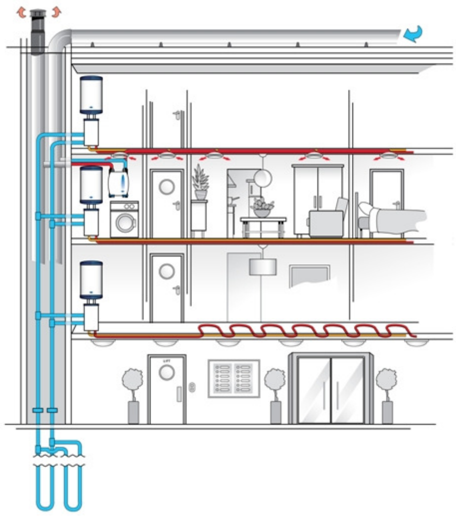
- Application: Apartments and high density housing blocks.
- Heat pump 3.5 to 7kW_{th}, floor heating, collective vertical closed ground source (water)
- Functions: Heating, cooling, hot water, ventilation
- Identified optimisation potentials: capacity reduction, integration with ventilation system and building
- Costs per apartment € 7.000 (Heat pump, boiler and shared collective source system, distribution system)

Background

In the EU, all buildings commissioned after January 1st, 2019 will be required to be net zero, meaning that a building's carbon emissions are offset by the generation of energy through non-carbon-emitting means. In the Netherlands some local goals are more ambitious and are set to reach net zero for projects commissioned after 2015 or even 2010, for a part of the volume. In 2011, the national energy performance requirement for dwellings will be changed from the present 0.8 to 0.6, comparable to passive house level plus 50%, bringing it to an effective low energy level. This includes room heating, cooling, hot water, lighting, ventilation and auxiliary energy, but not the energy consumption for consumer appliances such as washing, drying, computers and audio/video equipment.

While not obligatory, several parties have already developed and built projects with an energy performance that meets the low energy level. This performance is obtained by a combination of improved insulation quality of the building, south orientation and an efficient energy system, at least partly based on sustainable energy and thermal storage.

Thermal storage in the underground or in aquifers can be considered a standard technique in the Netherlands and is widely applied for utility buildings. Several collective heat pump systems are operational in the housing sector. Also a limited number of projects using individual heat pumps are operational. Proposed new low energy housing projects frequently use individual heat pumps.



Sketch of the system configuration

Technical concept

Heat pump systems are still relatively new to the Dutch housing market, the standard technology being natural gas heating with condensing boilers. The higher cost of heat pump systems has slowed down the market penetration.

The next change in the energy performance requirement can still be met by gas systems, if combined with ventilation heat recovery, solar energy and reduction of losses

To reduce building costs, and to be able to meet the increasing demands on building performance in the field of energy, acoustic insulation, fire safety and recycling of materials, the building industry switches more and more to prefabricated parts and components. Prefabricated floors and walls can come with a low temperature heating system already built-in.

A closed ground heat exchanger offers good working conditions for a heat pump in heating mode. The relatively cold water from the ground source can be used directly for cooling and dehumidification in summer, with only very little auxiliary energy consumption.

Balanced ventilation systems offer the possibility to effectively use the heat from the exhaust air to heat the incoming air through a ventilation heat exchanger, with a recovery rate of up to 95%, leading to a reduction in energy demand for room heating (and in principle, cooling).

Technical data of the unit

- **Collective closed ground sources**
- **Individual heat pump per dwelling for heating, cooling and hot water**
- **COP approx 6 for heating, COP approx 3 for hot water**
- **Balanced ventilation with a recovery rate of 95%**

State of market introduction

The technology has been applied in several low energy projects and is actively co-marketed by producers and project developers.

Field monitoring

De Tas, Biddinghuizen

Project: De Tas, Biddinghuizen
Type: apartment building for seniors
Monitored house:
floor area: 54 dwellings each approximately 76 m^2

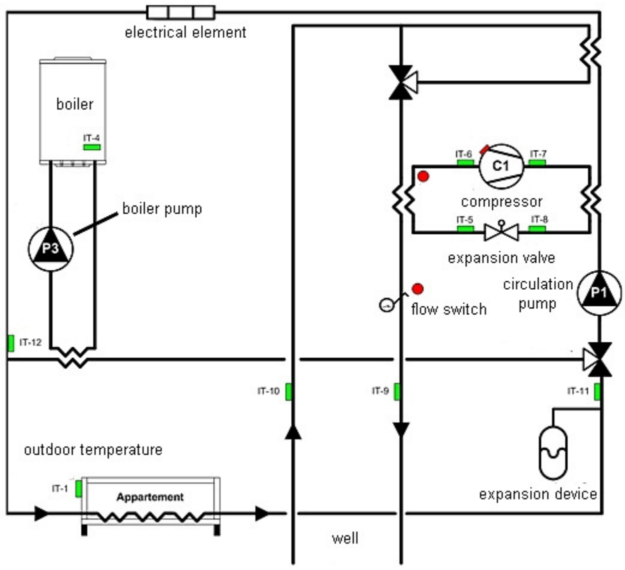
Walls	R_c = 3,0 m^2·K/W
Roof	R_c = 3,0 m^2·K/W
Ground floor	R_c = 3,0 m^2·K/W
Glazing	U_c = 1.2 W/m^2·K
Infiltration	0.625 l/s·m^2
EPC	< 0.5

