# EUROPEAN HEAT PUMP SUMMIT

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SYMPOSIUM + EXPO
NUREMBERG, 20–21.10.2015

Industrial | Commercial | Residential
Heating & Cooling | Components & Equipment

hp-summit.de

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EUROPEAN HEAT PUMP SUMMIT

# IEA HPT Annex 40
# Heat pump concepts for nearly Zero Energy Buildings

Carsten Wemhoener
Institute of Energy Technology
HSR University of Applied Sciences Rapperswil
EHPS 2015, Nuremberg, October 20, 2015

# Overview

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Schweizerische Eidgenossenschaft
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**Swiss Federal Office of Energy SFOE**

- Overview IEA HPT Annex 40
- State-of-the-art
  nearly Zero Energy Buildings (nZEB)
- Case studies for nZEB in Annex 40
- Technology development and monitoring of nZEB in Annex 40
- Integration of nZEB into the energy systems
- Conclusion Annex 40

*Retrofitting of office building to plus energy* *Source: Flumroc*

# Participants IEA HPT Annex 40

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Confédération suisse
Confederazione Svizzera
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**Swiss Federal Office of Energy SFOE**

- **Participating countries and institutions**
  - CA: CanmetENERGY, Hydro-Québec
  - CH: HSR, FHNW, Energie solaire SA
  - DE: Fraunhofer ISE
  - FI: Green Net Finland, VTT, Aalto Univ., SULPU
  - JP: Univ. Nagoya, HPTCJ, manufacturers
  - NL: platform 31, TNO
  - NO: SINTEF, NTNU, COWI AS, Enova SF
  - SE: SP, manufacturers
  - US: ORNL, University of Maryland, NIST

*5th Annex 40 working meeting Nagoya, JP*

# Overview IEA HPT Annex 40

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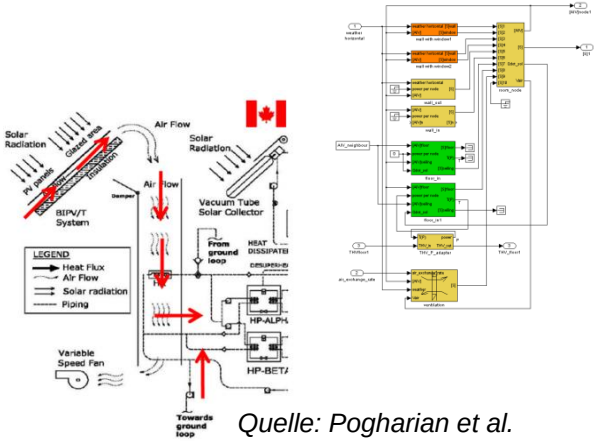
- Task 1: State-of-the-art nZEB-Technologies and concepts
  - Classification of used technologies

- Task 2: Assessment of nZEB concepts
  - Comparison regarding performance and cost




*Quelle: Pogharian et al.*

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  - Prototype development of heat pumps for nZEB
  - Monitoring of nZEB with heat pumps

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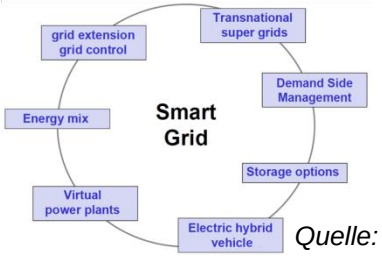
  - Storage integration and smart technologies to reduce grid interaction




*Quelle: Ebert et al.*

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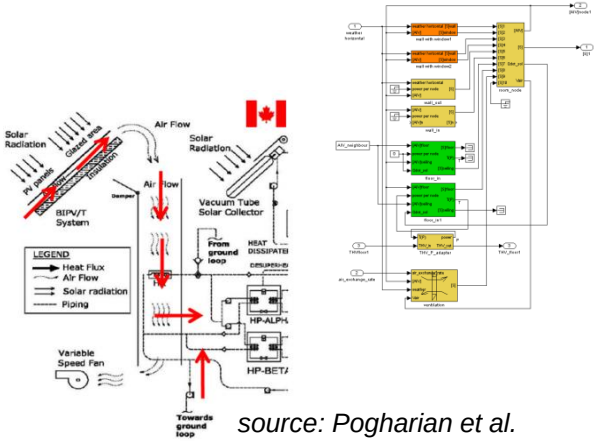


*source: Pogharian et al.*

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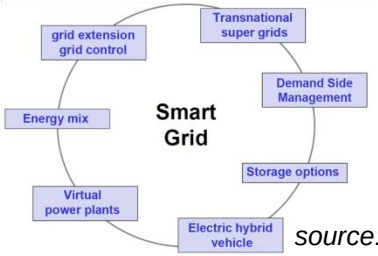


*source: Ebert et al.*

# nZEB projects worldwide

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NET ZEB TASK 40 /ANNEX 52

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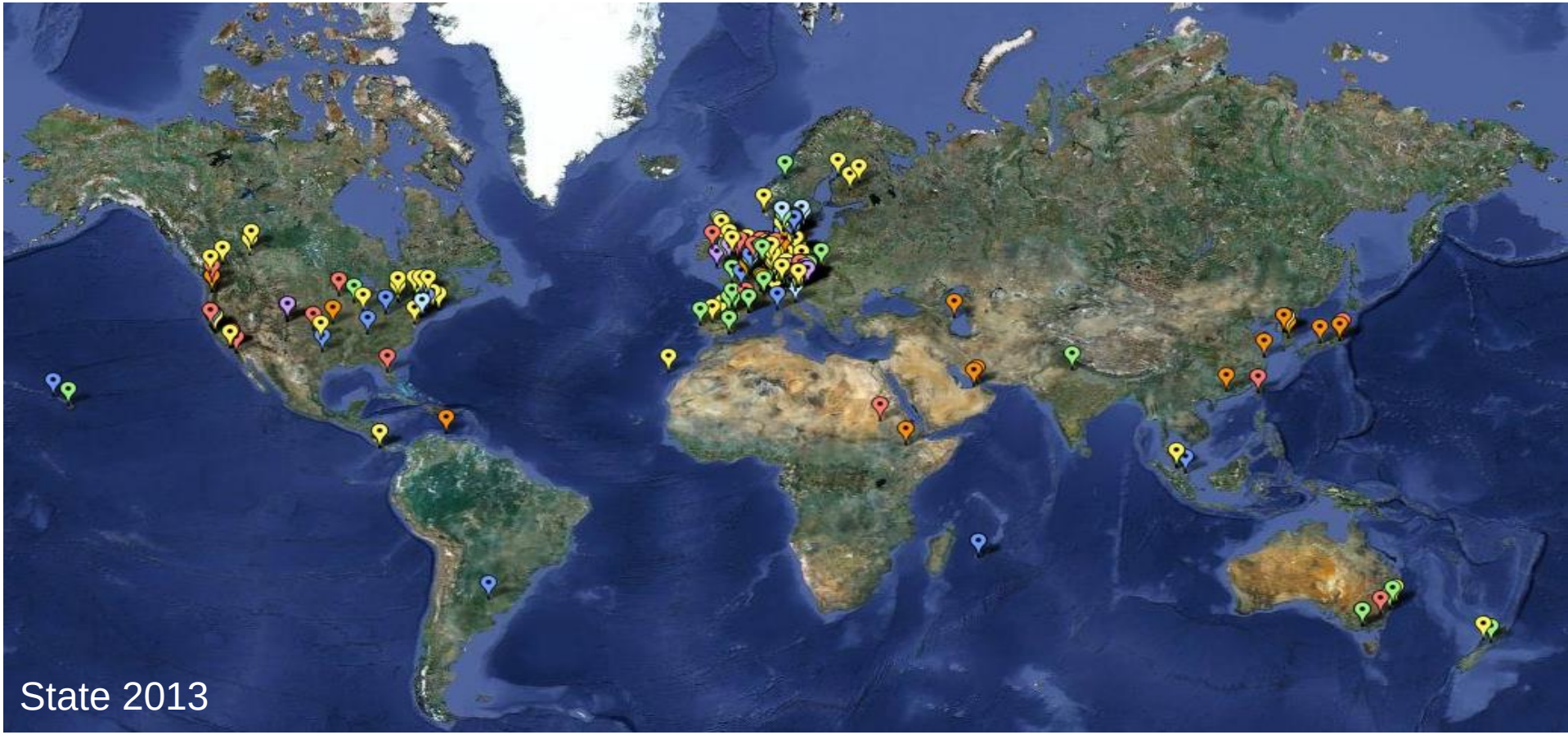

