Project Summary Report

Energy in Buildings and Communities Programme

EBC Annex 48

Heat Pumping and Reversible Air Conditioning

Philippe Andre

Jean Lebrun

Energy in Buildings and
Communities Programme

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International Energy Agency

The International Energy Agency (IEA) was established in 1974 within the framework of the Organisation for Economic Co-operation and Development (OECD) to implement an international energy programme. A basic aim of the IEA is to foster co-operation among the twenty-eight IEA participating countries and to increase energy security through energy conservation, development of alternative energy sources and energy research, development and demonstration (RD&D).

Energy in Buildings and Communities

The IEA co-ordinates research and development in a number of areas related to energy. The mission of one of those areas, the EBC - Energy in Buildings and Communities Programme, is to develop and facilitate the integration of technologies and processes for energy efficiency and conservation into healthy, low emission, and sustainable buildings and communities, through innovation and research. (Until March 2013, the EBC Programme was known as the Energy in Buildings and Community Systems Programme, ECBCS.)
The research and development strategies of the EBC Programme are derived from research drivers, national programmes within IEA countries, and the IEA Future Buildings Forum Think Tank Workshop, held in April 2013. The R&D strategies represent a collective input of the Executive Committee members to exploit technological opportunities to save energy in the buildings sector, and to remove technical obstacles to market penetration of new energy conservation technologies. The R&D strategies apply to residential, commercial, office buildings and community systems, and will impact the building industry in five focus areas of R&D activities:

– Integrated planning and building design
– Building energy systems
– Building envelope
– Community scale methods
– Real building energy use

The Executive Committee

Overall control of the program is maintained by an Executive Committee, which not only monitors existing projects but also identifies new areas where collaborative effort may be beneficial. To date the following projects have been initiated by the executive committee on Energy Conservation in Buildings and Community Systems (completed projects are identified in grey):

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Annex 2:	Ekistics and Advanced Community Energy Systems
Annex 3:	Energy Conservation in Residential Buildings
Annex 4:	Glasgow Commercial Building Monitoring
Annex 5:	Air Infiltration and Ventilation Centre
Annex 6:	Energy Systems and Design of Communities
Annex 7:	Local Government Energy Planning
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Annex 9:	Minimum Ventilation Rates
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Annex 11:	Energy Auditing
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Annex 13:	Energy Management in Hospitals
Annex 14:	Condensation and Energy
Annex 15:	Energy Efficiency in Schools
Annex 16:	BEMS 1- User Interfaces and System Integration
Annex 17:	BEMS 2- Evaluation and Emulation Techniques
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Working Group - Energy Efficiency in Educational Buildings
Working Group - Indicators of Energy Efficiency in Cold Climate Buildings
Working Group - Annex 36 Extension: The Energy Concept Adviser

Heat Pumping and Reversible Air Conditioning

General Information

Project leader: **Philippe Andre, ULg/DSGE/BEMS, Belgium**
Project duration: **2005 - 2011**
Further information: **www.iea-ebc.org**

Environmental damages and scarcity of fossil fuel resources motivate search for new solutions to satisfy the energy requirements of buildings and to develop more efficient energy conversion processes.

In many climates, office buildings are most often equipped with a heat pump which has primarily the function of providing cooling or air-conditioning to the spaces; for that reason, the energy converter is named "chiller". The existence of this heat pump offers attractive, but rarely implemented, opportunities to improve the energy performance of the building and to reduce the CO_2 emissions.

These opportunities consist in using the chiller to satisfy, at least partially, the heating requirements of the building. This can take place in two ways. The first option consists in recovering the heat released at the condenser of the chiller when it is producing cold; usually the heat is released in the atmosphere by a dry cooler or a cooling tower, at a moderate but still valuable temperature level. The second option uses the reversibility capability offered by certain chillers or by the (heat and cold) distribution circuits. By reversing the thermodynamic cycle of the chiller or the heat and cold distributions, the useful effect of the machine becomes the production of heat (at low temperature) which can be emitted

Participating Countries:

