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

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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 Task 34 (ES) and Annex 55 (HPT)

Part I – Summary

Introduction

According to the IEA report "Net Zero by 2050 – A roadmap for the global energy sector" (2021)[1] one of the defined key milestones, are "no new sales of fossil fuel boilers by 2025" and that "50% of heating demand is met by heat pumps in 2045". To fulfil this the stock of installed heat pumps needs to increase from 180 million units in 2020 to 600 million units in 2030 (almost quadruple) and thereafter a tenfold increase to 1.800 million units in 2050.

Early adopters of heat pump technology in many countries have bought their first heat pump by now. The next challenge is to attract a new group of consumers that is not particularly tech savvy or green. This group is not interested in the technology as such, but desires a comfortable home, a hot shower, a compact plug & play package and a reasonable energy bill. Therefore, integration of heat pump and storage, but also integration within the home, personal preferences and the electricity grid are key items to be recognized.

Especially the integration with the electricity grid is an important topic. When 50% of the annual heating demand is met by heat pumps, without flexible control they might be - together with further electrification (e-cars, solar PV)- a problem for maintaining and controlling the electricity grid. Flexibility is the key to keeping the electricity grids of the world stable while integrating power from intermittent renewable sources.

The Annex on the *Comfort & Climate Box* (CCB) has been jointly set up by both ES (Task #34) and HPT (Annex #55), because the integration of heat pump and storage is key to deliver a system that can satisfy consumer demand and the constraints of the electricity grid that is fed from renewable sources.

The most relevant implementation strategy differs across the globe, since the current market status is different. On top of that the technical boundary conditions for integrated solutions are also very different. Thus, there is not one optimal system, or one implementation strategy for the next generation of CCBs; there are several and this annex explores what the playing field looks like. Technically and implementation wise.The journey starts with the definition of a CCB. The annex started from the Mission Innovation Affordable heating and cooling workshop result: a request for an integrated HP and storage box, to speed up the development of CCBs and to bring CCBs closer to the consumer market. IEA HPT and ECES TCP networks took over with the Dutch government providing financing of the operating agent.

In 2018 there were no products on the market that would be classified as a CCB. In the mean time several market parties have introduced new products that are in fact CCB's. The introduction of these CCB's proves that the CCB concept can be translated into a technically and commercially viable products. That does not mean that our final goal has been reached and the mission has been accomplished, there is still plenty of work to be done.

[1] https://www.iea.org/reports/net-zero-by-2050

The market status in the participating countries and the technical boundary conditions are explored, which clearly shows a one size fits all approach will not work.

This Annex focusses on *improving* the integration between the heat pump and storage components. The spin-off of the combined Annex to speed up the development of CCBs and to bring CCBs closer to the consumer market.An overview and analysis of relevant research projects and field trials is performed to see where the developments are heading. An analysis of the current standards that are (partly) applicable to CCBs is done with suggestions for new standards that could help the future development of CCBs. Finally, a roadmap is presented that has recommendations for the different stakeholder groups on how to move CCBs forward.

The CCB concept

A *Comfort & Climate Box*, or CCB, is an integrated system consisting of a heat pump, storage and optimized control. The goal of the combined Annex to speed up the development of CCBs and to bring CCBs closer to the consumer market.

A CCB should be able to tackle issues, such as

- Balancing & controlling electricity grid loads;
- Capturing a larger share of intermittent renewable (local/regional) input (i.e., solar thermal, solar PV);
- Optimizing economics, CO_2-emissions, fuel use throughout time;
- Providing optimal supply security to building users;
- Providing smaller and more cost-effective renewable heating systems.

To achieve these goals, several different *implementation strategies* for the CCB concept can be used. Four 'archetypes' have been defined for possible implementation strategies that impact the focus and goal of CCB development.