# State of Definitions of nZEB in the EU

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BPIE

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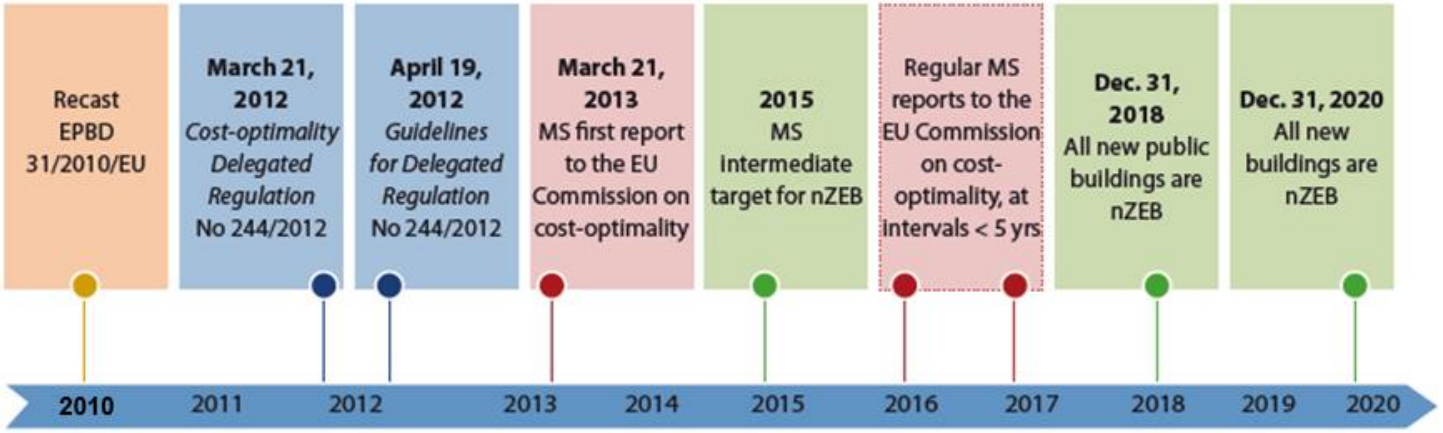
DEFINITION "Nearly Zero Energy Building" (nZEB)

- Means a building that has a very high energy performance
- ***Nearly or very low energy amount*** should be covered to a ***very significant extent by energy from renewable sources***, including renewable energy produced ***on-site or nearby***
- **Presently no common definition of nZEB, neither in policy nor in the market**




*source: BPIE*

# State of Definitions of nZEB in the EU

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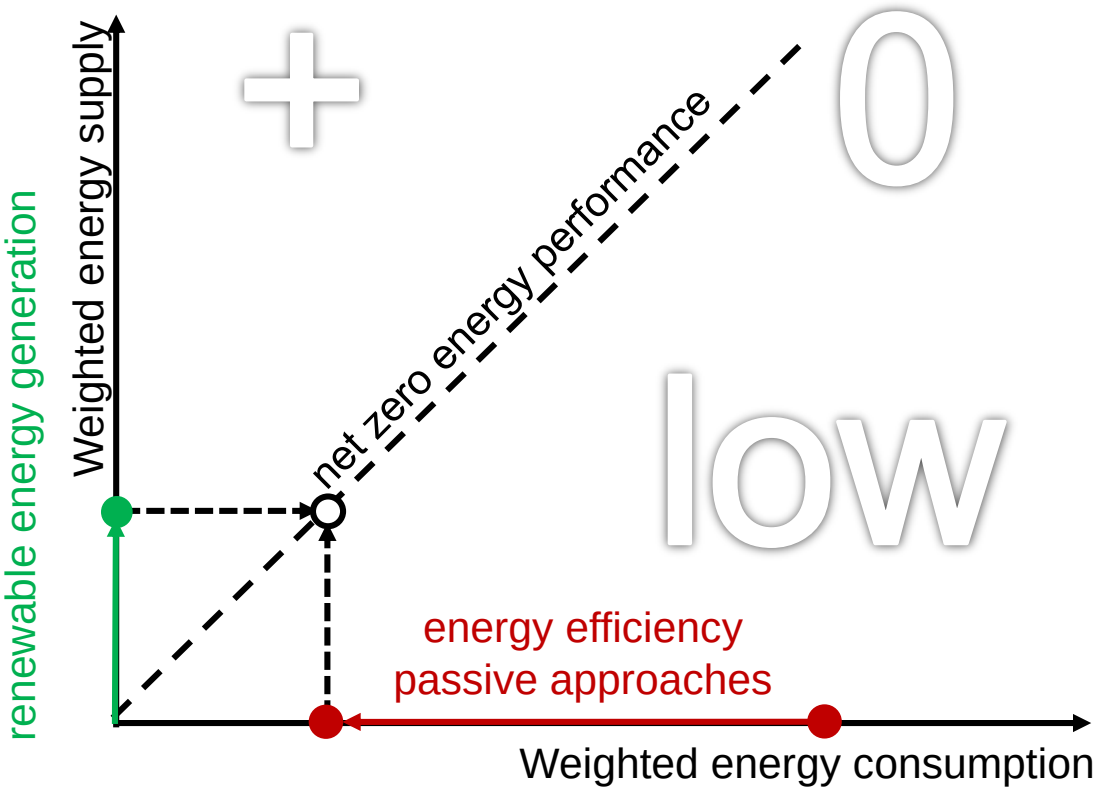
- **Framework IEA SHC Task 40/EBC Annex 52**




- **Requirements Definition of nZEB**
  - Building system boundary
    - Physical boundary (nearby?)
    - Balance boundary (energies?)
  - Weighting system
    - Metric (PE,$CO_2$,€)
    - Symmetric, time dependent
  - Balance
    - Period, type, add. requirements
  - Temporal characteristic
    - Load match, grid interaction
  - Measurement and verification

*based on Voss / Lollini*

# State of Definitions of nZEB in the EU

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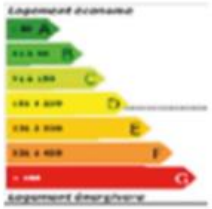
- **CEN/REVHA nZEB definition and rating**
  - "on-site" energy production refers to on the building or building parcel => unique and strong link to the building
  - "nearby energy source" refers to a dedicated connection to the building requiring specific equipment

**Hurdle 1:**
**Building needs**

**Hurdle 2:**
**Building use**
total primary energy

**Hurdle 3:**
**Building use**
non-renewable prim. energy

**nZEB rating:**
**Primary energy balance**



*source: Zirngibl, 2014.*

# State of Definitions of nZEB in the EU

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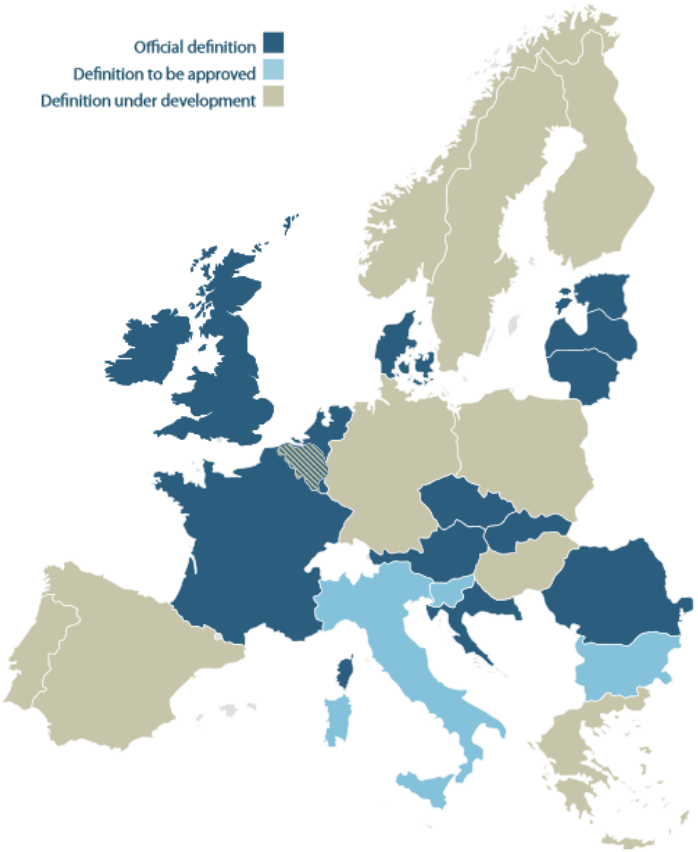
- **State of nZEB definition in 2015**
  - Significant progress in definition of nZEB in EU member states (MS) since 2012
  - 15 EU MS have a definition of nZEB in place
  - Definition in 3 EU MS to be approved
  - Definition in 11 EU MS under development
  - However, definition of max. primary energy varies a lot
  - Few EU member states set more ambitious targets than nZEB
    - NL: zero energy buildings
    - UK: zero carbon buildings (residential)
    - DK and FR: plus energy buildings
    - DE: climate neutral buildings