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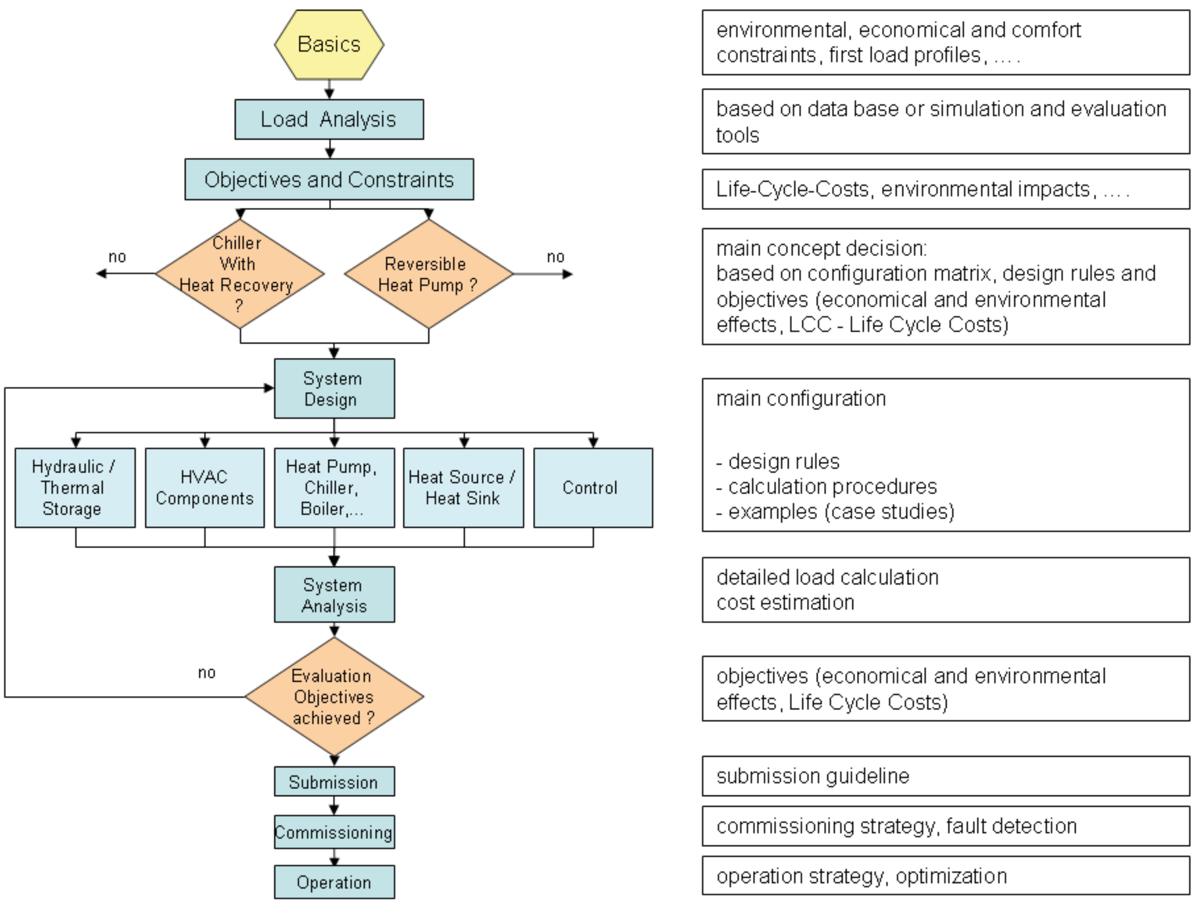


Scheme of the design process developed within Annex 48.

in the building. The potential offered by such solutions can be estimated on the basis of hourly temperature profiles either measured in the real life of buildings or generated by a dynamic simulation. A number of technical solutions are available and are based upon components that are, for most of them, already on the market. They require particular approach and attention from the sizing phase to the construction and commissioning processes.

Substituting a boiler with a heat pump may save more than 50% of primary energy, if electricity is produced by a modern gas-steam power plant (and even more if a part of that electricity is produced from a renewable source). The aim of this project was to promote the best heat pumping techniques applicable in air conditioning of commercial buildings. Focus was given to the integration of these techniques inside the whole air conditioning system.