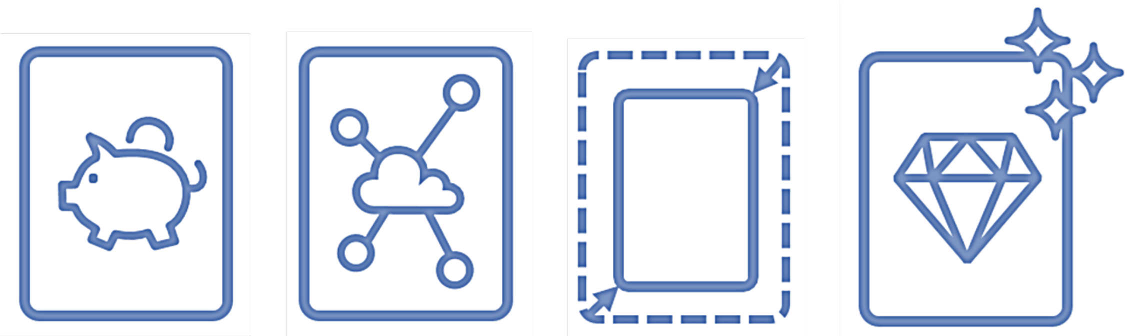

Figure 1 – Four archetypes for CCB implementations. From left to right: Affordability; Flexibility; Compactness; Energy efficiency.

Basic implementation strategies for CCB:

1. **Affordability**
   Focus on keeping the investment for the end user as low as possible. This generally implies a somewhat lower energy efficiency and modest capabilities for flexible operation strategies.
2. **Flexibility**
   Focus on high flexibility and optimal smart grid capabilities. This generally implies a large

storage size and a sophisticated control unit. Depending on the chosen flexibility goals and operating strategy, energy efficiency may change for better or for worse.

3. **Compactness**
   Focus on small footprint inside and outside the end user home. This generally implies a more compact storage size and lower energy efficiency.
4. **Energy efficiency**
   Focus on best performance under various use conditions. This generally implies a larger size and higher investment.

To assess the quality of a CCB solution, it is necessary to specify the criteria for doing so. Across the execution of the Annex, the participants' group has developed and have worked with a set of nine quality criteria:

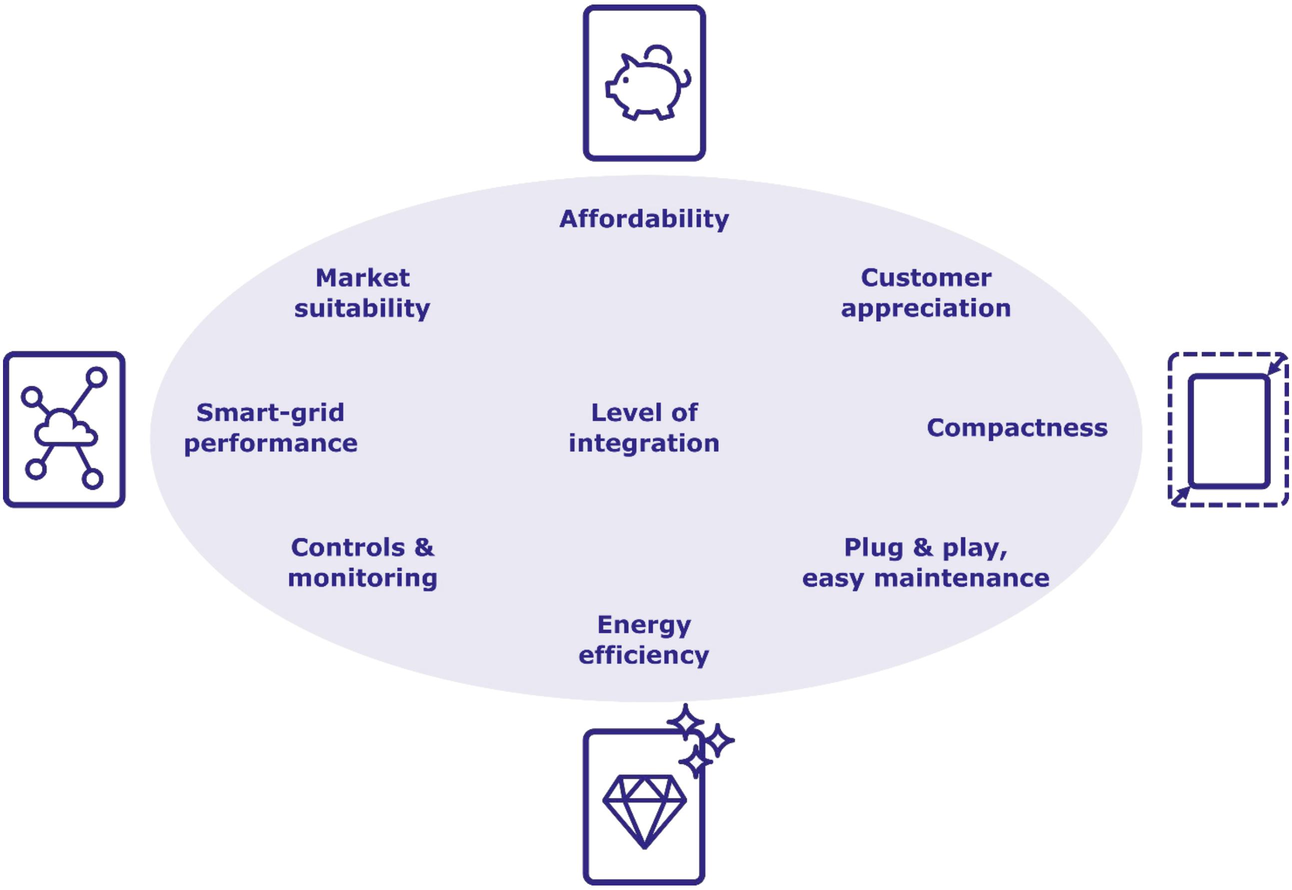

Figure 2 – Quality criteria for CCBs.

The quality criteria are applied to:

- CCB
- policy recommendations: which criterion is targeted by specific actions
- market developments: which aspects are developed strongly in a country, and
- research projects: which criteria does the research focus on.

Market status and technical boundary conditions

The market status report gives an overview of systems presently on the market or close to commercialization. National experts are asked to express their opinion on the quality criteria that are most relevant for their country and the current status of the same set of quality criteria, based on the market. The results are amongst others summarized in the tables below.

Figure 4 and Figure 5 show the results, with the color code as specified below.

Priority		Current	
1	very important	1	more or less solved
2	important, not top priority	2	not yet solved, but progress
3	relevant issue, no priority	3	just starting to get attention
4	not an issue	4	not yet addressed

Affordability	Canada	China	Italy	Turkey	USA	Austria	Germany	Netherl.	Sweden	USA
Market suitability	Austria	Canada	China	Germany	Netherl.	Turkey	USA	Italy	Sweden	UK
Smart-grid performance	Canada	Turkey	Italy	Austria	China	Germany	Netherl.	Turkey	USA	Sweden
Controls & monitoring	Austria	China	Italy	Netherl.	Turkey	Canada	Germany	Sweden	USA	UK
Energy efficiency	Austria	China	Italy	Turkey	Canada	Germany	Netherl.	Sweden	UK	USA
Plug & play, easy maintenance	Austria	Netherl.	Turkey	Canada	China	Germany	Sweden	USA	Italy	UK
Compactness	Turkey	Austria	Canada	China	Italy	Netherl.	Germany	Sweden	UK	USA
Customer appreciation	Turkey	USA	Austria	Canada	China	Germany	Italy	Netherl.	Sweden	UK
Level of integration	Austria	Turkey	Canada	Italy	UK	China	Germany	Netherl.	USA	Sweden

Table 3 – Priority of quality criteria in local markets.