*source: BPIE, 2015*

# Evaluation of systems in MINERGIE-A buildings

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MINERGIE-A®

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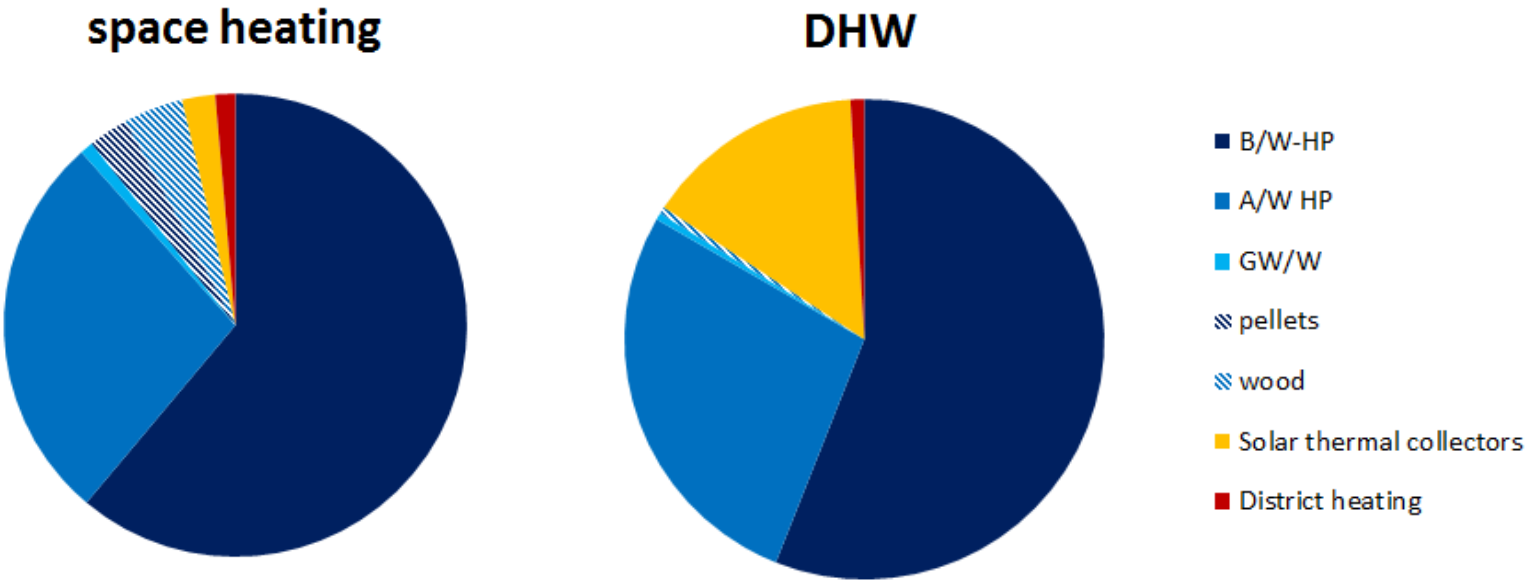
Swiss Federal Office of Energy SFOE

- **Evaluation of building technology in MINERGIE-A buildings (CH)**
  - Sample of 216 Buildings, 172 single family (SFH) and 44 multi-family houses (MFH)
  - Fractions of installed heat pumps for space heating (SH) and DHW
  - SFH: SH 89% / DHW: 85%, MFH: SH: 91% / DHW: 80%




*source: based on Hall et. al, 2013*

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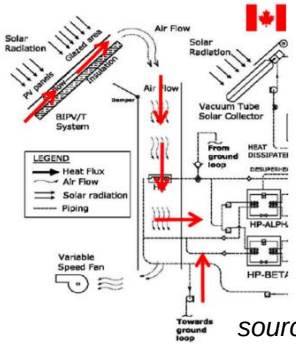


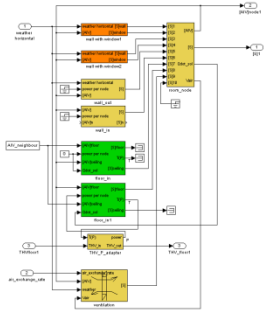

*source: Pogharian et al.*

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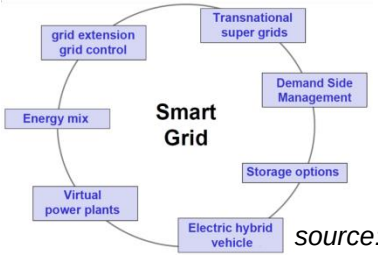


*source: Ebert et al.*

# Comparison of concepts

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HSR HOCHSCHULE FÜR TECHNIK RAPPERSWIL
FHO Fachhochschule Ostschweiz

Schweizerische Eidgenossenschaft
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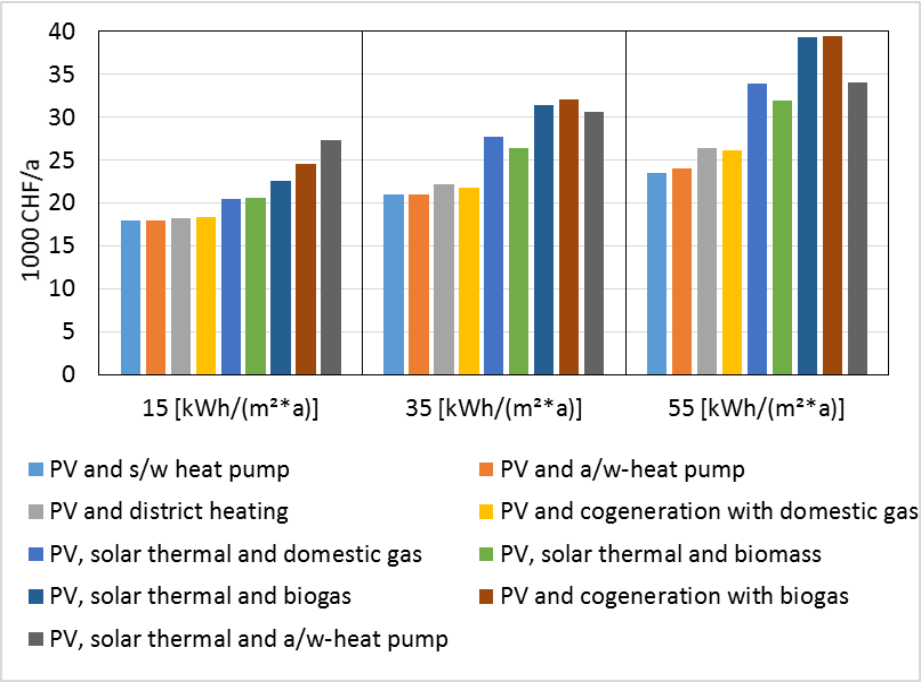
- **nZEB by different concepts, balance by PV systems**




- **Single-family house**
- nZEB reached for concepts up to 55 kWh/(m$^2$a)
- Heat pumps are most cost-effective solutions
- A/W cheaper than B/W for passive house level
- Biomass systems are more expensive

- **Multi-family house**
- nZEB reached, but for higher demand, partly use of façade required
- Heat pumps, district heating and cogeneration have lowest cost
- For larger demand B/W heat pumps cheaper than A/W
- Biogas has highest cost

# Comparison of concepts

Aalto University
School of Engineering

Schweizerische Eidgenossenschaft
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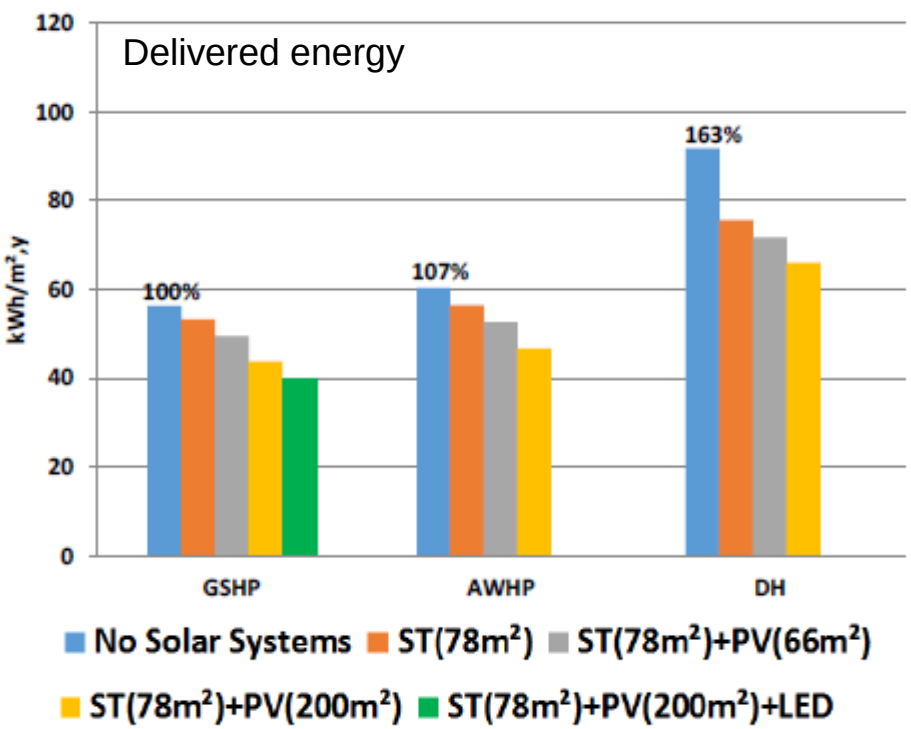
- **Similar results for Scandinavian countries (Finland)**




*source: Jokisalo et al., 2015*

- **Conclusions of Finnish case study**
- All studied concepts fulfill the suggested requirements of Finnish nZEB (FInZEB project)
- Delivered energy consumption is significantly lower for all heat pump concepts compared to district heating
- Ground source heat pumps and A/W heat pumps are most efficient solutions to save delivered energy among the studied concepts
- Heat pumps seem to be an excellent solution for both new and retrofitted nZEB

