Technology Collaboration Programme
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Technology Collaboration Programme on Heat Pumping Technologies (HPT TCP)

Annex 55

Comfort & Climate Box – towards better integration of heat pumps and storage

Final Report – Part 3

Field Trial Results

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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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Comfort & Climate Box – towards a better integration of heat pumps and storage

Final report of the combined Annex 34 (ECES) and Annex 55 (HPT)

Part III – Field Trial Results

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This report has been made available as part of the work under the combined ECES Annex 34/HPT Annex 55 on heat pumps and storage. The opinions expressed herein do not necessarily reflect a consensus within the working group from Annex 55/34.

Contents

1 Introduction

This report collects details about CCB field trials that have taken place in several of the participating Annex countries. The purpose of this collection is to highlight through real implementations in the field the basic functionalities needed in a CCB, problems in installation, considerations on system size and user interaction. We have projects from Canada, Austria, The Netherlands, UK and Turkey.

All information in this report is systematically ordered in a standard project overview template in the next chapter. The last chapter details the lessons learned.

2 Field trial results

2.1 Canada

2.1.a Key data

Title

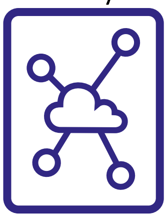
In-field monitoring of HP + Storage Systems in Canada

Organisation / contacts

Natural Resources Canada will direct questions to appropriate contacts leading this effort.

CCB implementation strategy

Flexibility



2.1.b Installation description

Several phases of field monitoring have been undertaken by a Canadian company and partner utilities, using **prototype** (initial iteration), **pre-production** (refined and improved) and **production** units.

Prototype

Details on HP and storage system are limited for the prototype demonstration:

Heat Pump
- Type: Ductless, air to air heat pump
- Modes: Heating

Storage
- Material: PCM
- Installation: Storage unit located outside, as separate component from HP outdoor unit

Integration
- Worked with a municipal electric utility to test prototypes in residential and small business settings.

Pre-Production

Heat Pump
- Type: Ductless, air to air heat pump
- Compressor: Two-stage

- Modes: Heating & Cooling
- Capacity: 1.5 ton units (18000 BTU/h, 5.3 kW)
- Control: Customer controls temperature, utility decides to charge/discharge/maintain storage

Storage
- Material: PCM (exact composition proprietary)
- Installation: Storage unit located inside occupied space in radiator-like configuration
- Energy Storage/Cycle (Heating): 48,000 BTU
- Number of Daily Cycles: 2
- Number of Total Cycles (Material): 7000
- Discharge Power (Heating): 12000 BTU/h (1 ton, 3.5 kW)
- Load Shifting Capability: 2 kW for 4 hours (heating), 1 hour for cooling

Production
Heat Pump
- Type: Ductless, air to air heat pump
- Compressor: Two-stage
- Modes: Heating & Cooling
- Capacity: 1.5 ton units (18000 BTU/h, 5.3 kW)
- Control: Customer controls temperature, utility decides to charge/discharge/maintain storage

Storage
- Material: PCM (exact composition proprietary)
- Installation: Storage unit located inside occupied space in radiator-like configuration
- Storage Details
- Energy Storage/Cycle (Heating): 36,000 BTU
- Number of Daily Cycles: 2
- Number of Total Cycles (Material): 5000
- Discharge Power (Heating): 12000 BTU/h (1 ton, 3.5 kW)
- Load Shifting Capability (demand reduction): 2 kW for 4 hours of heating, 1 hour of cooling.


Figure 1 – Stash M1 Heat Pump (indoor component).

Integration
- Working with 7 utilities in Canada and the United States
- Building Vintage: Single family homes and multi-family low-rise buildings. Retrofits and new construction.

- Typical primary heating systems: Fuel oil furnaces and boilers; natural gas furnaces; electric resistance baseboards; heat pumps
- Typical Construction parameters are provided in Table 1.

Floor Area (m2)	100 - 145
Wall RSI (m2°C/W)	2.1 - 3
Roof RSI (m2°C/W)	2.8 - 5.6
Infiltration (ACH50Pa)	2.9 - 5.6

Table 1 – Summary of typical envelope construction by vintage for demonstration locations.

2.1.c Testing period and location

Both in-field demonstrations were performed in Canada, under a cold maritime climate. Dates for each trial were:

- Prototype: 2016-2017
- Pre-production: 2018 – 2019
- Production: 2020 – present

2.1.d Measured data available

Available measured data is currently limited:
Prototype testing focused on allowing the system developer to prove their concept and demonstrate its value and function in Canada.
Pre-production testing included in-home and lab testing.
Production: As of March 2021, Stash Energy has 5 utility customers in Canada and 2 in the United States.

2.1.e Lessons learned

Completed monitoring (i.e., for the prototype unit) focused primarily on demonstrating the ability of Climate & Comfort Box (CCB) type systems to use the thermal storage to provide heating to the home during on-peak hours. While operational data is not currently available, several key aspects were noted, including:

- Storage size and location are critical:
  Larger units can be difficult to integrate into Canadian homes, as there may be limited area inside the occupied space, or within the dedicated mechanical space of the building.
  Also, locating the storage outside in a cold climate like Canada could lead to potential issues with freezing of any secondary heat transfer fluids if additional protections are not put in place.
- Optimized, system-level design is important:
  The ability of the heat pump to adequately store thermal energy and shift peaks requires an appropriate balance between heat pump capacity, storage size, and any related components.