Number of units monitored: 54

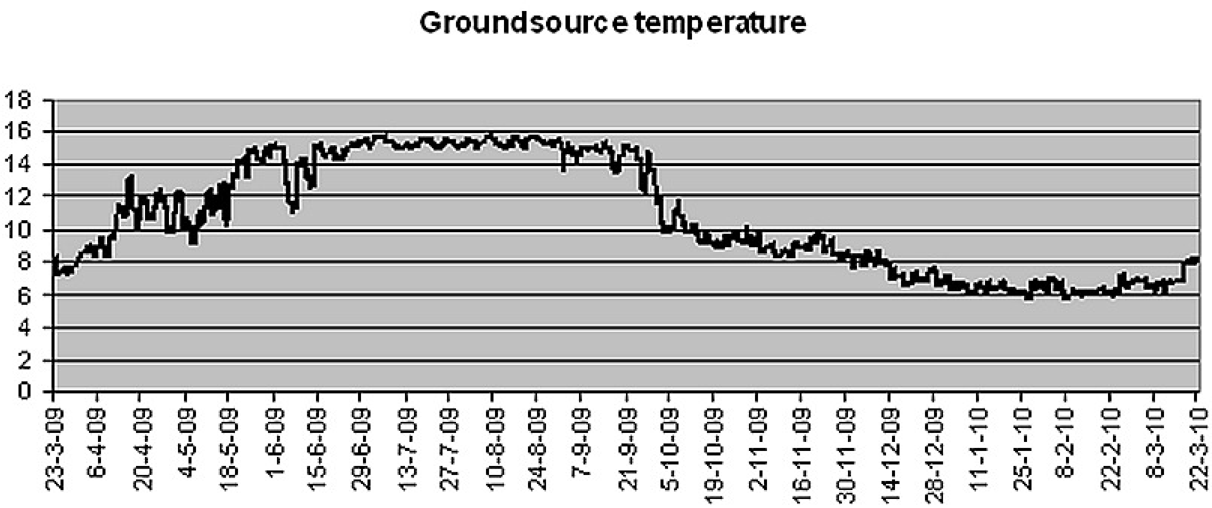
Variables monitored: room temperature, room temperature setting, operating mode, temperature, ground source temperature

Evolution of ground source temperatures over one year

Results:
Even after a very cold winter, the ground source temperature a the end of the winter is the same as one year earlier, and starts to build up as early as in March. This can be explained by the oversized ground source system giving an ample peak capacity and thermal regeneration of the sources through heat conduction in the underground from parts further away from the sources. The resulting temperature swing of the extracted water is only 9 degrees Celcius, and the temperature never reaches the freezing point. This also has the advantage that pure water can be used as the medium in the closed sources, avoiding the risk of contamination of the underground in the unlikely event of leaks altogether.
The source system consists of two loops: a ground source loop and a circulation loop, coupled through a mixing box. These systems are regulated separately. Experience shows that source circulation is not necessary in large parts of the year, leading to energy conservation.
Compared to the cost of gas equipment and heating, the system is cost effective, offering lower emissions and increased comfort through the availability of cooling.



Hydraulic sketch of the field monitoring plant



Evolution of ground source temperatures over one year

Technical innovations

In the Netherlands, ground source heat pumps are often used with an individual source, i.e. one or more ground collectors per dwelling. Typically, the ground source has a footprint of approximately 25 to 50m^2.

For apartment dwellings this is often not possible, as the available area for ground sources is not sufficient. The proposed concept therefore uses a system of parallel ground sources creating one closed loop ground source for a number of apartments. Each apartment has an individual heat pump to supply heating and hot water.

The separate regulation of the collective source system and distribution system leads to energy conservation in the source pump and has simplified the control algorithms and control conflicts. The source system kicks in automatically on the basis of the temperature in the mix box. The circulation pump maintains a constant pressure on the supply side of the distribution system. By using a reverse return system, an equal flow in the parallel branches of the distribution system is realised, without the use of flow restrictions. The individual heat pumps have an intelligent PID-control system.

Economy, Ecology and Costs

A heat pump with ground source will produce heating, cooling and hot water. A gas boiler can only produce heating and hot water. To achieve cooling, an additional investment is necessary and operating costs will occur. When this and the lower energy bill is taken into account, a ground source heat pump is an attractive option, with a pay back time within 12 years.

Ecology

Heat pump systems are the best performers on CO_2-emission reduction. This will even improve as more sustainable electricity is fed on the grid. The CO_2-emission can be reduced further by integrating sustainable energy systems such as a solar collector or photovoltaic cells.

Other environmental benefit

In homes, the internal space is important. Heat pump systems can appear to take o lot of space, but this does not take into account that no stack gas channel and radiators are necessary. The room requirement is actually less than for a conventional system, providing the building is optimised for the heat pump system

Imprint

Company

Oost Flevoland woondiensten, Biddinghuizen
Itho systems, Schiedam

Development

Itho systems, Schiedam

Date of System concept sheet: June 2010

Literature

Monitoring results will be forthcoming

System concept

Economical heating and cooling systems for low energy houses

Integrated water-to-water propane heat pump installed in a passive house in Southern Norway

NTNU SINTEF

Contribution of the Norwegian national project

Summary

This System Concept Sheet describes the field-monitoring of a 2.9 kW water-to-water propane (R290) heat pump prototype installed in a passive house in Flekkefjord (Southern Norway). The heat pump system covers the entire space heating (SH) and domestic hot water (DHW) demand in the residence. The heat pump can be operated in SH mode, DHW mode and in simultaneous mode. The heat pump supplies heat to a low-temperature (LT) storage tank for SH and preheating of DHW and a high-temperature (HT) DHW storage tank. The LT storage tank is connected to a low-temperature floor heating system. The DHW temperature is about 60-65 °C and the supply temperature in the SH system is about 35 °C.
The field monitoring started in autumn 2007. The weighted average SPF is **3.7** excluding the electricity to operate the pumps while the average SPF including the total energy input to the compressor and pumps is **3.1**. These values correspond to about **70% energy saving** compared to an electric heating system. During testing of the heat pump unit an optimisation potential for the evaporator and the expansion valve operation have been detected.