# Comparison of concepts

SP Technical Research Institute of Sweden

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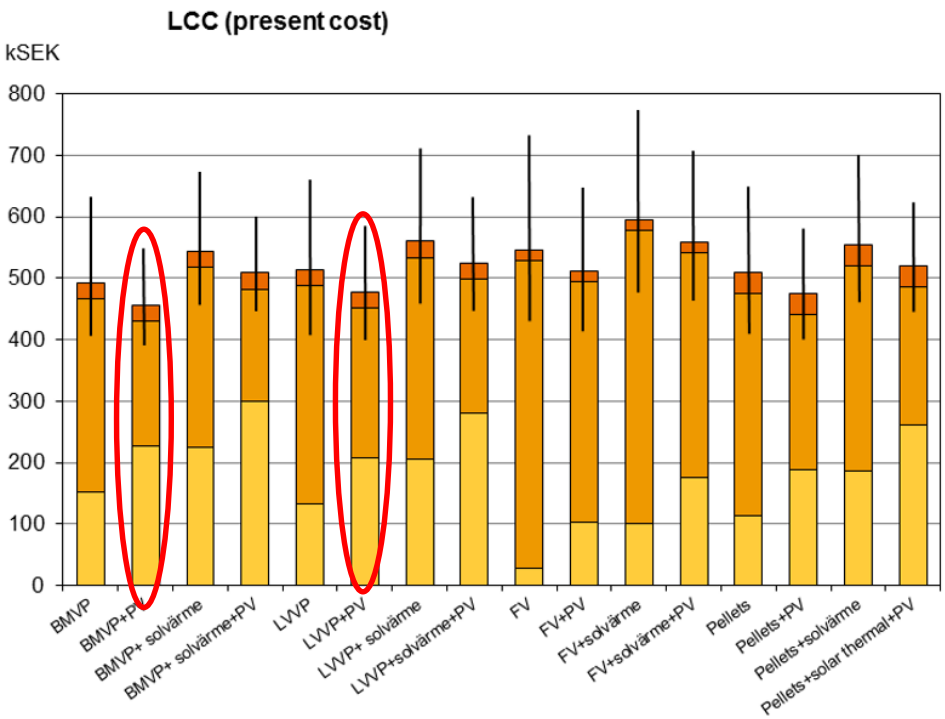
- **Similar results for Scandinavian countries (Sweden)**




*source: Ruud et al., 2015*

- **Conclusions of Swedish case study**
- **Single family house**
- Brine-to-water heat pumps economically feasible for nZEB in Swedish market conditions
- Low Life-Cycle-Cost (LCC) reached by ground-source and air-source heat pumps in combination with PV
- **Multi-family house**
- In multi-family houses ground-source heat pumps and PV are more cost-effective than district heating and PV

# Comparison of concepts

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NAGOYA UNIVERSITY

Public University Corporation
Nagoya City University

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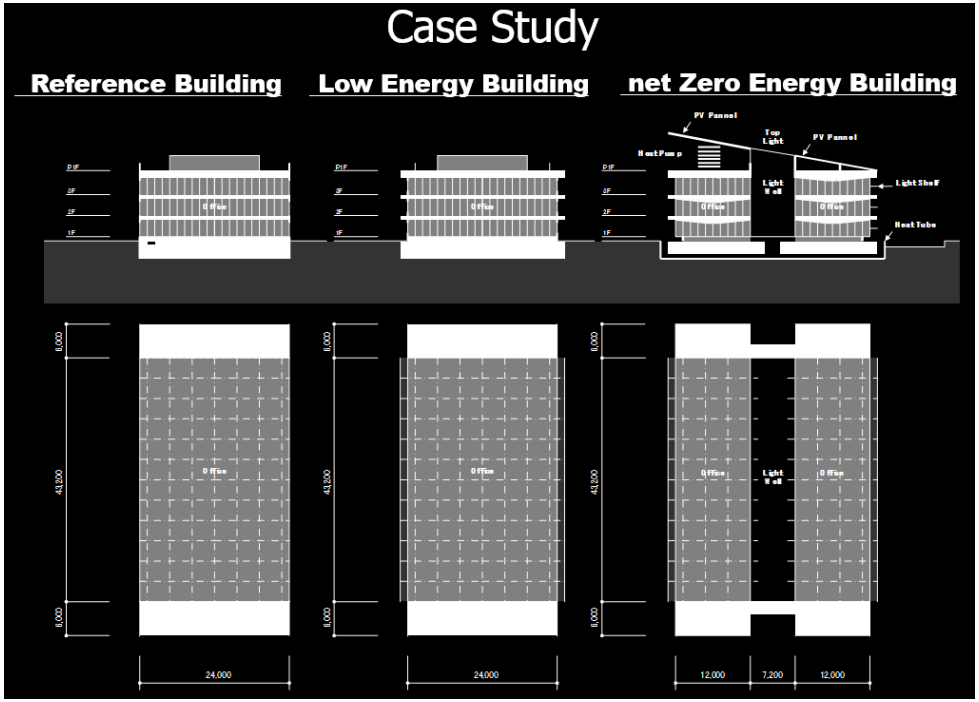
- **Case study in Japan for office buildings**




- **Outline Japanese case study**
- Comparison of three building types
- Reference building with conventional layout and technology
- Low energy building with improved building envelope
- nZEB with improved daylighting, high performance appliances and electric lighting and PV generation system on the roof

*source: Yoon et al., 2015*

# Comparison of concepts

NAGOYA UNIVERSITY

Public University Corporation Nagoya City University

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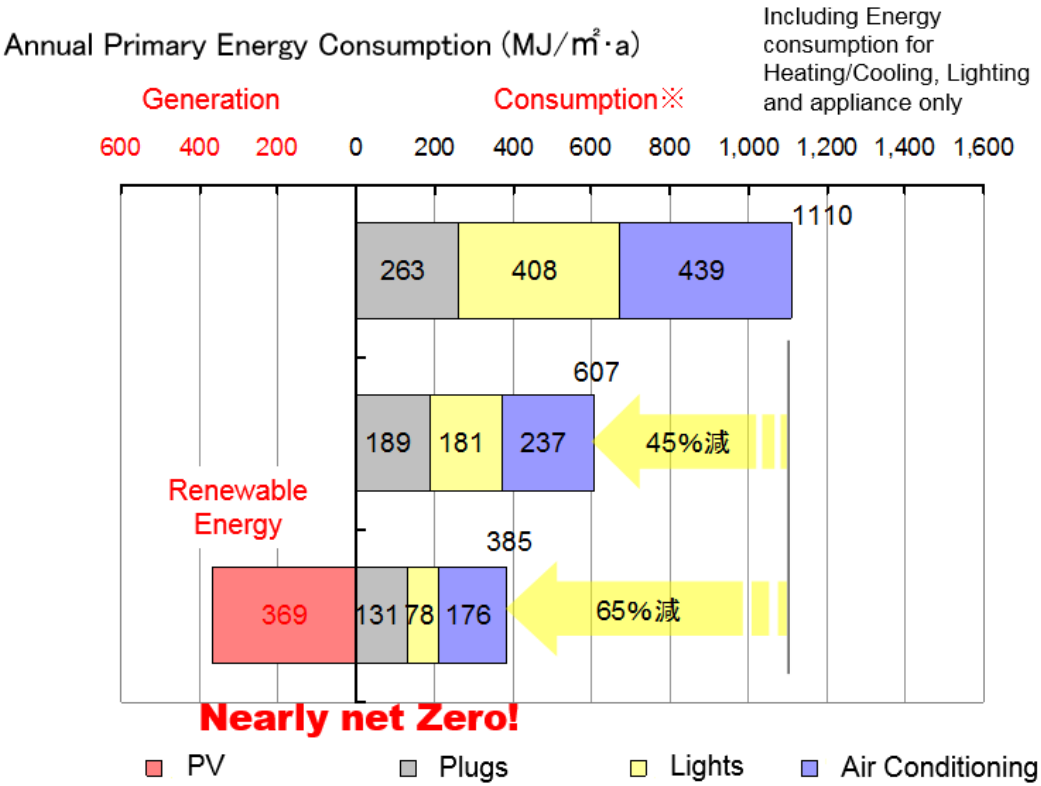
## Case study in Japan for office buildings




*source: Yoon et al., 2015*

- **Conclusions of Japanese case study**
- nZEB can be reached in Japanese office buildings in Tokyo climate with
  - Reduced internal load by efficient lighting (daylighting, LED)
  - Efficient appliances
  - PV production
- Efficient heat pump equipment for space heating and space cooling is an adequate system technology for the application in nZEB

# Comparison of concepts

Natural Resources Canada / Ressources naturelles Canada

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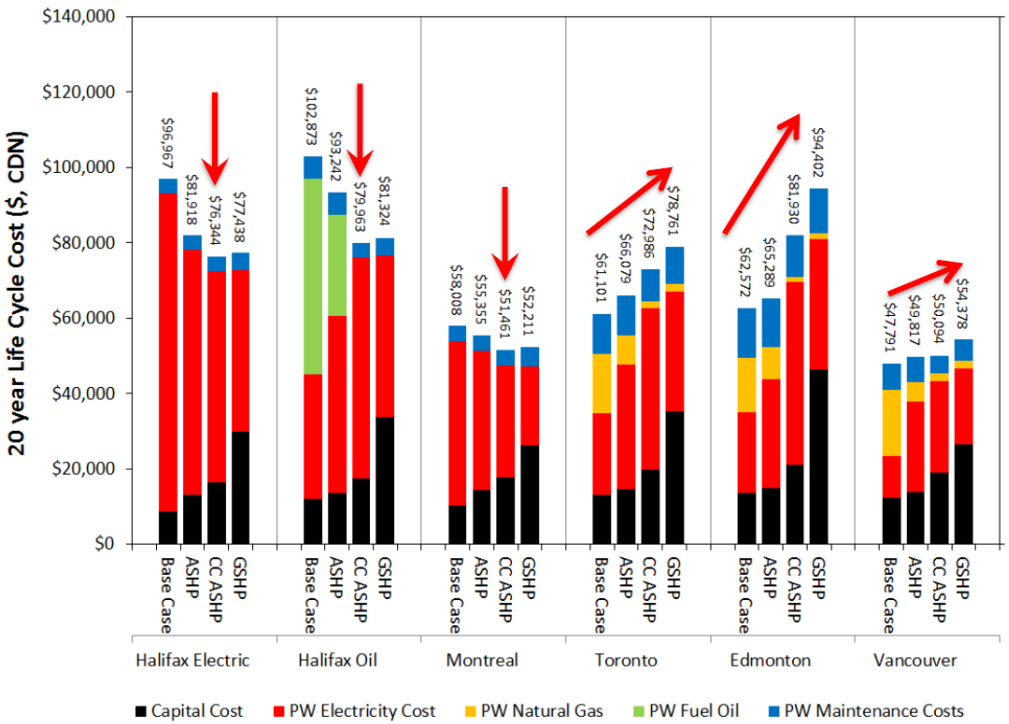
## Case study in Canada