The advantages and disadvantages of completed prototype demonstration/testing included:
Advantages

- Demonstrating ability of CCB unit to offer meaningful peak demand reductions.
- Identification of future areas of improvement (e.g. storage design, integration with HP)

Disadvantages

- Little information on overall performance of heat pump system (e.g., COPs, refrigerant cycle performance (temperature, pressure), internal controls)
- Limited scope (single building type and location)

- Difficulty in comparing and quantifying performance. There is a clear need for effective metrics that can be used to compare different systems, locations, and applications.

Ongoing Monitoring

The findings of the initial round of testing have led to greater interest in these systems. The current round of monitoring (pre-production, in progress) will include several improvements:

- Increased Scope: Up to 4 monitoring cases will provide greater diversity in data acquired and mitigate impacts of installation or equipment issues on overall conclusion.
- More Detailed Measurement: Use of on-board HP monitoring to develop a better understanding of heat pump operations and system performance (i.e., COPs, development of relevant metrics)

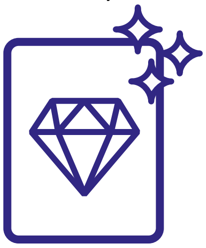
2.2 Austria

2.2.a Key data

Title
Living Lab Energetikum

Organisation / contacts
FH Burgenland; Forschung Burgenland

CCB implementation strategy
Efficiency



2.2.b Installation description

Heat pump

- heat pump (HP) type: **A/W W/W** (on-off controls)
- nominal power heat: Q_dot=49,3kW P_el=19,1kW
- nominal power cool: Q_dot=45,3kW P_el=20,1kW
- model GEA GLWH 0202 BD2

Storage

- volume 1000 liter (water)
- operating temperature range: cool=13/7 heat=52/47

Building

- type: office building
- area: 751.49 m² (gross floor)
- volume: 3525,33m³ (gross volume)
- U values
    - roof 0,136 W/m²K
    - windows 0,79-0,90 W/m²K
    - outside wall 0,149 W/m²K
    - door 1,7 W/m²K
- yearly energy performance (label) f_{GEE}=C (1,06)
- transfer system characteristics
    - underfloor heating summer=18/23 winter=33/28
    - concrete core activation summer=16/19 winter=33/30
    - air system summer=25°C/43,8%rh winter=24,6°C/53,6%rh
- central air handling unit (AHU) with separate variable volume-rate-control unit for each office room with over 2000 monitoring points/ sensor technology (temperature, humidity, CO2, VOC, water and air enthalpy flow etc.) to ensure a detailed room air quality and energy flow analysis.
- Building Management System with BACnet-OPC-Matlab Interface and digital twin (cloud-based data storage system with more than 10000 items)

- Redox flow battery system will be installed in 2020 (see H2020 project PVadapt)
- PV system will be installed in 2020 (see H2020 project PVadapt)

Controls

- Model based energy management system with weather forecast, data driven state space model and multi objective function will be integrated in 2020 (see H2020 project PVadapt)

2.2.c Testing period and location

- location: Living Lab Energetikum
- permanent data recording since 2018 with Siemens Desigo and the cloud system aedifion

2.2.d Measured data available

The ENERGETIKUM has an open platform communication, a building automation, and control network interfaces, which enables the integration of the application demonstrator into the building control and communication system.

- temperature, flow rates, electric power and provide a schematic showing where the sensors are placed
- sampling time: up to 10 sec
- high quality weather station with short-wave (horizontal and in each direction) and long-wave radiation sensors
- instruments used and their accuracy
  - temperature Siemens QAE2121.010 and Siemens QFM 2160
  - humidity Siemens QBM3020-10 and S+S KFTF-U PT100
  - heat/cool consumption Siemens UH50
  - air speed S+S EE650
- COP 2,58 (manufacturer information)
- EER 2,25 (manufacturer information)

2.2.e Lessons learned

- Analysis of the AHU shows huge energy saving potential up to 60%
  - A tailor-made control offers time scheduled and usage specific operation.
- Inadequate shading control led to high energy demand for cooling and heating.
  - Tailor-made control allows massive reduction of energy consumption in electric energy as well as heating and cooling energy demand.
- Inadequate data acquisition with the standard building automation system
  - 3rd party application aedifion with cloud data logging installed.
- Over sizing of the heat pump systems and wrong control strategy leads to very short runtimes and high frequency stop and go operation. The thermal storage potential of thermally activated constructions are not utilized. Only simple control strategies which are not able to consider both - the buffer tanks and the thermal inertia of the building – are generally used.
  - A model-predictive control strategy (MPC) which is able to consider the thermal inertia was developed and will be tested for one zone over the summer months 2020.
  - In 2021 the whole building will be controlled based on the developed MPC (see H2020 project PVadapt).