Building Data:

- Location: Flekkefjord, Southern Norway
- Inhabitant: 2 adult persons
- Total floor area: 172 m^2
- Total calculated heat demand (SH/DHW): ~35 kWh/(m^2·a)
- Wall/roof: U-value 0.1/0.09 W/(m^2·K)
- Window area: 83 m^2, 63% south-facing
- Windows: Low-e triple glazing with Argon gas, U-value 1.0 W/(m^2·K)

Background

A novel propane water-to-water prototype heat pump system for space heating (SH), domestic hot water (DHW) and simultaneous SH and DHW has been designed, constructed and field monitored by NTNU and SINTEF Energy Research. Design goals were the use of a natural and environmentally benign refrigerant, minimum condensation temperatures for all operation modes, monovalent design for DHW temperature up to 60-65 °C and design of the unit according to the safety regulations in EN 378.

Technical Concept

The heat pump unit has a desuperheater connected to a high temperature (HT) storage tank for domestic hot water (DHW) and a condenser connected to a low temperature (LT) storage tank for SH and preheating of DHW. Both storage tanks have integrated coils of stainless steel.

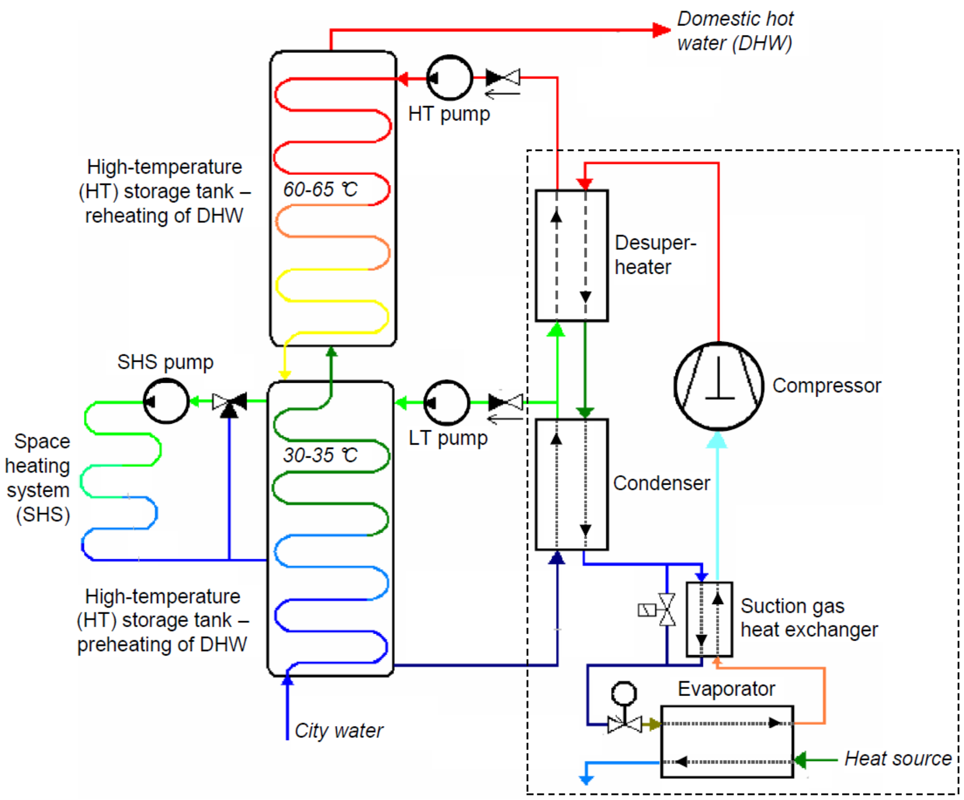
The heat pump unit utilizes a suction gas heat exchanger (SGHX) in combination with a desuperheater (DHX) which raises the discharge gas temperature to maximum 100°C. The superheat, which is used for DHW heating, constitutes about 30% of the total heating capacity of the heat pump. To limit the maximum discharge gas temperature, the SGHX can be by-passed.

Due to the high flammability (AIT* 470°C, LEL/UEL** 2.1, 9.5%) and a charge of 250 g (>150 g) of the refrigerant propane (R290, C_3H_8, GWP 3), an indirect, closed design of the heat pump in a gas-tight cabinet (IP 20) has been applied. The cabinet is vented to the ambient and has leak detectors connected to a visual alarm. All joints for the heat pump unit inside the cabinet are soldered; the system uses ex-proof high- and low-pressure controllers (IP 44) and a gas-tight cabinet for the electrical equipment (IP 20). In DHW mode the cold city water is preheated in the LT tank and reheated in the HT tank. In simultaneous heating and DHW mode, both the desuperheater and condenser are operative. In SH mode only the condenser works on the LT storage tank.

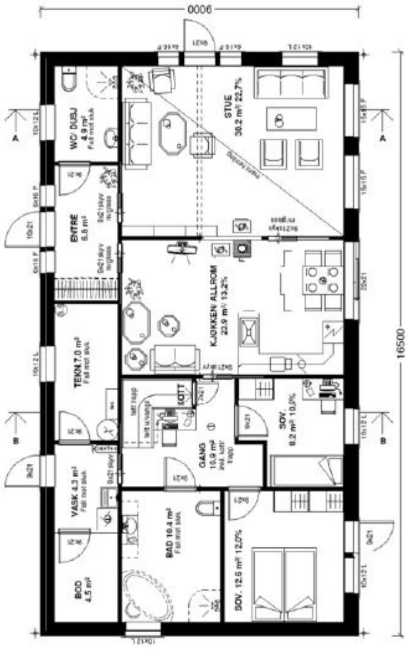
AIT Auto Ignition Temperature** * LEL/UEL Lower/Upper explosion limit**

State of Market Introduction

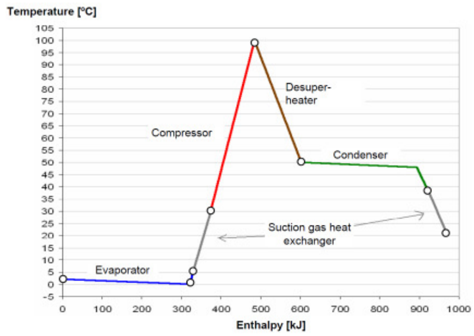
The system is a prototype system developed at the Norwegian University of Science and Technology (NTNU, David Zijdemans) in co-operation with SINTEF Energy Research.