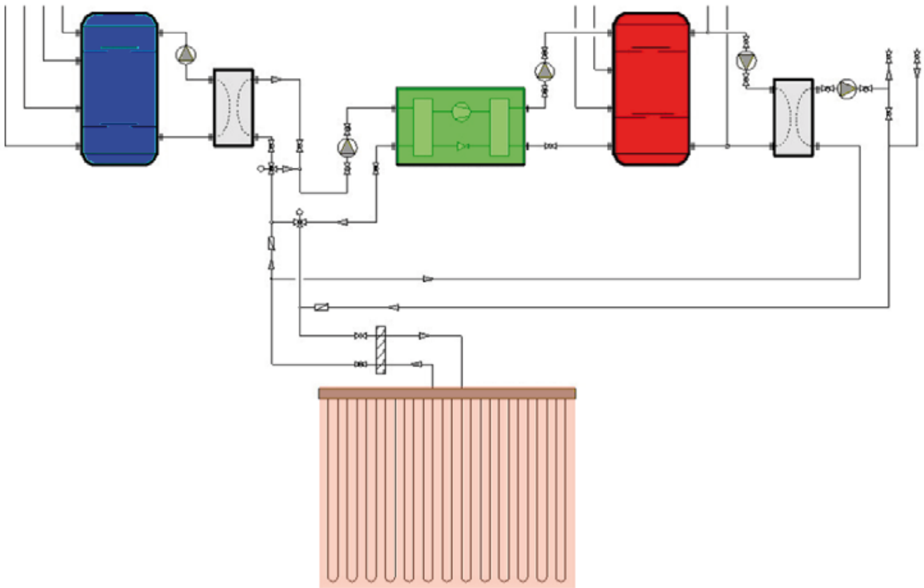
Between 2005 and 2010, Annex 48 investigated the possibilities to use a chiller to satisfy the heating needs of buildings. The work which was carried out included the analysis of the heating and cooling demands of buildings, developed a detailed design strategy to follow, including the development of specific design tools to compare heat pumping solutions with more classical production of heat and cold. A number of case studies (11 buildings in 5 countries) were analysed by the project partners.

The project addressed both new building projects and retrofit of existing cases. Indeed, the retrofit of an existing building and even more, the design of a new one, should take all possibilities of heat pumping into consideration as soon as possible in the project.

Based the case studies, the research work conducted in this project identified a number of constraints and obstacles on the route of the application of this strategy.

This four-years research project examined in details the problems raised when moving to a more systematic use of heat pumps for providing both heating and cooling to office buildings. Not all the problems were solved, but the Annex delivers a set of tools, design methodology and practical illustrations that will help designers, commissioning agents and building operators to pay more attention to these new options and to reduce, in that way, the environmental impact of buildings.

Typical plant scheme of a geothermal system with heat and cold demand.



Project Outcomes

Project leader: Philippe Andre, ULg/DSGE/BEMS, Belgium
Project duration: 2005 - 2011
Further information: www.iea-ebc.org

Project goals

Still today, the most common solution to provide heating and cooling to office buildings in moderate climate is to run a fossil fuel boiler to satisfy the heating needs and to use a vapour compression chiller to provide cooling and dehumidification. This traditional is solution is well mastered by design engineers and plant installers but I's also known to generate significant environmental impacts and entirely relies on fossil fuels for heating.

In office buildings in temperate climates where a heating demand is frequently observed simultaneously with a cooling demand, boilers and chillers run very often at the same time. The question which was targeted in this project was to analyse whether a chiller could be used in order to, at least partially, cover the heating needs of the building.

This can take place in two ways. The first option consists in recovering the heat released at the condenser of the chiller when it is producing cold; usually the heat is released in the atmosphere by a dry cooler or a cooling tower, at a moderate but still valuable temperature level.

The second option uses the reversibility capability (also called change-over) offered by certain chillers or by secondary circuits (heat and cold distributions): by reversing the thermodynamic cycle or the heat and cold distributions, the useful effect of the machine becomes the production of heat (at low temperature) which can be emitted in the building. A variant of this solution consists in realizing the reversibility at the level of the terminal units directly supplied by refrigerant in so-called "VRF" systems.

The main goal of Annex 48 was to develop a specific design methodology and associated design tools in order to take these innovative solutions into better consideration in the course of a new building project or in case of retrofit of the energy system in an existing building. Substituting a boiler with a heat pump may indeed save a substantial amount of primary energy, if electricity is produced by a modern gas-steam power plant and even more if a part of that electricity is produced from a renewable source.

Description of the work done in the project

To achieve this goal, Annex 48 addressed the following issues. First, the success of the solutions proposed in this project is heavily depending upon the heating and cooling demand profiles observed in a building. Characterising these demands was consequently an important step in order to assess whether the heating and cooling demands were simultaneous or not.

The relative magnitudes of the peak power asked for in heating or cooling mode was also an important aspect to observe. Therefore, a number of typical buildings were defined, covering two tertiary sectors: offices on one hand, hospitals and rest homes on the other hand. For each building type, choices were made about the building envelope, operation parameters (infiltration, ventilation, heating/cooling setpoint, domestic hot water production), HVAC systems allowing to calculate the hourly profile of heating and cooling demands in 5 typical European climates (Paris, Münich, Lisboa, Athens, Torino). Hourly simulations were run to generate the demands profiles and to analyse the impact of different parameters. To produce synthetic results, two performance indexes were defined, calculating the potential for reversibility and the potential of heat recovery. The methodology to define those potentials is similar in both cases and is based upon the hour by hour comparison of the heating demand and cooling demands.