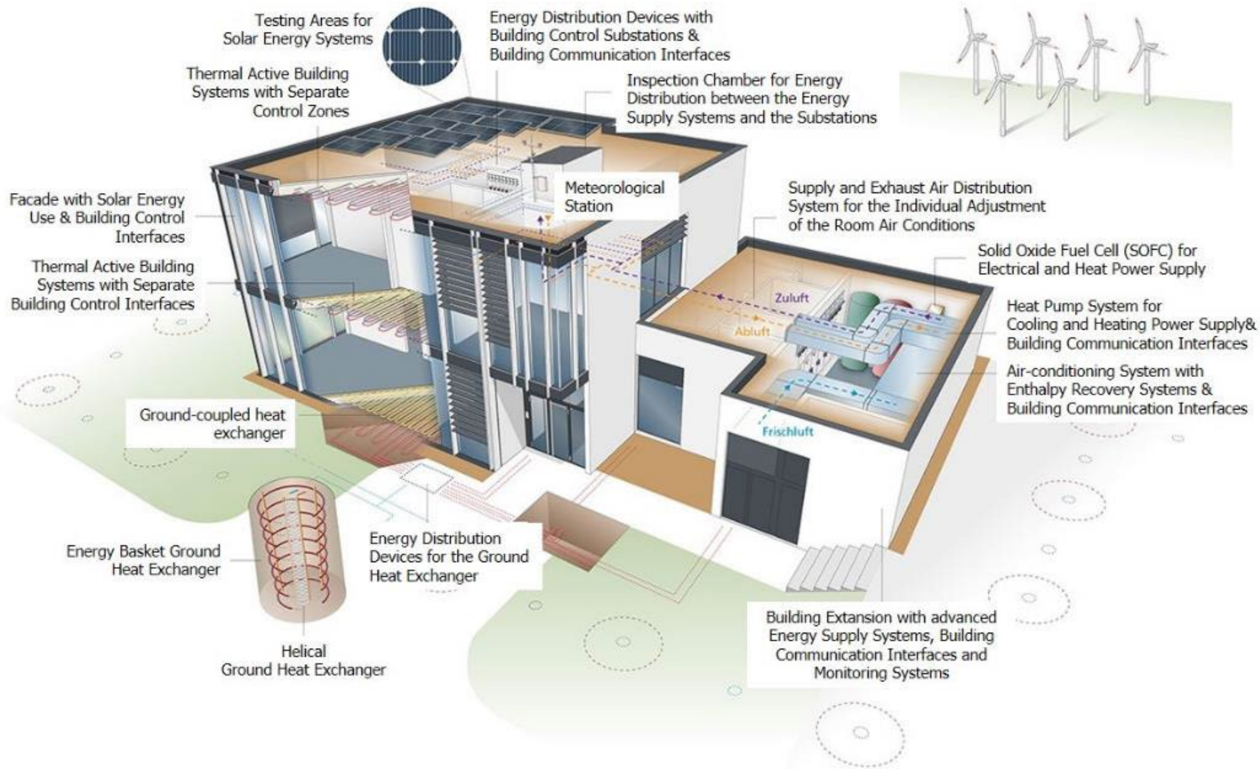


Figure 2 – Overview of the Energetikum

2.3 Austria (research) / Germany (testing location)

2.3.a Key data

Title

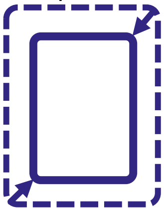
Row Houses in Passive House Standard with Compact Heat Pump Units

Organisation / contacts

UIBK, Fabian Ochs, Georgios Dermentzis

CCB implementation strategy

Compactness



2.3.b Installation description

One Passive House Compact Heat Pump Unit for each dwelling

Heat pump

- type: Exhaust air (+ ambient air) to supply air for space heating and separate heat pump for DHW (combined evaporator) with 212 l storage, maximum power heat pump for space heating: A2 1300 W, variable capacity, Pichler PKOM4, supply air cooling option

Storage

- volume 212 l (DHW), operating temperature range 55 °C with HP, max 65 °C with electric heater

Houses

- SFH row houses, area: 156 m² (treated area), volume 390 m³, Passive House, U-values external wall 0.138 W/(m² K), roof 0.108 W/(m² K) basement 0.131 W/(m² K), yearly energy performance: heating demand: 13 kWh/(m² a) (PHPP calculation)

Heat transfer system

- supply air heating systems, operating temperature: 33 °C

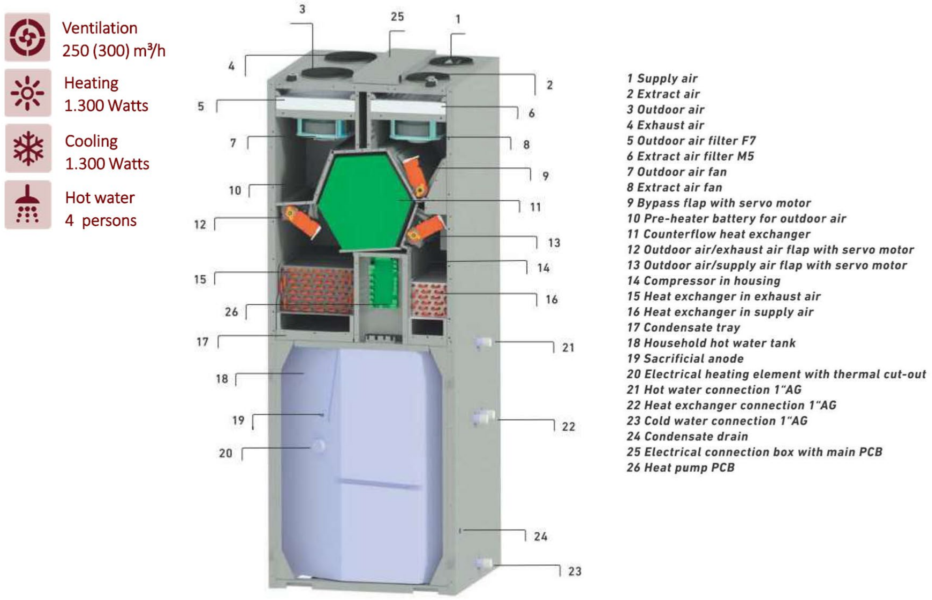


Figure 3 – Components of a Passive House HP compact unit (PKOM4, Pichler).