Affordability	Austria	China	Germany	Netherl.	Canada	Italy	Sweden	Turkey	UK	USA
Market suitability	China	Italy	Austria	Germany	Turkey	USA	Netherl.	Sweden	Canada	UK
Smart-grid performance	China	Germany	Austria	Germany	Italy	Netherl.	Turkey	USA	Canada	UK
Controls & monitoring	Austria	China	Germany	Sweden	Turkey	Canada	Italy	Netherl.	UK	USA
Energy efficiency	Germany	Netherl.	Turkey	Austria	Italy	Sweden	UK	USA	Canada	China
Plug & play, easy maintenance	Austria	Netherl.	Sweden	Turkey	USA	Canada	China	Germany	UK	Italy
Compactness	Austria	Turkey	USA	Canada	China	Germany	Italy	Netherl.	Sweden	UK
Customer appreciation	Austria	Sweden	Turkey	Canada	China	Germany	Netherl.	UK	USA	Italy
Level of integration	China	UK	Austria	Canada	Germany	Italy	Netherl.	Turkey	Sweden	USA

Table 4 – Status of local markets. I.e. 'how much is there to be done'?

Tables 3 and 4 show that the national priorities given to the quality criteria vary between the countries, but also provide an insight of the progress already made. This implies that it will pay off to define *nationally specific* research and support goals for CCB technologies, to facilitate the necessary market development. In particular, energy efficiency does not seem to be the most important quality criterion in most countries, while market suitability, smart-grid integration, customer appreciation and a better integration of storage and HP components generally need more attention.

The optimal design for a CCB is very location dependent due to several boundary conditions, that vary a lot over the world. Heating demand is based on building size, solar orientation and envelope quality, weather and climate and lifestyle choice.

The home user can take advantage of local renewable energy (whether building integrated or delivery via the local low voltage electricity networks) and any constraints on increased electricity consumption imposed by the local electricity distribution network. Heat pump operations are improved by lower temperature heat delivery systems (e.g. underfloor heating) in terms of performance, but considerations must be made for potentially longer running times, thus reducing thermal energy storage opportunities during colder periods. Superior building envelopes reduce the size of thermal energy storage requirements but then electricity network constraints, electricity network ancillary services and aggregation may influence thermal storage sizing on top of the chosen heat pump source.

Research projects and field trials

When looking at the fourteen research projects from six different countries that have been summarized in the report, it is clear that efficiency is still the main implementation strategy under investigation. There are however only three projects where energy efficiency is the sole parameter being investigated and five projects where energy efficiency is not the focus anymore. Flexibility and affordability are both being looked at six times, where compactness is the subject of investigation four times.

Implementation strategy / **Project name**	Affordability	Compactness	Flexibility	Efficiency
(AT) Energy4Buildings				X
(AT) HybridHeat4San				X
(AT) HYBUILD		X		X
(CA) CCB prospects for Canada	X	X		
(DE) Smart-CASE-NZEB			X	X
(DE) Low charge HP circuit using propane		X		
(SE) CCB solutions for Sweden	X		X	
(UK) Smart Community Demonstration	X		X	
(UK) HP data from RHPP scheme				X
(UK) Freedom project			X	X
(UK) H2020 Chess-setup	X			X
(UK) Ulster University terrace st.	X		X	X
(US) Low cost PCM	X			
(US) HP with integrated thermal storage			X	X
(US) HP with underground PCM storage		X		X

Table 1 – Overview of research projects with their associated implementation strategies.

One development in the Netherlands really stands out, where the Stroomversnelling organization promoted a series approach to deep renovation. This led to the introduction of at least 10 different ‘energy modules’, from manufacturers like Nibe, Nefit, LG, Factory Zero and Nathan. But also construction companies developing their own energy module like; BAM, van WIjnen and Volker Wessels.

These energy modules typically consist of a heat pump, hot water storage vessel, balanced ventilation system with heat recovery, a solar inverter and a monitoring system. The manufacturers each have a different focus for optimization and additions to the concept. The key take away is that the integration of the components in one box allows them to do these additions and integrations.

Figure 5: Energy Module from Factory Zero

Table 1 – 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

From the five different field trials, efficiency is the main focus of only one trial. They are nearly evenly split over the four implementation strategies. The lessons learnt from these field trials all revolve around the optimal sizing and integration of storage and implementation of better control strategies. It is very clear that a lot can be gained by improved control algorithms and better sizing of the energy storage vessels. This leads to less on/off switching, higher COP's and better integration in the grid.