Principle sketch of the prototype water-to-water propane heat pump system



Floor plan of the passive house



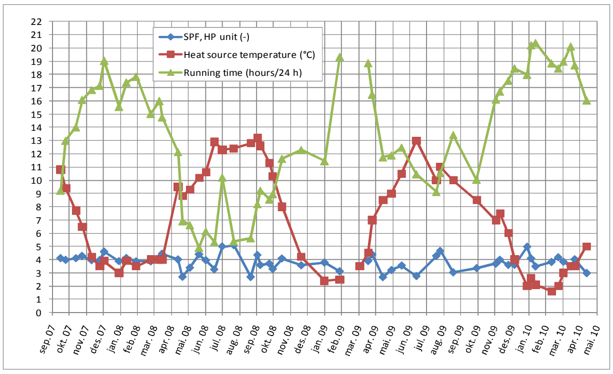
Use of a suction gas heat exchanger

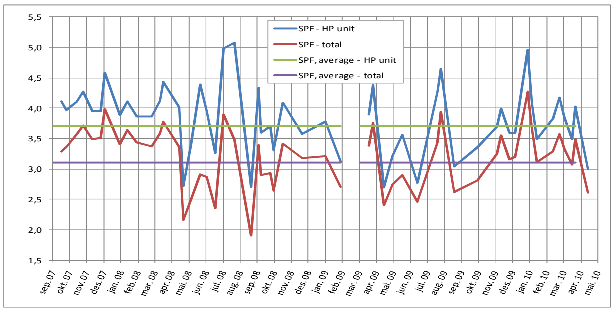
Technical data of the Unit

Type:	**W/W propane (R290) heat pump**
Heat source:	**Lake water, 5-15 °C**
Output capacity:	**2.1 kW (W10/W35)** **2.5 kW (W15/W35)**
COP:	**4.1 (W10/W35),** **4.4 (W15/W35)**
Storage volume:	**DHW: 300 l** **SH: 300 l**
<u>Components:</u>	
Evaporator/ Condenser:	**SWEP PHE, B15-10, 0.36m^2, H/W* 6.5**
Desuperheater:	**SWEP PHE, B8-10, 0.23 m^2, H/W 4.3**
Suction gas HX:	**SWEP PHE, B5-10, 0.12 m^2, H/W 2.6**
Compressor:	**Danfoss SC15CNX, single-stage, hermetic piston, 2900 rpm, 15.28 cm^3**
Expansion valve:	**Danfoss TUA R22, thermostatic, intern. pressure equalization**

***height/width**

Field Monitoring





Measured monthly Seasonal Performance Factor (SPF) and average SPF (2007-2010, 31 months)

Measurement period

The prototype water-to-water propane heat pump system was installed in the pilot house July 2007, and has been monitored from September 2007 to April 2010 (31 months). The measurements have been carried out and prepared by Peter Leendert Zijdemans and David Zijdemans.

Measurement results

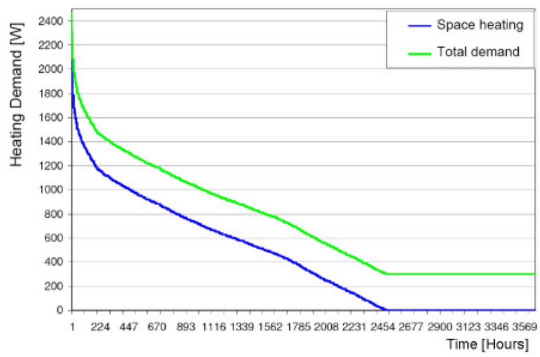
The measured COP for the heat pump system ranged from about 2.8 to 4.0, with a weighted average value of the entire period of 3.1 (electricity of pumps included). This corresponds to about **70% energy saving** compared to an electric heating system. The COP is depending on the ratio of DHW production. This is due to variations in the condensation temperature and the temperature in the LT storage tank. The measuring results with SPF for the heat pump unit (blue line), SPF for the total system (red line without markers) and heat source temperature (red line with markers) are shown in the two upper graphs on the right hand side

Measurement equipment

The prototype was instrumented with heat flow meters for the space heating system (LT tank), preheating of DHW (LT tank) and reheating of DHW (HT tank), electric power/energy meters for the compressor and pumps as well as temperature sensors for the heat source, heat pump unit (miscellaneous) and ambient air.

Annual heating demands – space heating and DHW heating

The calculated (estimated) net heating demand duration curve for the pilot house, i.e. the thermal power demand for space heating and hot water heating during the entire year are shown in the figure on the right hand side. The areas under the curves for “Space heating” and “Total demand” represent the total annual space heating demand and the total annual heating demand for space heating and domestic hot water heating, respectively (Zijdemans, 2007). The heat exchanger coil in the LT storage tank covers about 60-70 % of the total DHW heating demand, whereas the remaining 30-40 % is covered by the heat exchanger in the HT storage tank.



Estimated heating demand duration curve for the pilot house (Zijdemans, 2007).

Changes during measurements

The filter for the lake water was changed due to clogging problems.

Comparison field test results to calculated values

The measured SPF values are lower than expected, and this is mainly due to relatively poor performance of the evaporator (low gas velocity) and the fact that the energy meter for the DHW system (HT tank) has limited accuracy at small DHW draw offs. When the house owners have visitors and the DHW demand increases, the accuracy of the heat meter (volume flow meter) is improved and the COP rises considerably.