Figure. 1 shows the calculation principle of the reversibility potential while Figure. 2 shows the equivalent principle applied to calculate the recovery potential.

Figure 1. Estimate of the space heating potential of the chiller used in heat mode.

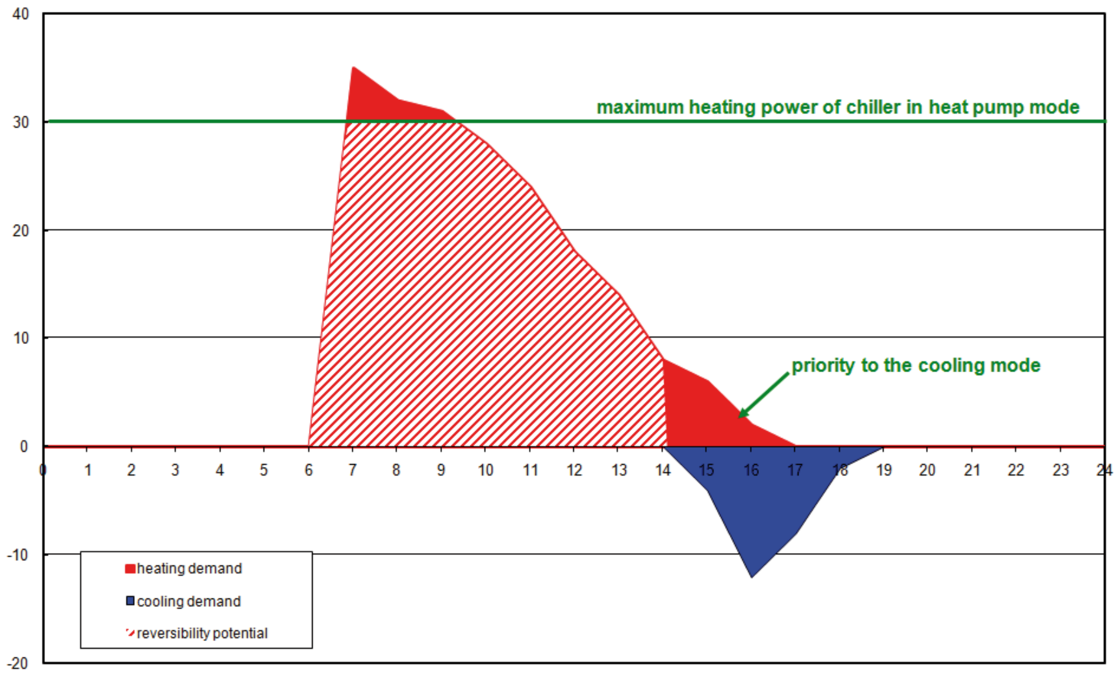
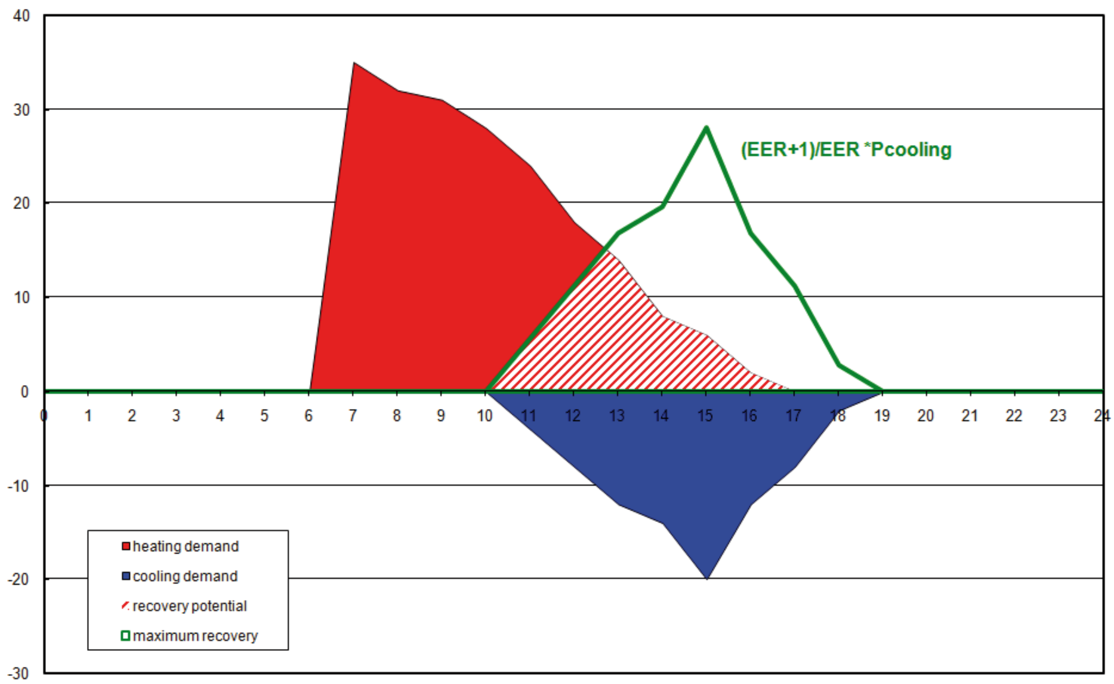