*source: Kegel et al., 2014*

## Conclusions of Canadian case study

- Most cost-effective solution depends on the region
- In Halifax and Montréal regions GSHP and Cold Climate ASHP has cheapest LCC in residential application
- Heat pump applications are cheaper than the base case (electric or oil)
- In Toronto, Edmonton and Vancouver region ASHP LCC are above the base case with natural gas

# Comfort Evaluation Tool

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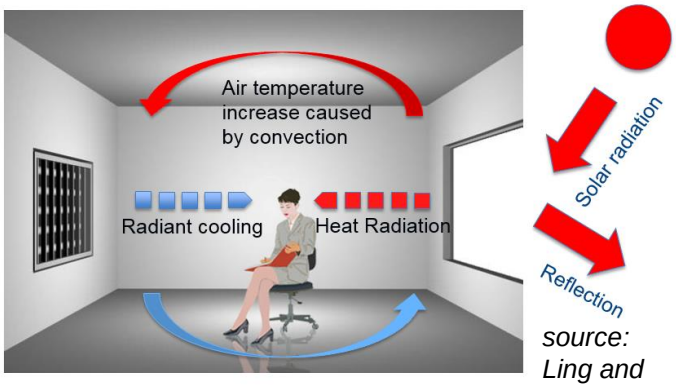
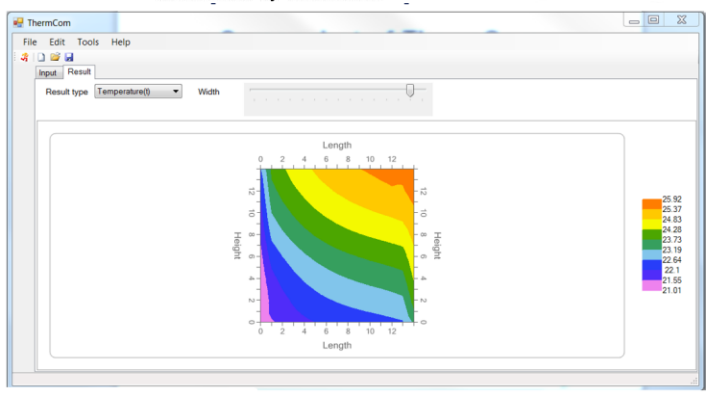
- **USA, University of Maryland**




*source: Ling and Radermacher, 2015*

Air cooled by convection




- **Comfort evaluation tool for room emission**
- Motivation: low supply temperature for HP
- Radiative cooling/heating panels evaluation
- Reduced order model based on 3-D CFD investigation
- Software offers comfort evaluation of 3-D room
  - equipped with radiative panels
  - equipped with conventional ceiling mounted air conditioning outlets
  - thermal comfort simulation in automotive cabin (mid-sized sedan)

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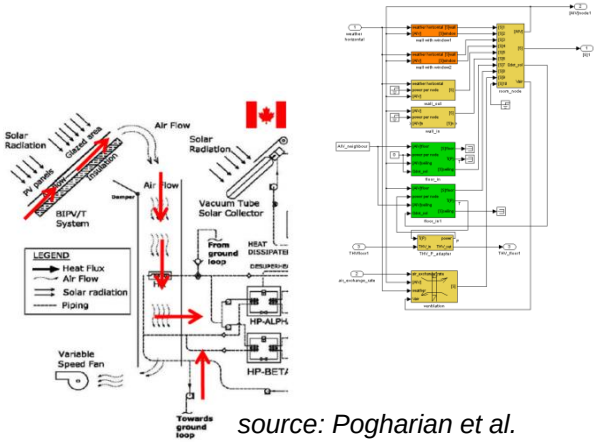


*source: Pogharian et al.*

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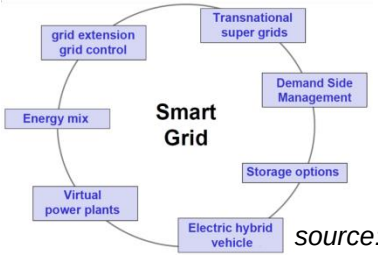


*source: Ebert et al.*

# IHP Development in the USA

Oak Ridge National Laboratory
Managed by UT-Battelle for the Department of Energy

U.S. Department of Energy
Energy Efficiency and Renewable Energy

IEA OECD

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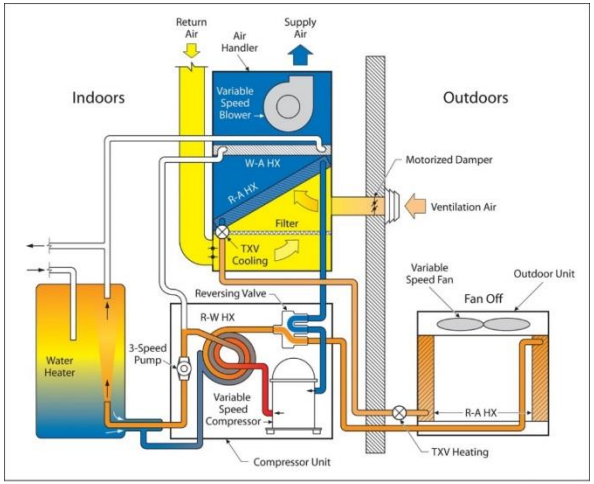
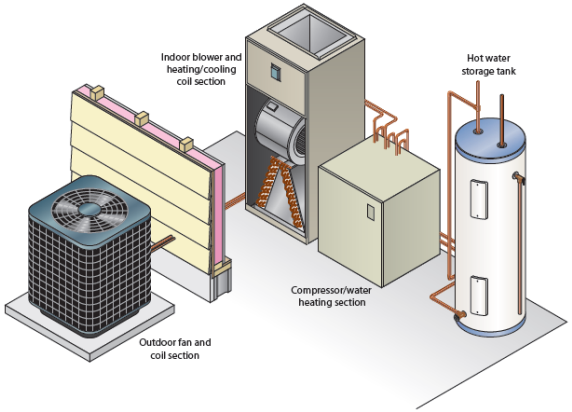
- **Integrated heat pump development in the USA**
  - Integrated Heat Pump (IHP) for
    - Space heating, space cooling, DHW, dehumidification
    - Ground source (GS) and Air-source (AS) prototype
  - Simulated saving potentials vs. Baseline (5 climate zones)
    - GS-IHP: 52%-65%
    - Air-IHP: 46%-67%
  - GS-IHP on the market
  - AS-IHP in field monitoring
  - Tests of different prototype variants




*source: ORNL*

# Field monitoring results AS-IHP

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OAK RIDGE NATIONAL LABORATORY
Managed by UT-Battelle for the Department of Energy

U.S. Department of Energy
Energy Efficiency and Renewable Energy

IEA OECD

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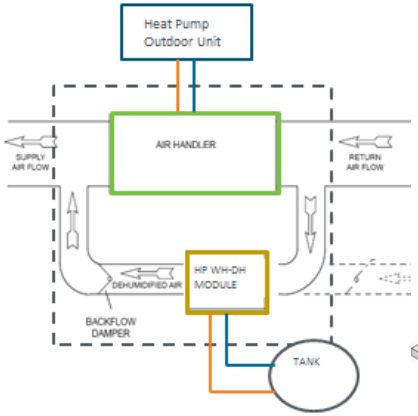
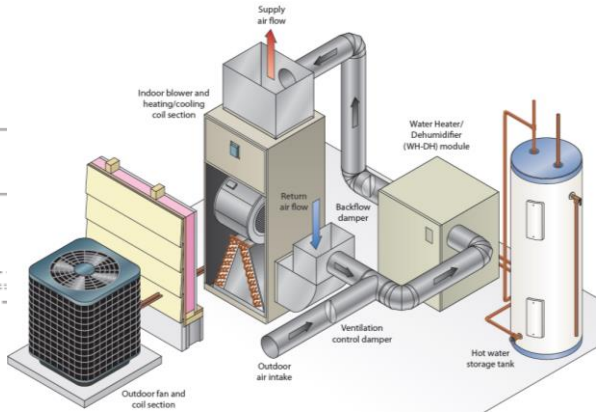
- **Field test results AS-IHP in Knoxville, TN**
  - Summer operation from May – September 2014
  - DHW Temp. 49 °C, SC Design Temp. 24.4 °C