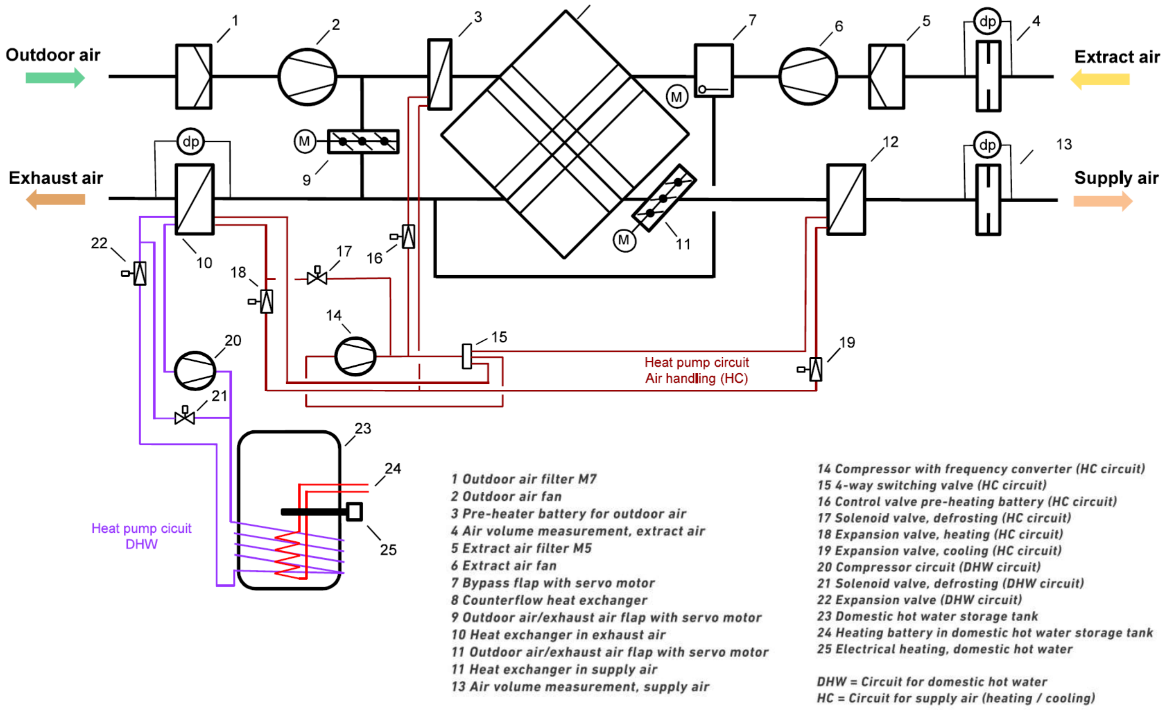
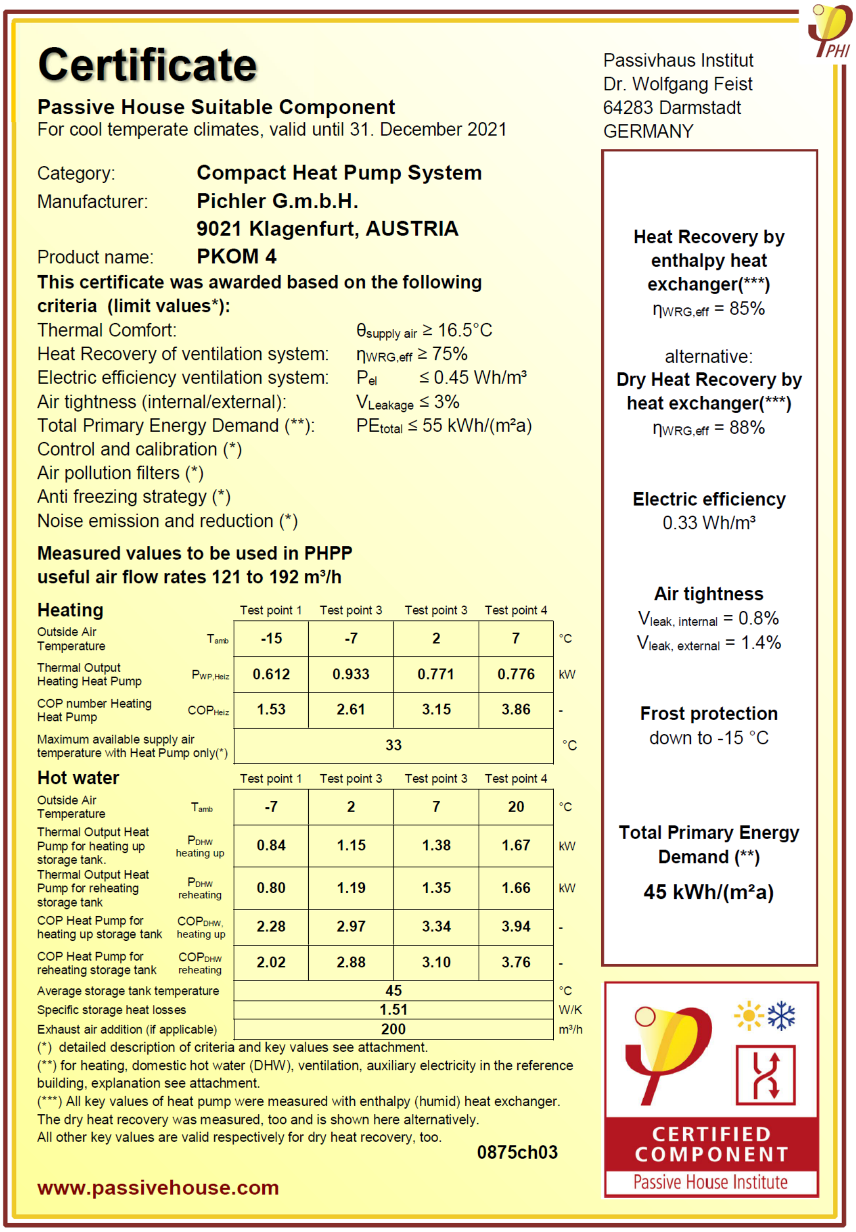