Standards

The report package on standards explores the available standards in the participating countries, for standards that are suitable for the characterization and testing of a CCB. There are plenty of standards for heat pumps and there are plenty of standards for storage solutions. However, there are no standards found for the combination of these systems. A void which needs to be filled in.

The sole standard that gets anywhere near a standard usable for a CCB is the EN 16147, which looks at the combination of a heat pump and storage, but solely focusses on the production of domestic hot water. Also, the impact of the control system is barely ever the subject of standardization. There are standards like the Canadian CSA EXP07 that do make use of dynamic testing to better reflect real-life performance, but they focus only on the heat pump.

Standardization can show the benefits of a CCB, when the dynamic behavior of the CCB is the subject of the standard. This type of standardization reflects real-life performance of a CCB better and makes the performance difference between a CCB and an in-situ integrated solution visible as a CCB designed as an integrated system outperforms an installation composed of standard components.

Flexibility that a CCB can provide is another aspect that is not covered in existing standards. Standardization of a communication protocol for CCBs, which allows for bi-directional communication and the activation of flexibility enables demand response and other services by CCBs. Two suggestions for standardizing the measurement of the flexibility delivered by a CCB are provided; an experimental and a theoretical approach. These two approaches are in detail explained in the work package # 6

Roadmap

The CCB concept shows there are multiple directions wherein manufacturers can develop their products to meet the local demands. Which are the main steps that stakeholders can take to move forward in the four implementation strategies?

However, depending on the actual main barriers and drivers in a particular location (country or region), different strategies are recommended to be implemented - Affordability, Flexibility, Compactness or Energy efficiency. The following recommendations can help the different implementation strategies. (A condensed overview of policy recommendations has been included in the report package as a separate document.)

Affordability

To ensure affordable offerings in the market it is key to discover which aspect of the CCB is too costly; if it’s the running costs then focus on reduction of fuel consumption, or making insulation more attractive. If it’s a matter of upfront cost, subsidies or lease offerings can reduce the CAPEX barrier. When it’s the total life cycle cost it is beneficial to focus on the installation costs and the removal of unnecessary features on CCB’s. Upscaling market volume can result in lower installation costs and potential less grid strengthening investments.

Flexibility

There is plenty of ongoing research on flexibility, also combined with heat pumps, but large-scale introduction is still lacking. There are many things to be done to bring progress to this market and they focus around three areas: A standardized communication protocol including cloud options for communication with heat pumps is lacking. Flexibility business cases for consumers are limited or unreliable and there are very few products with integrated storage capacity.

Although aggregating heat pumps & storage and therewith opening up their flexibility potential, with large numbers of relatively small heat pumps can offer significant flexibility options.

Compactness

When it comes to compactness it's the manufacturers as the only stakeholder that can make the difference. When there's a local demand for compact solutions, they could design CCB's with compactness in mind. As a project the 'box approach' was perhaps a bit early.

Efficiency

Efficiency is the topic that has been invested in the most in the past years. Even though efficiency improvements are always welcome, this is not the area that should be the main focus for the coming years. A CCB should be more versatile then just the single hp and storage components on itself, storage features and flexibility in connection to the grid should also be taken into the equation. More development in this perspective seems to be more then justified by the sheer potential of the solution.

Final conclusion

This report gives an overview of the state of the art in CCB development. It has shown the differences in market status, technical boundary conditions and priorities in quality criteria in the participating countries. From this we can conclude that a one size fits all approach for CCB's will not work.

In research projects and field trials there seems to be a shift away from efficiency, toward other quality criteria that are indicators for the game changers for the local requirements like compactness, affordability and flexibility. The latter making an integrated-box-type solution its integration in the grid a promising type of technology. The gaps in current standardization and testing procedures that could benefit the upscaling of integration of CCB's are identified and solutions are proposed. A roadmap for policy makers and other stakeholders has been presented.

The development of energy modules by more than ten different companies in the Netherlands shows that it is technically and commercially viable to bring integrated solutions to the market that offer other benefits than purely efficiency. In the near future we hope to see more local developments like these that answer the local demand for integrated comfort and climate box solutions.

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