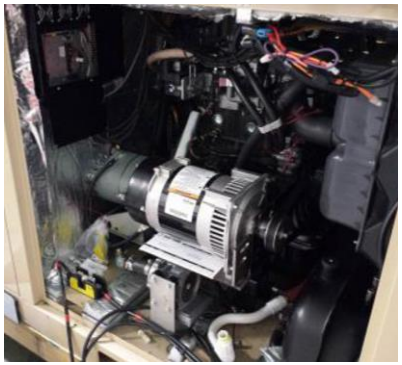
*source: ORNL*

# IHP variants

- **IHP Variants**
  - Two-box system
    - Separation of water heating and dehumidification unit
    - Outdoor unit linked to air-handling unit
    - Advantage for shoulder seasons with DH/DHW needs and for retrofit
  - Gas-driven IHP with AC generator
    - Can be attractive in areas with natural gas driven heating systems
    - First prototype tested in Las Vegas
    - Second prototype with power generator to supply auxiliaries and external appliances





*source: ORNL*

# NZERTF

NIST National Institute of Standards and Technology U.S. Department of Commerce

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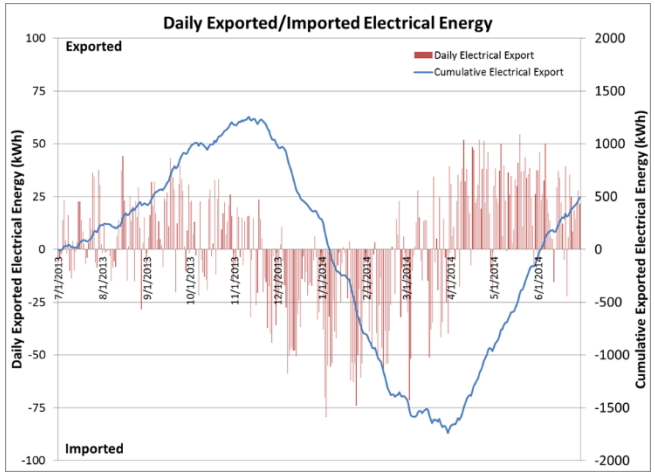
- **Test platform for NZEB technologies at NIST**
  - **N**et **Z**ero **E**nergy **R**esidential **T**esting **F**acility (NZERTF) on the NIST campus
  - Test house built according to NZEB design
  - Test house equipped with tunable loads in order to realise arbitrary load patterns
  - Real-world testing of NZEB equipment, which can be installed in the test house
- **Energy balance**
  - NZERTF is operated for two years since 2013
  - First year energy balance resulted in a plus energy balance
  - Further research will be dedicated to indoor air quality and respective technology




*source: NIST*

# Retrofitting of office building to plus energy

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- **Powerhouse Kjørbo (Sandvika near Oslo)**
  - 5200 m$^2$ office building retrofitted to plus energy
  - Estimated energy consumption 20 kWh/(m$^2$a)
  - BREEAM-Nor classification „Outstanding“
  - 64 kW B/W HP (10 boreholes of 225 m) for space heating and free cooling (HP as liquid chiller back-up)
  - District heating as peak load and back-up for SH
  - 8.5 kW B/W Heat Pump Water Heater
  - Hydronic emission system with 50/40 °C (SH) and 12/17 °C (SC) design temperature
  - Solar PV generation system of 1556 m$^2$ => estimated annual yield 225‘000 kWh/a

*source: NTNU, COWI AS*

# Retrofitting of office building to plus energy

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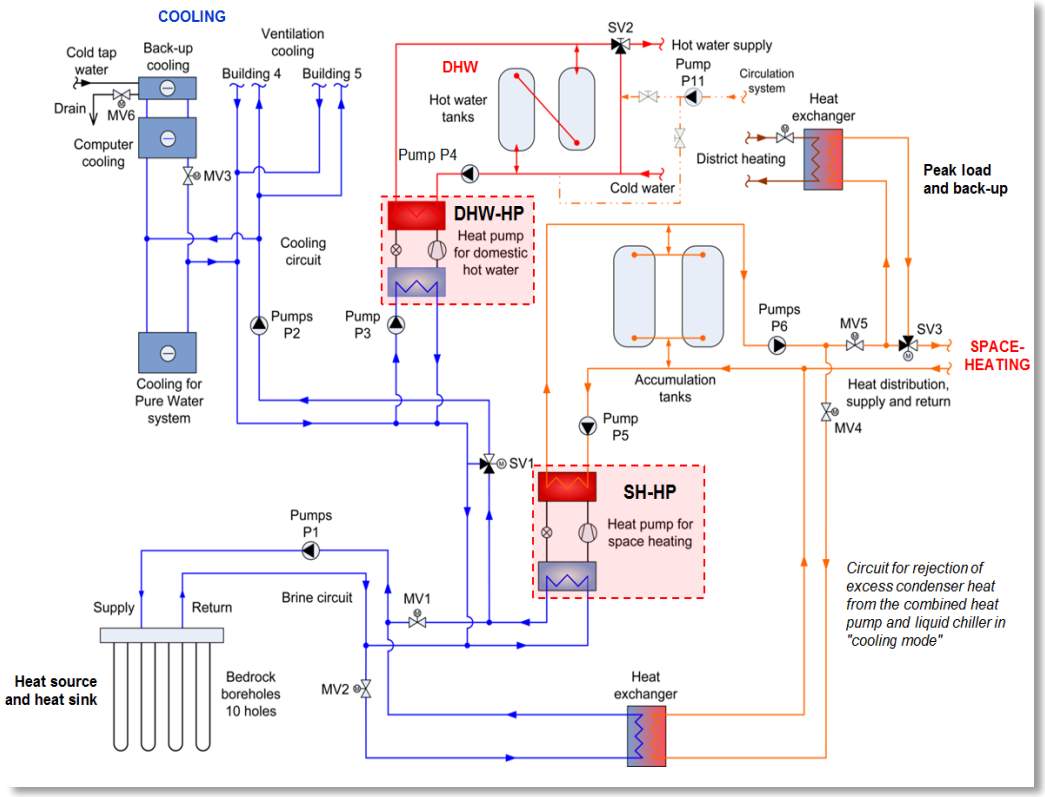
## Powerhouse Kjørbo (Sandvika near Oslo)




| | CALCULATED | MEASURED | DEVIATION COMMENT |
|---|---|---|---|
| Space heating heating vent air | 19.1 kWh/(m²a) | **19.9 kWh/(m²a)** | + 4 % |
| | 52 kW | **69 kW** | + 32 % |
| DHW heating | 4.8 kWh/(m²a) | **1.9 kWh/(m²a)** | - 60 % |
| Space cooling | 1.8 kWh/(m²a) | **2.0 kWh/(m²a)** | + 9 % |
| | 65 kW | **71 kW** | + 9% |
| SPF – heat pump for space and vent. air heating | * | **3.9** | Incl. pump energy for the borehole system |
| SPF – heat pump water heater (DHW heating) | * | **2.9** | Incl. pump energy |

*source: NTNU, COWI AS*

# Retrofitting of office building to plus energy

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- **Powerhouse Kjørbo – Optimisation potentials**
  - Boreholes oversized => expensive
    - 5 boreholes for 90% heating and peak cooling
  - Variable speed compressors offer optimum control and higher SPF values
    - Instead of intermittent two compressor control
    - Instead of load leveling by buffer storages
  - Switch to natural working fluids (propane and $CO_2$) should be considered
    - Instead of HFC
  - Use of excess heat of process cooling can be improved
    - Use process heat on evaporator side of heat pump

*source: NTNU, COWI AS*

# Overview IEA HPT Annex 40

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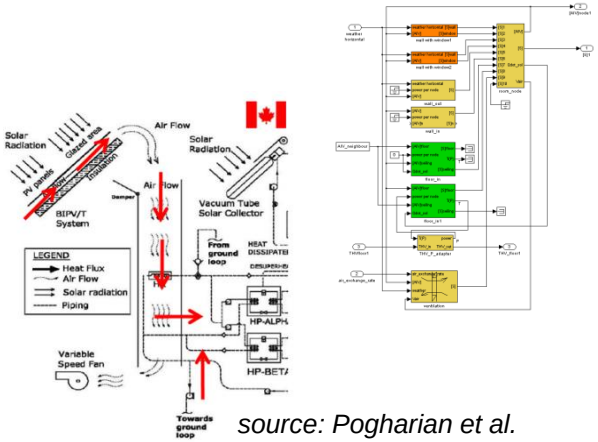
- Task 1: State-of-the-art nZEB-Technologies and concepts
  - Classification of used technologies

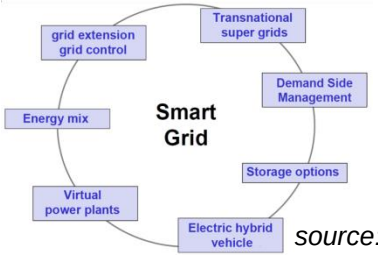
- Task 2: Assessment of nZEB concepts
  - Comparison regarding performance and cost




*source: Pogharian et al.*

- Task 3: Technology development and monitoring
  - Prototype development of heat pumps for nZEB
  - Monitoring of nZEB with heat pumps

- **Task 4: Integration of nZEB into the energy system**
  - **Storage integration and smart technologies to reduce grid interaction**




*source: Ebert et al.*

# Load management in Swiss field monitoring

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- **Evaluation of load management of on-site PV generation**