Figure 4 – Scheme of the Passivce House compact heat pump with MVHR (PKOM4, Pichler)



Certificate

Passive House Suitable Component
For cool temperate climates, valid until 31. December 2021

Passivhaus Institut
Dr. Wolfgang Feist
64283 Darmstadt
GERMANY

Category: **Compact Heat Pump System**
Manufacturer: **Pichler G.m.b.H.**
9021 Klagenfurt, AUSTRIA
Product name: **PKOM 4**

This certificate was awarded based on the following criteria (limit values*):

Thermal Comfort:	$\theta_{supply\ air} \geq 16.5°C$
Heat Recovery of ventilation system:	$\eta_{WRG,eff} \geq 75\%$
Electric efficiency ventilation system:	$P_{el} \leq 0.45$ Wh/m³
Air tightness (internal/external):	$V_{Leakage} \leq 3\%$
Total Primary Energy Demand (**):	$PE_{total} \leq 55$ kWh/(m²a)

Control and calibration (*)
Air pollution filters (*)
Anti freezing strategy (*)
Noise emission and reduction (*)

Measured values to be used in PHPP
useful air flow rates 121 to 192 m³/h

Heating		Test point 1	Test point 3	Test point 3	Test point 4	
Outside Air Temperature	T_{amb}	-15	-7	2	7	°C
Thermal Output Heating Heat Pump	$P_{WP,Heiz}$	0.612	0.933	0.771	0.776	kW
COP number Heating Heat Pump	COP_{Heiz}	1.53	2.61	3.15	3.86	-
Maximum available supply air temperature with Heat Pump only(*)		33				°C

Hot water		Test point 1	Test point 3	Test point 3	Test point 4	
Outside Air Temperature	T_{amb}	-7	2	7	20	°C
Thermal Output Heat Pump for heating up storage tank.	P_{DHW} heating up	0.84	1.15	1.38	1.67	kW
Thermal Output Heat Pump for reheating storage tank	P_{DHW} reheating	0.80	1.19	1.35	1.66	kW
COP Heat Pump for heating up storage tank	$COP_{DHW,}$ heating up	2.28	2.97	3.34	3.94	-
COP Heat Pump for reheating storage tank	COP_{DHW} reheating	2.02	2.88	3.10	3.76	-
Average storage tank temperature		45				°C
Specific storage heat losses		1.51				W/K
Exhaust air addition (if applicable)		200				m³/h

(*) detailed description of criteria and key values see attachment.
(**) for heating, domestic hot water (DHW), ventilation, auxiliary electricity in the reference building, explanation see attachment.
(***) All key values of heat pump were measured with enthalpy (humid) heat exchanger. The dry heat recovery was measured, too and is shown here alternatively. All other key values are valid respectively for dry heat recovery, too.

0875ch03

Heat Recovery by enthalpy heat exchanger(***)
$\eta_{WRG,eff} = 85\%$

alternative:
Dry Heat Recovery by heat exchanger(***)
$\eta_{WRG,eff} = 88\%$

Electric efficiency
0.33 Wh/m³

Air tightness
$V_{leak,\ internal} = 0.8\%$
$V_{leak,\ external} = 1.4\%$

Frost protection
down to -15 °C

Total Primary Energy Demand (**)
45 kWh/(m²a)

CERTIFIED COMPONENT
Passive House Institute

www.passivehouse.com

Figure 5 – Passive House certified component (www.passiv.de)

2.3.c Testing period and location

Germany, Frankfurt, 8th January to 31st May 2020

2.3.d Measured data available

- Available data: temperature of ambient air, supply air, exhaust air and extract air, flow rates (ambient air and extract air), DHW storage temperature (center, bottom), electric power of both compressors, fans and auxiliary devices (control) and provide a schematics showing where the sensors are placed, see attached scheme
- sample time 2 min
- I&C system (sensors and meters of the control system) of the compact heat pump unit.