Conclusions, evaluations, recommendations

The heat pump system has a very good thermodynamic design, although the measured SPF is lower than expected the heat pump system is considered to be a great success. By further optimization of components and system design, the heat pump system has the potential to be one of the most energy efficient integrated heat pump systems on the market.

Energy and performance indicators

Estimated total energy consumption	**6020 kWh/a**
Estimated space heating consumption	**3400 kWh/a**
Estimated DHW consumption	**2620 kWh/a**
DHW energy fraction	**43.5%**
Seasonal performance factors	
SPF heat pump (boundary COP)	**3.7**
SPF system (all system components)	**3.1**

System Performance and Optimisation

During the first heating period, the evaporator showed poor performance and the superheat control of the expansion valve was unstable.
The problem in the evaporator is probably caused by a low liquid/vapour velocity which limits the heat transfer coefficient to 50% of the calculated value.
The vapour from the suction gas heat exchanger was superheated 5-16°C, and the unstable superheating was caused by bad thermal contact between the temperature sensor and the tube wall. The stability was significantly improved by using thermal paste at the contact surface.
During February and March 2009 the filter for the lake water inlet was gradually clogged, which resulted in a drop in the water flow rate and finally freezing of the drain pipe (i.e. heat pump halt).

Interpretation of performance
The average SPF during the entire measuring period for the heat pump unit including only the drive energy to the compressor ("SPF average – HP unit") is 3.7, while the average SPF including the total energy input to the compressor and pumps is 3.1, These SPF values correspond to about *70 % energy saving* compared to an electric heating system. Lake water represents an excellent heat source, and the temperature ranges from about 1.5 °C to 13 °C.

Weak points, optimisation potentials
The evaporator should be optimized, and the heat flow meter for the DHW should have higher accuracy.
The problems that occurred with the lake water filter can be avoided with good/regular maintenance.

Reached comfort
The heat pump covers the entire heating demand of the residence even during periods with large DHW demands, and the peak load system (electric heaters) has never been used, which clearly demonstrates that the heat pump system was correctly designed for this passive house.

Economy, Ecology and Costs

Environmental impact of the heat pump based on thermal energy produced*:

CO_{2eq} emission factor**:	7 $g/kWh_{el.}$
CO_{2eq} emission:	13.6 kg
Primary energy factor**:	1.5 $kWh_{prim.}/kWh_{el.}$
Primary energy:	2913 $kWh_{prim.}$

Comparative environmental impact of a condensing gas boiler based on thermal energy produced**:

CO_{2eq} emission factor**:	277 $g/kWh_{th.}$
CO_{2eq} emission:	1737 kg
Primary energy factor**:	1.36 $kWh_{prim.}/kWh_{th.}$
Primary energy:	8528 $kWh_{prim.}$
Annual efficiency of the gas condensing boiler ***:	96 %

* estimated energy consumption (SH/DHW) 6020 kWh/a based on 35 $kWh/(m^2a)$
** values based on EN 15603, Annexe E for hydro power and natural gas (fraction hydro power in Norway 99% acc. to www.statkraft.com)
*** acc. to field monitoring results of 59 gas condensing boilers (Wolff et al. (2004))

Conclusion

The presented data confirm that the water-to-water heat pump prototype system is very efficient and has the potential to save significant amounts of CO_2-emission compared to a conventional system with a condensing gas boiler for space heating and DHW operation.
Also in passive house application with relatively high DHW fractions due to the very low space heating requirement, the performance of the prototype is above three with the respective primary and CO_2-emission savings as shown above.
Moreover, the developed prototype uses a natural refrigerant, which has a negligible global warming potential, and thus also regarding the refrigerant the system does not harm the environment.

Imprint

Prototype development
David Zijdemans (NTNU) in co-operation with
Jørn Stene (SINTEF Energy research)

Field monitoring
Peter Leendert Zijdemans
David Zijdemans

Date of Best practice sheet: June 2010

Literature

Maria Justo Alonso, Jørn Stene
IEA HPP Annex 32 Umbrella report, System solutions, Design Guidelines, Prototype system and field testing - NORWAY
Technical report A6966, SINTEF Energy research, Trondheim Norway, May 2010

David Zijdemans
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Master thesis, NTNU, July 2007 (in Norwegian)

David Zijdemans
Analysis of a heat pump system for a low energy houses/ passive houses
Project work NTNU, 2006 (in Norwegian)

Norwegian Annex 32 project website
http://www.energy.sintef.no/prosjekt/Annex32

System concept

Economical heating and cooling systems for low energy houses

Ground-source and air-source Integrated Heat Pump (IHP) concept for Low or Net Zero Energy Homes

U.S. DEPARTMENT OF ENERGY

OAK RIDGE National Laboratory ZEBRAlliance

Contribution of the US national project

Summary

One of the strategic goals of the US Department of Energy's Building Technology Program is a broad market introduction of Net Zero Energy Houses (NZEH) by the year 2020. Therefore, development of adapted energy service systems technology started in 2005. An Integrated Heat Pump (IHP) proved to be the most promising system concept for the application in NZEHs.

Both ground-source and air-source IHP systems are under development. Lab-prototype test results have been used to set parameters of a heat pump model. System simulations for 5 major climate zones yielded a reduction of energy consumption in the range of 52%-65% for the ground-source IHP and 47%-67% for the air-source IHP compared to a baseline system consisting of an ASHP, a water heater, ventilation fan and dehumidifier that meet current minimum DOE energy efficiency requirements. For the different climate zone payback times range between 5-10 years for the air-source and 6.5 -14 years for ground source IHP with borehole heat exchanger.