*source: Setz*

- Multi-family building in Rupperswil, CH
- 2 x 4.5 room apartment and 1 x 1.5 room office/apartment
- MINERGIE-P-Eco® certified
- B/W heat pump (8.9 kW)
- Vertical borehole heat exchanger (180 m)
- PV 20 $kW_p$, forecasted yield: 18’000 kWh/a
- Surplus electricity that cannot be used is fed into local power grid
- Building based electrical car (shared by tenants)
- Batteries charged by surplus of the photovoltaic energy

# Load management in Swiss field monitoring

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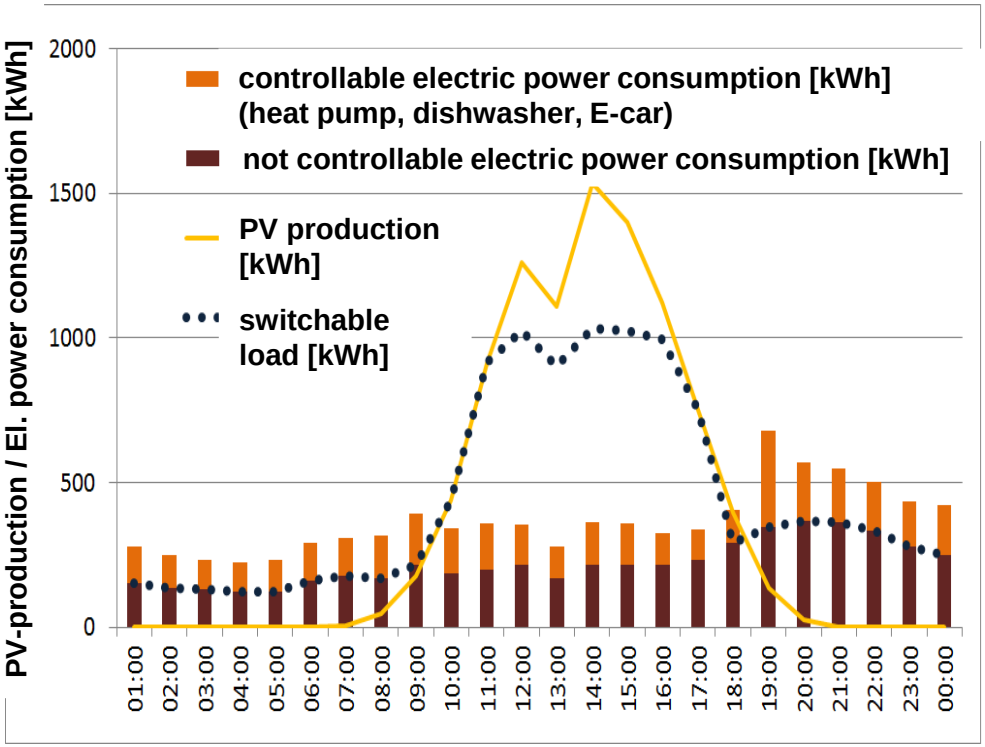
- **Evaluation of load management of on-site PV generation**




*source: Hall et. al., 2012*

- Evaluation of switchable load
- PV production: 19’800 kWh
- Total power consumption (0-24h) 13’165 kWh
- Total power consumption (10-16h) 3’191 kWh
- Possible switchable load: 3’674 kWh
- About 15% enhanced self-consumption

# Load management in German field monitoring

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- **Field monitoring of office buildings in Germany**

*Source: Kalz*

# Load management in German field monitoring

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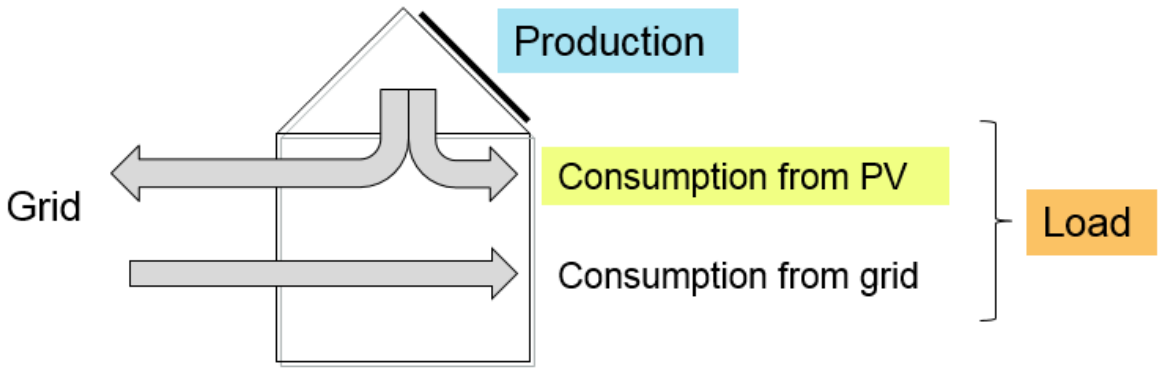
- Evaluation of characteristic numbers

$$load\ cover\ factor = \frac{W_{el,\ consumption\ of\ local\ production}}{W_{el,\ total\ electric\ load}}$$

$$supply\ cover\ factor = \frac{W_{el,\ consumption\ of\ local\ production}}{W_{el,total\ local\ production}}$$




*Source: Kalz et al., 2015*

# Load management in German field monitoring



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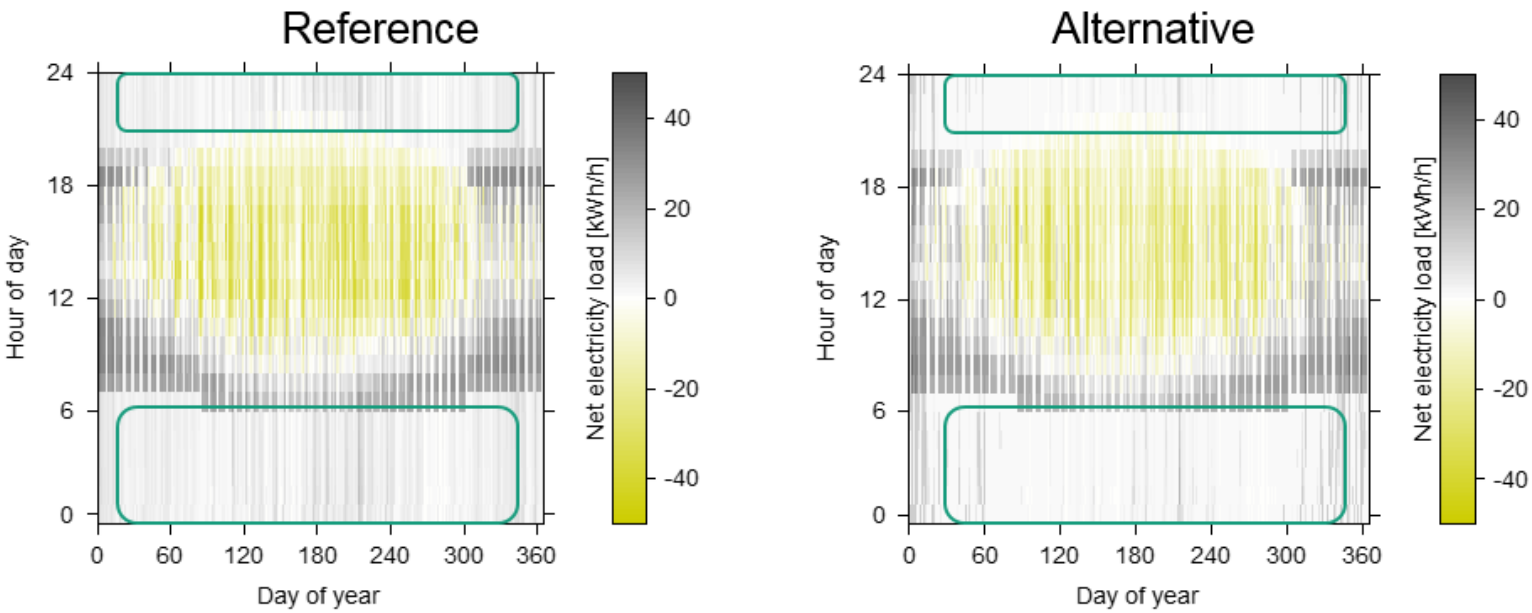