KPIs
SPF (Jan to May) heating mode 2.64
SPF (Jan to May) system (MVHR + HP space heating) 4.52

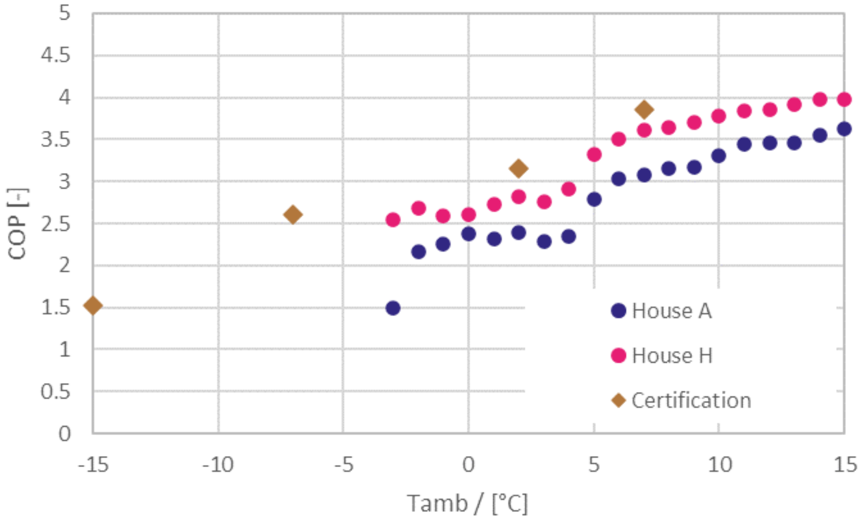


Figure 6 – COP (space heating) vs. ambient temperature according to certification and as measured in House A and House H.

2.3.e Lessons learned

Performance in real conditions depends on the building energy level and user behavior (i.e. set points, etc.).
Overall, the performance in real conditions is in relative good agreement with the predictions with PHPP and the test and certification performance data.
De-icing of evaporator (exhaust air) has significant influence on overall performance.
Limited heating power because of capacity of heat pump and because of supply air heating.
Use of post-heating in buildings with higher heating load could increase the electricity demand and thus reduce the system SPF of the heat pump.

2.4 Netherlands

2.4.a Key data

Title

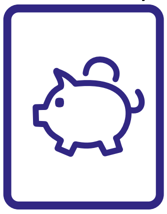
Nul Op de Meter – Zero Energy Houses

Organisation / contacts

Stroomversnelling (Maarten Hommelberg hommelberg@bdho.nl)

CCB implementation strategy

Affordability



2.4.b Installation description

The market for compact heat pumps and storage solutions in the Netherlands has been heavily influenced by the developments in the 'Stroomversnelling' program in the Netherlands. The Stroomversnelling aims to convert the Dutch housing stock to energy neutral by 2050.

The NZE approach is a logical, though challenging one: If we want the Dutch housing stock to be energy neutral on average, then we should start renovating houses to an energy neutral level. If we want to get that done on time for 2050 then we need a lot of industrialization. And if we want to do that cost neutral for the tenant, then the renovation should be cheap enough to be paid from the energy savings.

The program has led to the introduction of a new concept called an 'energy module', which contains all the required installations for an average home after a thorough renovation. At least 10 manufacturers introduced new products based on this concept, each with their own approach. Each successful development provokes a counter movement, which is also the case here; other manufacturers are attempting to integrate the buildings installations into the façade and roof.

The energy module

An energy module is a box with all the building related installations integrated. It typically consists of:

- Heat pump
- Hot water storage vessel
- Balanced ventilation system with heat recovery
- Solar invertor
- Monitoring system

At first, energy modules were developed for renovation, but now there are also several models for newly built houses. Some manufacturers added specific features like; a hot water storage vessel for space heating, a battery, or a gas-fired heater for a combination with a hybrid heat pump.

Figure 7 – Energy module.

Examples of energy modules

Because the Stroomversnelling challenge was first given to construction companies, several them decided to create their own energy module: BAM, van Wijnen and Volker Wessels all developed their own solution.

Figure 8 – The energy modules of BAM, van Wijnen and Volker Wessels.

The concept of van Wijnen has been developed for newly built houses. The roof of the energy module is the floor of the bathroom and has a toilet connected to it.

Then there are several suppliers of heat pumps and ventilation systems that developed their own concepts: LG, Nathan, Nibe and Nefit all created their own energy module. Especially the Nefit model stands out as it stands two stories tall and is attached on the outside to the façade.

Typical size of an energy module:

- HP capacity: 3-3.5 kW (closest commercial size for private homeowners approx. 4-5 kW)
- TES: 180 liters
- PV electricity production: 6000 kWh/year

Figure 9 – The solutions of LG, Nathan, NIBE and Nefit.

Figure 10 – The solutions of Factory Zero, VDM/Rensa and Wattz-In.

2.4.c Testing period and location

Approximately last 5 years.

2.4.d Measured data available

Electric energy use measurements per dwelling.

2.4.e Lessons learned

Extensive experience has been accumulated in the Netherlands by renovating blocks of houses to ‘zero energy’ level, in particular with upscaling and industrial-scale integrated systems renovation. Different aspects are included in the renovation process:

- Completely new insulating ‘shell’ around the house
- Modern and integrated heating/hot water/ventilation system
- Smart controls and smart metering
- Subsidy scheme depending on smart metering

The Stroomversnelling network consists of contractors, component suppliers, housing providers, local governments, financiers, TSOs and other parties. Its goals are to reduce the price of NZE renovations, increase occupants’ acceptance of these renovations and increase the momentum and growth pace of the NZE housing market itself.