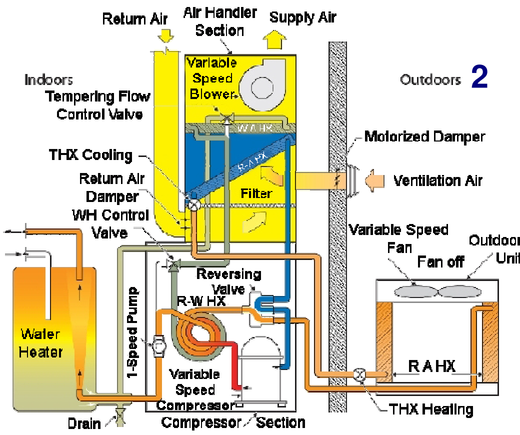
Currently, prototype systems are in preparation by manufacturers for field testing in research houses near Oak Ridge, TN. Field test of the ground-source prototype will start in summer 2010, the air-source field test will follow in winter 2010/11. Besides the IHP prototypes other innovative technologies will be tested: A ZEHcor internal utility wall, which integrates internal pipes and duct, a foundation heat exchanger as heat source for ground-source heat pumps and different types of insulations of the building.

Building Characteristics (7 monitoring houses)

- Location: Knoxville & ORNL test site, Tennessee
- Single-family homes; 7 test houses
- Floor area: ≈220-340 m^2 (2400-3700 ft^2)
- Different HERS Ratings: 31-85
- Different types of innovative insulation concepts

Background

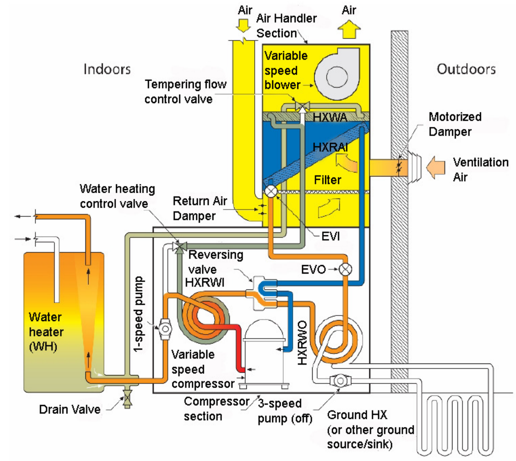
The strategic goal of US Department of Energy (DOE) Building Technology Program is the broad market introduction of Net Zero Energy Homes (NZEH) by the year 2020. According to a working definition of the DOE, a Net Zero Energy Home is “a home with greatly reduced needs of energy through efficiency gains (60-70% less than conventional practice) with the balance of energy needs supplied by renewable technologies”.
Therefore, respective building technology is to be developed now to be marketable by 2020. A scoping technology assessment in 2005 revealed that an integrated heat pump (IHP) is the most promising concept.
Air-source and ground-source variants of the IHP have been investigated in lab-tests and simulations and field test prototypes of each are now in preparation. Field test of the ground-source prototype is planned in summer 2010 followed by the air-source prototype in the winter 2010/2011.



Schematic of AS-IHP concept design

Technical concept

To achieve this goal will require energy service equipment that can meet the space heating and cooling (SH and SC), ventilation (V), water heating (WH), dehumidification (DH), and humidification (H) needs while using 50% less energy than current equipment. The energy benefits of an IHP stem from the ability to utilize otherwise wasted energy (e.g., heat rejected by the space cooling operation can be used for water heating) and from the ability to justify the cost of more expensive, more energy efficient components because they serve multiple functions (e.g., a variable speed compressor is used to both provide space conditioning and water heating). An integrated heat pump can be designed to be air-source or ground-source.
A laboratory prototype was developed and tested over a range of operating modes and conditions. Test data was used to validate a detailed heat pump system model - the DOE/ORNL Mark VI Heat Pump Design Model (HPDM). HPDM was then linked to TRNSYS, a time-series-dependent simulation model. The experimentally validated analytical tool was used to calculate the annual performance of IHP system designs optimized for R-410A in five major cities, representing the main climate zones within the United States: Atlanta (mixed-humid), Houston (hot-humid), Phoenix (hot-dry), San Francisco (marine) and Chicago (cold). The calculations extended for a full year using 3-minute time steps. For the AS-IHP version, the simulation results showed ~46-67% energy savings depending upon location. For the GS-IHP version, the simulation showed over 50% savings in all locations - ~52-65% range.



Schematic of GS-IHP concept design

State of market introduction

The technology is in the prototype status.

Possible arrangement of the Air-source Integrated Heat Pump

Basic design specifications AS-IHP

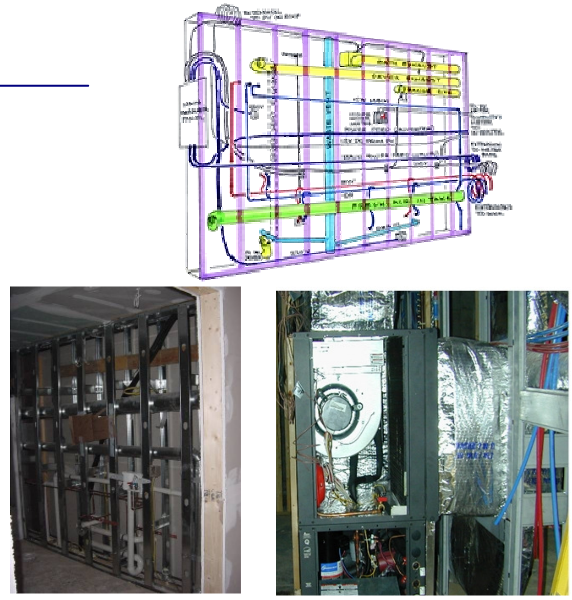
- Variable speed rotary compressor with electronically commuted BDC drive motor and permanent magnet rotor, variable speed ranges:
  SH: 3.6:1. DHW: 2:1, SC: 2.8:1
- High efficiency variable speed motor/fan combinations
  indoor: 3.5:1, outdoor: 2:1
- Ref/W HX: counterflow, helical, tube-in-tube, min. UA: 570 W/K at 7 l/min water
- W/A HX: perpendicular coil, copper tubing, aluminium fins, min. UA: 43 W/K
- Indoor Ref/A HX: sloped coil with grooved copper tubing and aluminium fins, min. UA: 425 W/K at cooling design conditions
- Outdoor Ref/A HX: wrap around coil with copper tubing and aluminium fins, min. UA: 755 W/K at
- Water pump: 45 kPa at 12 l/min
- El. Resistance heater: 4.5 kW
- Water storage tank: min. 180 l
- Other components: two or bi-directional expansion valve, reversing valve, bypass valves