→ Shift operation of heat pump from night to PV-production time

- load cover factor: 43 % → 53 %
- supply cover factor: 42 % → 50 %

*Source: Kalz et al., 2015*

# Conclusions of IEA HPT Annex 40

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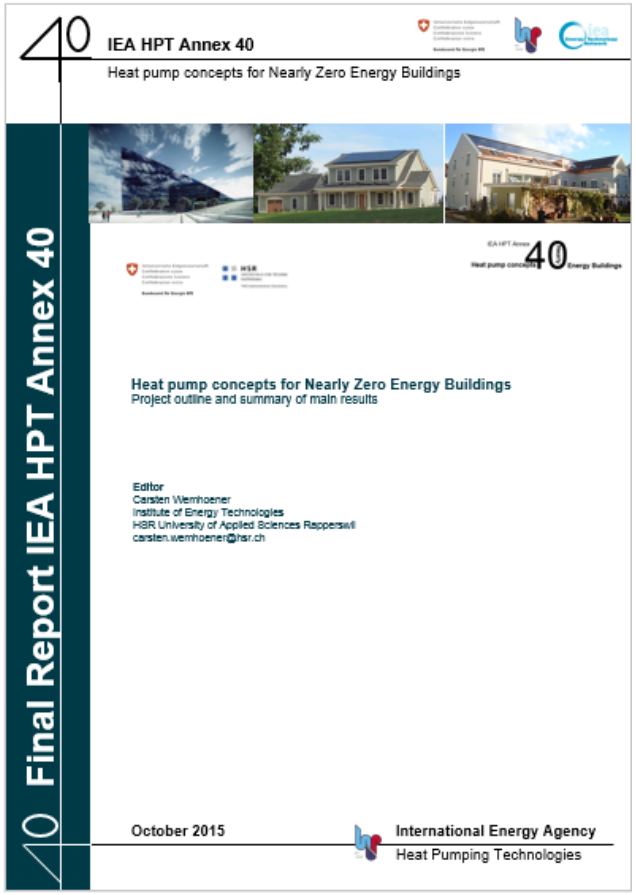
- **Conclusions IEA HPT Annex 40**
  - Several hundred nZEB as showcase buildings have been built
  - Focus is on nearly zero energy balance
  - The majority of concepts are all-electric buildings equipped with heat pumps as on-site PV generation
  - Balance is quite easily reached in SFH MFH and office harder due to limited building surface
  - In residential buildings heat pump most energy-efficient and cost-effective, in larger buildings, CHP and district heating may be added
  - Heat pumps have also potential to grid-supportive operation with enhanced flexibility



# Conclusion of IEA HPT Annex 40

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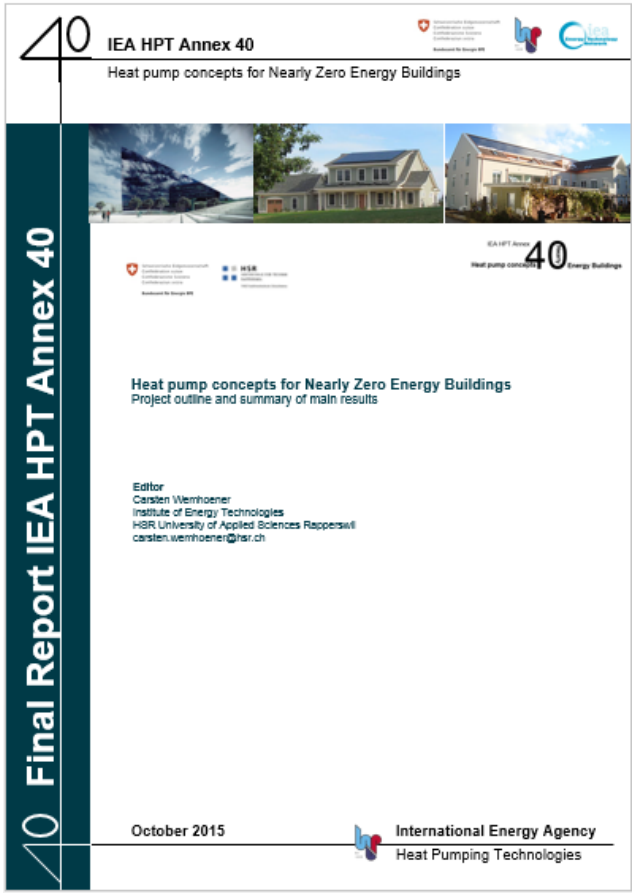
- **Conclusion IEA HPT Annex 40**
  - Final report currently in preparation
  - ExCo Review until March 2016
  - Implementation of comments afterwards
  - Final approval on HPT ExCo spring meeting 2016
  - Reports to be published by June 2016


IEA HPT Annex 40
Heat pump concepts for Nearly Zero Energy Buildings

Final Report IEA HPT Annex 40

Heat pump concepts for Nearly Zero Energy Buildings
Project outline and summary of main results

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October 2015

International Energy Agency
Heat Pumping Technologies

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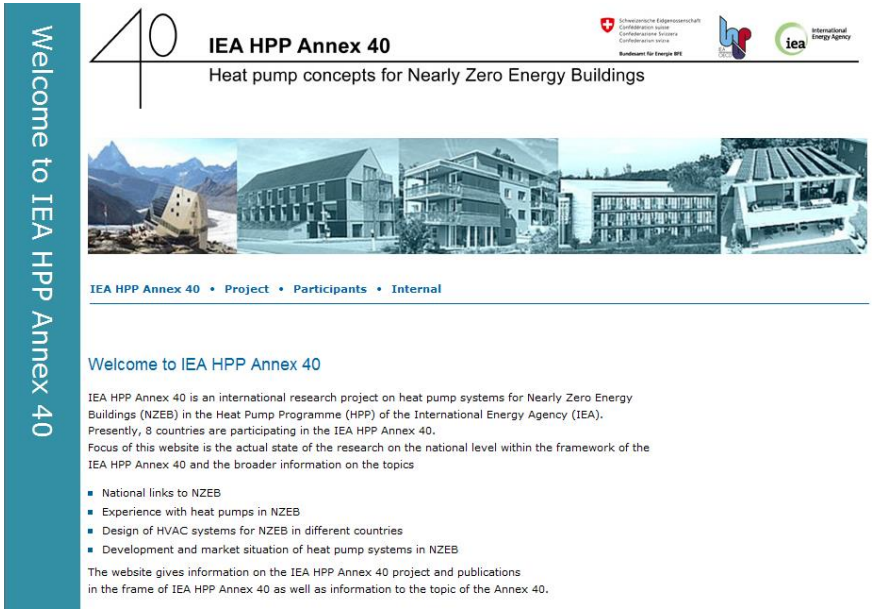
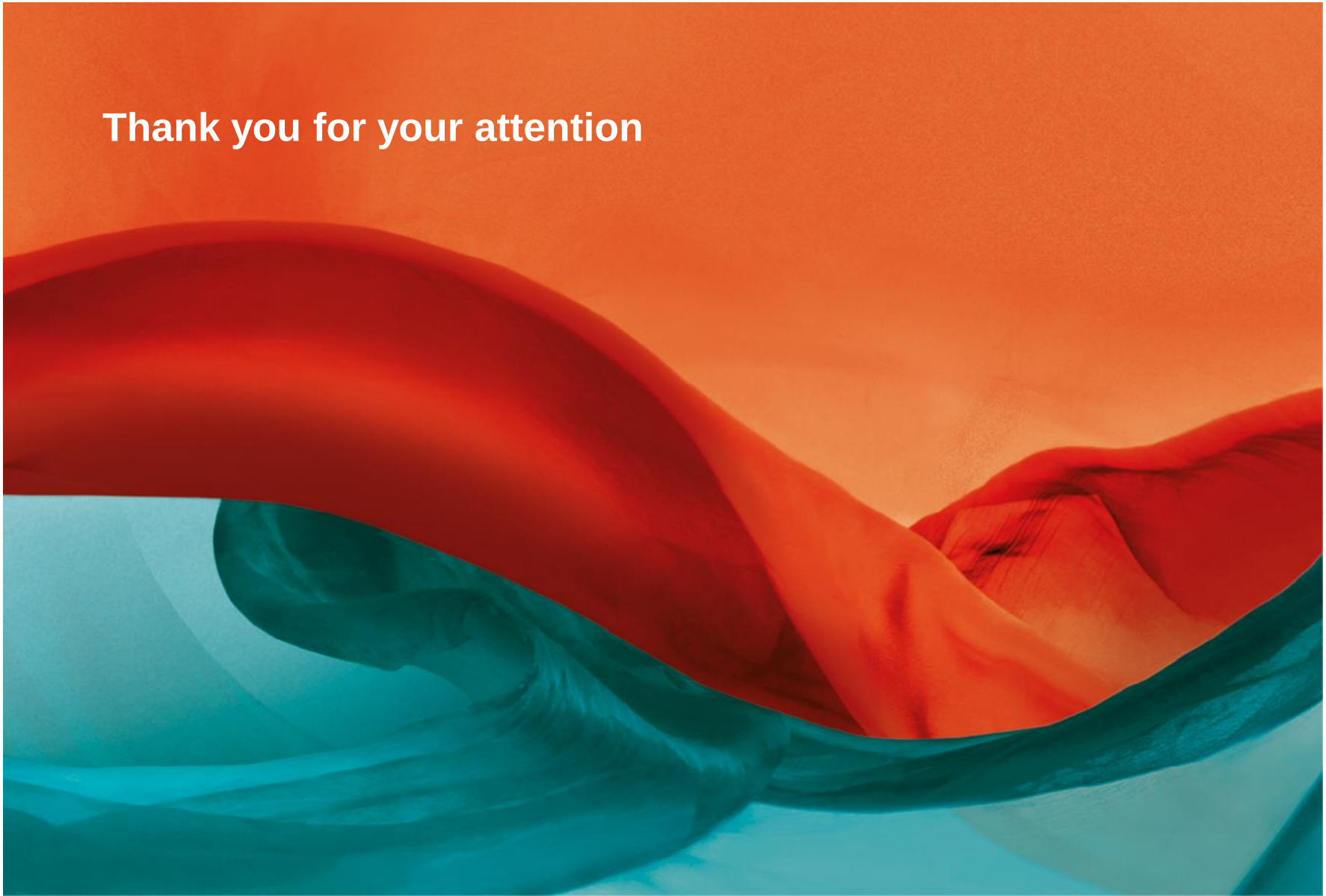
- **Information on IEA HPT Annex 40**
  at website http://www.annex40.net





# Thank you for your attention