The project started in 2013 with 4 construction companies and 6 social housing associations. The organization supporting this movement, Stroomversnelling, now has more than 60 members. Now (2021) there are more than 15,000 NZE dwellings in the Netherlands. Part of these houses are renovation projects, and part of these are newly built. 48 construction companies have done NZE renovations, 60 social housing associations were involved. For newly built houses these number are even higher with 91 construction companies and 93 social housing associations.

Advantages of the “energy module”

One of the challenges with this type of renovation is the placement and connection of an entirely new building installation.
This volume can never be achieved with traditional ways of working that require a lot of manual labor. Thus, we need to industrialize the renovation process with which we approach the energy transition. Such an industrialized process makes use of standardized components, that are produced off-site in a factory. This increases productivity, quality and reduces on site labor and nuisance for the inhabitants.
That means that the process is to be broken down in standardized parts, like the energy module, which require limited manual labor to install.
The renovation process has to be completed while the tenants remain in the house, which limits the amount of noise and dust during the renovation process. The process also has to be finished within 10 working days, so custom installations and much manual labor are out of the question. On top of that energy performance of the building must be guaranteed, which again limits the room for manual labor or errors.
Offsite Industrialized solutions with quality control implemented have a huge advantage under these circumstances. Hence the birth of the Energy module.

Services and optimizations through integration

Apart from the other benefits of industrialization the integration of the same components in a single ‘skid solution’ is a large positive result. Especially from an IT perspective this is interesting as most of the energy modules integrate some means of communication to the outside world. On top of that the machines integrated into the module are also capable of communicating with each other. This opens a range of new possibilities.

An internet connected energy module can download the weather forecast and schedule the optimal time to charge the tap water buffer, this saves around 400 kWh yearly. Another factor is operation and maintenance of installations. Malfunctions in any of the components can be detected remotely, even before the inhabitant notices a problem. This improves the user experience. When a problem occurs, a mechanic knows which spare parts to bring. This saves costs as the mechanic only needs to drive to the house once.

Taking this one step further predictive maintenance can forecast for a fleet of energy modules which parts will be failing when. This allows the manufacturer to buy spare parts in bulk and replacing them all at once, instead of having to deal with a lot of separate phone calls from users.

2.5 Turkey

2.5.a Key data

Title

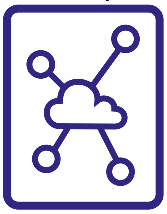
Yozgat House

Organisation / contacts

Veli Özbek, Özbek Yenilenebilir Enerji & Mühendislik Sistemleri, Veliozbek72@icloud.com

CCB implementation strategy

Flexibility



2.5.b Installation description

- Heat pump:
  - A/W HP (Viessmann), Power: 16 kW X 2
- Storage:
  - Water tank storage: 400 L (for heating system) ; Domestic Hot water tank storage : 300 L
- House
  - Single family house, 300 m2 floor area
  - PV panels,20 X 275 W, Li-ion batteries 9 KW capacity
- Transfer system
  - Underfloor heating, each room has a separate control

2.5.c Testing period and location

The building is located in city of Yozgat in the inner part of Turkey. It has been continuously monitored since September 2018. The monitored real time data and previous ones can be reached at :
https://www.solarweb.com/PvSystems/PvSystem?pvSystemId=55086ea4-adb5-4407-a13b-e4d13c6b7baa

2.5.d Measured data available

- Temperature and power consumption are measured. Sensors are built in the control units.
- The system is controlled by a number of instruments:
  - Consumption regulator (Fronius Ohmplot) to use excess solar power to produce heat (heat pump and hot water) with adjustable regulation from 0 to 9 kW
  - bidirectional smart meter (Fronius Smart Meter TS) to optimize self-consumption, record the load curve and controls the various energy flows
  - inverter (Fronius Symo Hybrid) allows surplus energy from the photovoltaic system to be stored in Li-ion batteries
- Self consumption, cost optimization

2.5.e Lessons learned

The most interesting finding is system can operate at 100% self-consumption. The heat pump operation is optimized with less on/off times.

Problems during installation and operation
Dimensions of pipes used for under-floor heating may not fit to the energy system.

Critical issues and solution
Pump choice was adjusted according to the pipe dimensions used in the under-floor system.

Pros and cons of the installation
It is important to develop the project concept as a whole and use components with right capacities that can be easily integrated and connected.

Suggestions for future improvements on the basis of the field test experience
- Increasing performance of heat pumps,
- System design should consider outdoor design temperatures
- Choosing right dimensions of piping
- Using floor heating at the optimum temperatures for best results
- Increasing awareness

3 Overview and summary of lessons learned

Based on the analysis of the collected field trials, some general conclusions on CCB installations can be drawn. It is worth noting that such conclusions are based on the results of the considered projects, thus they cannot be considered comprehensive or generally applicable to every CCB, but they provide useful insights in relationship with the related CCB archetypes.

In Table 2 on the next page, an overview of the field trial cases, and their main specifications is given.