Field monitoring

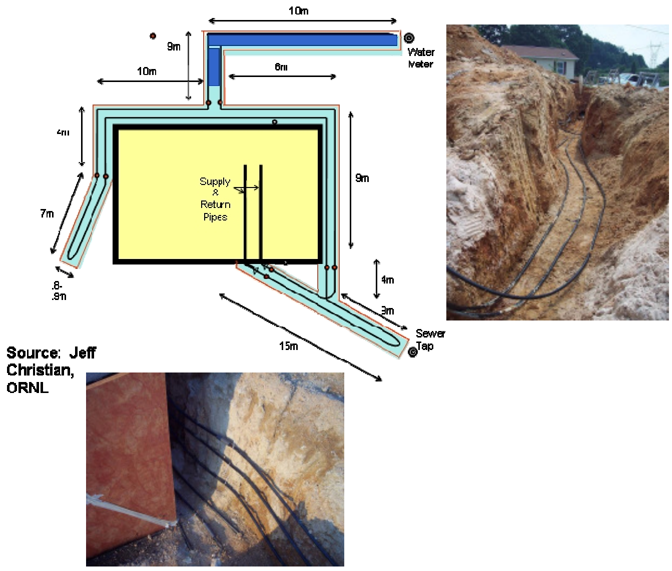
NZEH field monitoring is being carried out at two research house sites near Oak Ridge National Laboratory and sponsored by DOE's Building Technology Program and the regional electric utility TVA.
The 7 houses under field monitoring fulfil different standards of the Home Energy Rating System (HERS®-Index). Three of the houses are located at Campbell Creek (co-funded by TVA):

- a "Builder House" (HERS®-Rating 85 corresponding to EnergyStar®) with 223 m^2, a standard framing package of R-13 walls and R-30 ceiling, 2 air-source heat pumps, one per floor, SEER 13 (3.8), 4.5 tons (~16 kW) total and ducts and top floor indoor unit not in conditioned space
- a "Retrofit House" (HERS®-Rating 65 which is a bit better than the so-called builders challenge of 70 and lower), 223 m^2 with sealed and insulated attic, a 3 ton (~10.5 kW) heat pump, HSPF= 9.5(2.8), SEER 16(4.7), air-side zone control, 100% CFL (compact fluorescent lighting), EnergyStar appliances as well as single-hung low-e, argon gas-filled, double-pane windows
- a "Research House" (HERS®-Rating 31 incl. Solar) with Advanced framing (2 x 6) and insulated sheathing (R-2.74) rather than OSB, R-49 attic with radiant barrier sheathing, R-6 triple-pane gas-filled windows, a 2-ton (~7 kW) air-air heat pump, SEER 16(4.7), HSPF 9.5(2.8), air-side zone control, energy recovery ventilator (ERV), advanced appliances, waste heat recovery, HPWH, 2.5 kW solar PV, etc.

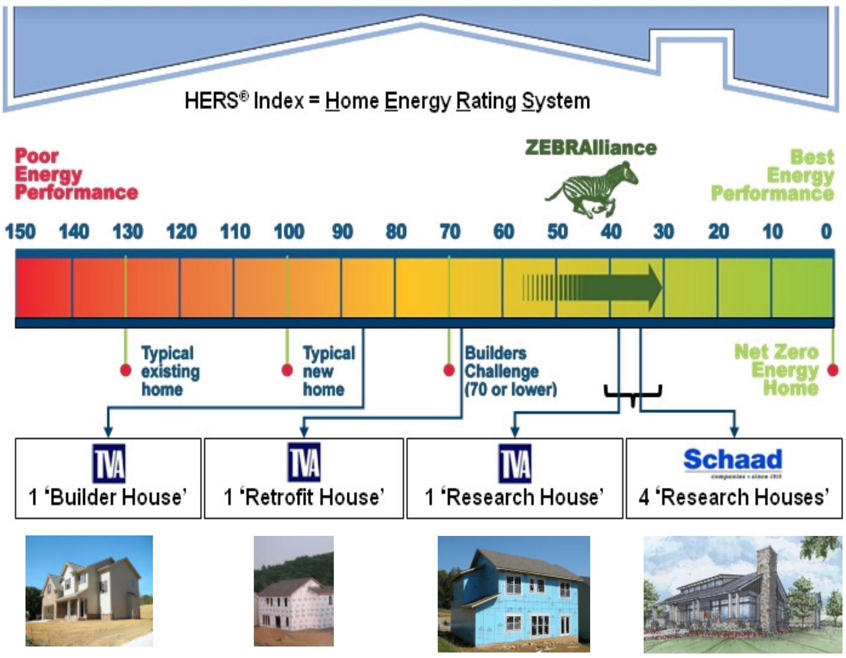
The other four houses, 230-340 m^2, are part of the Zero Energy Building Research Alliance (ZEBRAlliance). Partners include BarberMcMurry Architects (designer of the houses) and the regional home builder Schaad. Plans call for GS-IHP field monitoring in three of the houses starting in summer 2010 and AS-IHP field monitoring starting 2010/2011 winter in the 4th house.
Besides the IHPs other new technology concepts for NZEHs will be evaluated in these field tests. They are given in the figures on this page and described in the text box "Major innovations…" on the next page.