The following general lessons can be drawn from the field trials:

Heat pumps

- Optimized, systematic design is needed:
  The ability of the heat pump to adequately store thermal energy and shift peaks requires an appropriate balance between heat pump capacity, storage size, and any related components (e.g. heat exchangers linking the two). It is important to develop the project concept as a whole and use components with right capacities that can be easily integrated and connected. System design should consider outdoor design temperatures; right dimensions of piping for floor heating should be selected as well as optimum supply temperature. The awareness about HP installations, their behaviour and performance of final users and installers need to be improved.
- Heat pump size:
  If the HP is undersized, it is needed a long time for TES charging and it is even difficult to provide load shifting for peak periods. Over sizing of the heat pump systems and wrong control strategy leads to very short runtimes and high frequency stop and go operation. As a rule of thumb in Canada every 5kW of thermal power, a 14 kWh thermal storage is installed. In the case from the Netherlands in a typical residential application the HP size is 4-5 kW with 180 liters TES.
- Back up heater (BUH). The integration of a back up heater (BUH) is not always necessary, e.g. in the Netherlands the climate is only moderately cold and the presence of the BUH is not a common practice. The BUH can considerably decrease the overall efficiency of the system, so it is better to design the system to work without this component, if possible.

Storage

- Storage size is critical:
  Larger units can be difficult to integrate into homes, as there may be limited space within the dedicated mechanical space of the building. Locating the storage outside in a cold climate (like Canada) could lead to potential issues with freezing of any secondary heat transfer fluids if additional protections are not put in place.
- It is important to make a distinction between thermally stratified storage and phase change material (PCM) storage. PCM allows to have fixed working temperatures, chosen on the basis of the HP operating conditions, that could increase the overall performance. Furthermore, PCM can considerably reduce the storage size depending on the medium: they can reduce the size by 1/2 for salt hydrate and 1/4 for paraffins.
- Storage size and flexibility are strictly related: adding larger storage capacity (i.e. hot water tanks) can deliver more flexibility in terms of modification of the electricity demand.

Lessons learned continued after summary table →

Table 2 – Overview of field trial specifications.

Case	Implementation strategy	Description	Heat Pump	Storage	Control	Other
Canada	Flexibility	Several phases of field monitoring with ductless air to air heat pumps and PCM storage for peak shaving strategy	Optimized, systemic design of CCB's is needed	Storage size is critical. PCM's allow for fixed working temperature		
Austria LLE	Energy efficiency	Large scale building with TABS, CCB, PV systems and BAC.	Over sizing of the heat pump systems leads to very short runtimes and high frequency stop and go operation	The inherent thermal mass cannot be well exploited with RBC	Tailor made control (MPC) are needed in complex and high thermal inertia systems	
Austria PH	Compactness	Passive House Compact Heat Pump with storage	SH and DHW are managed separately. Exhaust air (+ ambient air) to supply air for space heating and separate heat pump for DHW	DHW storage is equipped with a BUH		Performance in real conditions depends on building energy level and user behavior (i.e. set points, etc.).
Netherlands	Affordability	Introduction of a new concept called 'energy module' for industrial-scale renovation			The energy modules can communicate among them and with external parties	All the components are integrated and built to satisfy space constraints
Turkey	Flexibility	Air source heat pump, thermally stratified storage, DHW and PV panels in a dwelling			The control can achieve 100% self-consumption from integrated PV panels	Holistic design is needed

Control and performance

- The common practice is to have Rule Based Control (RBC). They are preferred for their easiness and good effectiveness in most of the installations. Predictive RBC could be a possible improvement of simple RBC, still maintaining a limited complexity in implementation and tuning.
- CCB can also be controlled through external signals from the grid, such as in Demand Response (DR) programs. The storage of the CCB can allow to satisfy the requests from the grid, while maintaining the internal comfort.
- Tailor-made control, which takes into account the occupant behaviour (load scheduling), the building features (thermal mass, existing shadings…), has a huge potential to reduce energy demand in case of larger scale applications or high thermal mass emission systems.
- Difficulty in comparing and quantifying performance: while heat transfer rates and storage capacities can be monitored, there is a clear need for effective metrics that can be used to compare different systems, locations, and applications.

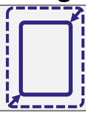
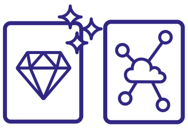
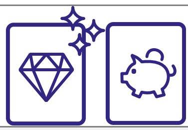
Broader design issues

In this category some relevant issues are collected that apply to broader applications including the CCB together with other components rather than the heat pump, the storage and their control.

- Hybrid installations (i.e. including more generators, such as heat pumps and boilers): using hybrid systems together with the inherent storage capacity of the building allows a wide range of optimization strategies. The field trials cases have demonstrated satisfaction of the final users.
- Model predictive controls are needed in presence of complex systems including energy storage (both thermal storage and building envelope) with a large thermal inertia (e.g. Thermally Activate Buildings, TABs).
- CCB coupled with PV can operate at 100% self-consumption if properly sized and controlled.
- Correct data acquisition is paramount for a proper working of the building automation system and it is necessary in case of complex systems with more components interacting, thermal mass activated and management strategies in place.

Finally, the following table below summarizes the main lessons learned clustered by application strategy.

Table 3 – Lessons learned per CCB implementation strategy.

Feature	Component	Design strategy
Storage size is critical	storage	
PCM's allow for fixed working temperature	storage	
Holistic design is needed	other	
Tailor made control can be efficient	control	
model predictive control for complex and slow systems	control	
predictive rule-based control as a compromise	control	
Correct data acquisition is important	control	
Optimized, systemic design of CCB's is needed	other	
Don't oversize	other	
Try to avoid electric backup heaters	heat pump	
Heat pump hybrids with gas boilers are flexible	heat pump	
CCB's are flexible appliances towards the grid	control	
CCB's can be autarchic with PV panels	control	
New metrics for performance benchmarking are needed	other	

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