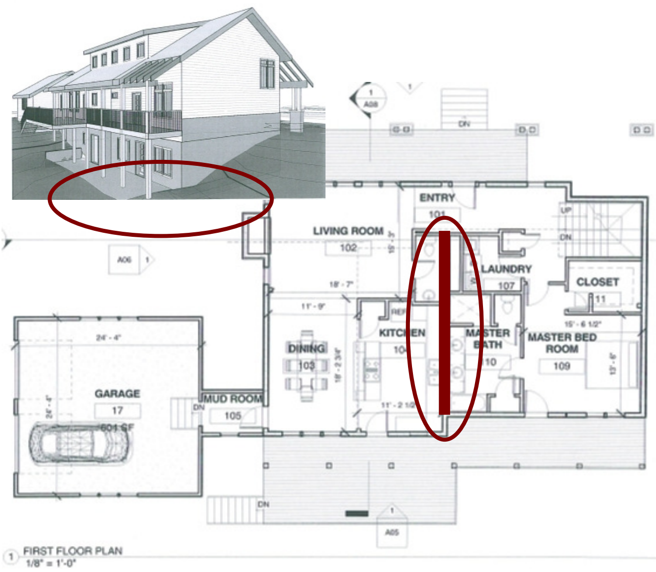
Concepts of the ZEHcor Interior utility wall



Concepts of the foundation heat exchanger (FHX)



Outline of field tests for near Zero Energy Buildings



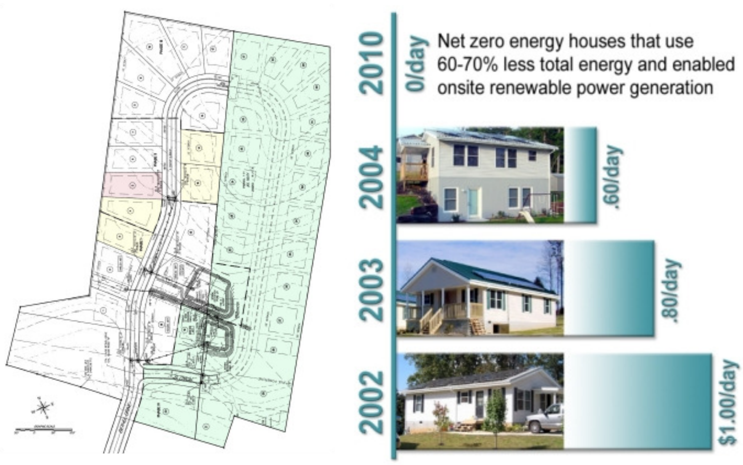
Position of Foundation Heat Exchanger and ZEHcor Interior wall in floor plan of ZEBRAlliance Research house #1

Innovations in NZEH Field test

- **ZEHcor interior wall**: The ZEHcor interior wall comprises all supply and return lines of electricity, ventilation, air distribution and water. It enables reduced hot water distribution losses and facilitates heat recovery via easy coupling of energy recovery ventilation (ERV)-to-FHX, appliances & grey water to FHX, etc. Moreover, it reduces costs due to pre-fabrication in a controlled factory environment.
- **Foundation heat exchanger (FHX)**: The foundation heat exchanger is the heat source for the GS-IHP variant. It saves energy by enabling the use of geothermal HP and reduces costs by using the excavations needed anyway to build the house, i.e. no extra digging or drilling is required. Performed field tests show promising results.
- **Dynamic thermal insulation – PCM**: This features a double wall with 2”x4” (.05m x .1m) wood studs, offset to minimize thermal bridging through the studs. Microencapsulated phase change material (PCM)-enhanced cellulose insulation. It is expected that the PCM will provide some thermal buffering to this lightweight wall system.
- **Structural insulation panels – SIP**: Walls and roof decking made of ~.15m thick SIPs – two oriented strand board (OSB) panels with extruded polystyrene (EPS) insulation sandwiched between.
- **Advanced Framing**: Walls with 2”x6” (.05m x .15m) wood studs, 24” (0.6m) on center with .15m fiberglass batt and .013m polyurethane sheathing.
- **Exterior Insulation finishing**: Walls of conventional 2”x4” (.05m x .1m) wood studs, 16” (.4m) on center, with .13m of EPS fastened to outside of studs and low-e foil facing on inside of EPS.

Economy, Ecology and Costs

Initial cost analyses (based on 2006 equipment costs and electricity prices) yielded estimated simple paybacks of the IHP systems vs. a baseline HVAC/WH/DH/H system in a net ZEH - about 5 to 10 years for the AS-IHP and 6.5 to 14 years for the GS-IHP (with vertical bore ground HX).
The figure below shows energy costs for field tests of different stages of the NZEH development performed from 2002 to 2004 at a Habitat for Humanity development near ORNL. Developments decreased operation costs from 1 $/day to 0.6 $/day. For the IHP field test prototypes to be examined in this field test series, which fulfill DOE targets, negligible daily energy costs are expected.
The targeted energy reduction of 60-70% implies respective CO_2-emission savings.



Operational Energy Costs in NZEH Field Test of the DOE/ORNL

Imprint

Prototype Development
Dr. C. K. Rice, Dr. R. Murphy, Van D. Baxter, William G. Craddick
Oak Ridge National Laboratory

Field monitoring (ZEBRAlliance)
DOE Building Technology Program
Oak Ridge National Laboratory
Schaad Home Building Company
TVA Regional Utility
BarberMcMurry Architects

Date of System concept sheet: June 2010

Literature

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A. Vohra, Van D. Baxter
Integrated Heat Pump System Technology Development for Net Zero Energy Home Application, Workshop Paper IEA HPP Annex 32 Workshop, Kyoto
Download at http://www.annex32.net/presentations.htm

IEA HPP Annex 32

IEA HPP Annex 32 is a corporate research project on technical building systems with heat pumps for the application in low energy houses.
The project is accomplished in the Heat Pump Programme (HPP) of the International Energy Agency (IEA).

Internet: http://www.annex32.net

www.heatpumpingtechnologies.org

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Report no. HPT-AN32-6