Figure 2. Estimate of the heating energy recovery on chiller condenser.



The calculation of these potential was only based upon the heating and cooling demands and didn't take the HVAC system into account.

Definition of typical HVAC systems in each building type allowed to extend these results to global system performances and to compare to reference solutions (boiler + cooling only chiller).

In this analysis, focus was given to the simplest technical aternative:

1) adding a water cooled condenser to an air-cooled chiller for heat recovery;

2) reversing the refrigeration cycle without adding any technical device other than an inverting valve (the condenser becoming an evaporator and vice-versa).

The combination of both solution was not considered here. In office buildings, such reversibility can generate savings in the order of magnitude of 20% while the potential of heat recovery is very low, due to, among other factors, the degradation of the chiller performance to produce sufficiently hot water to feed the heating system. In health care buildings, the important demand for Domestic Hot Water increases the savings potential, specially for heat recovery, given the heating demand remains high when the cooling demand is important.

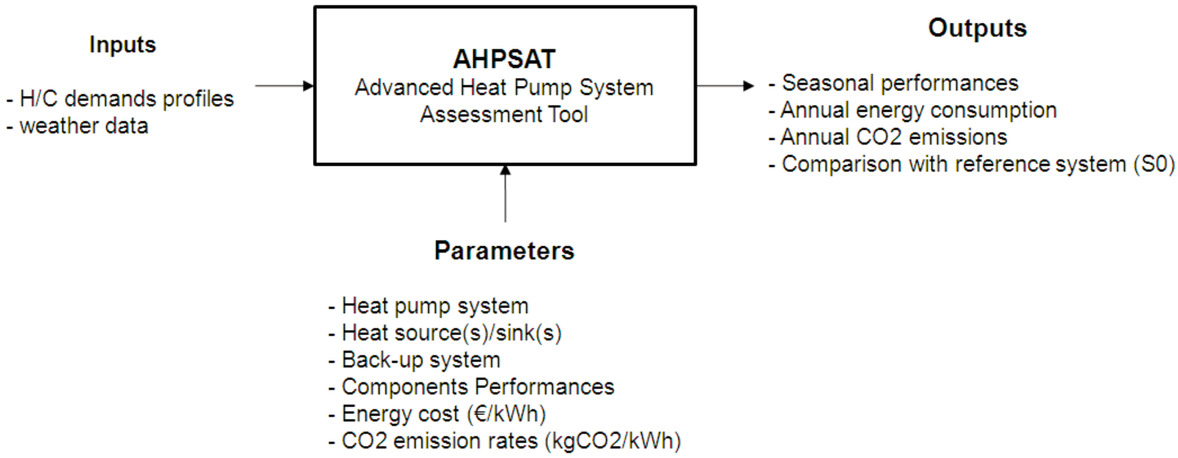
The different options technically feasible to achieve either the reversibility or the heat recovery were also deeply analysed. These solutions show a high diversity and are characterized by the following criteria: heat sources and heat sinks, packaged units or direct expansion units, possibility of recovery and/or reversibility. The project addressed the most common heat pump systems:

- reversible air-to-water heat pump
- reversible geothermal/hydrothermal heat pump
- split and multi-split systems
- air-to-air dual duct heat pump
- exhaust air heat pump system
- water-cooled chiller with heat recovery
- dual condenser chiller
- templifier
- reversible water/air-to-water heat pump
- reversible geothermal heat pump with heat recovery
- water loop heat pump system
- VRF system.

Two specific design tools (FAST and AHPSAT) were developed to assess the performance of a number of the technical options listed above.

Figure 3. View of the results presentation of the FAST tool.

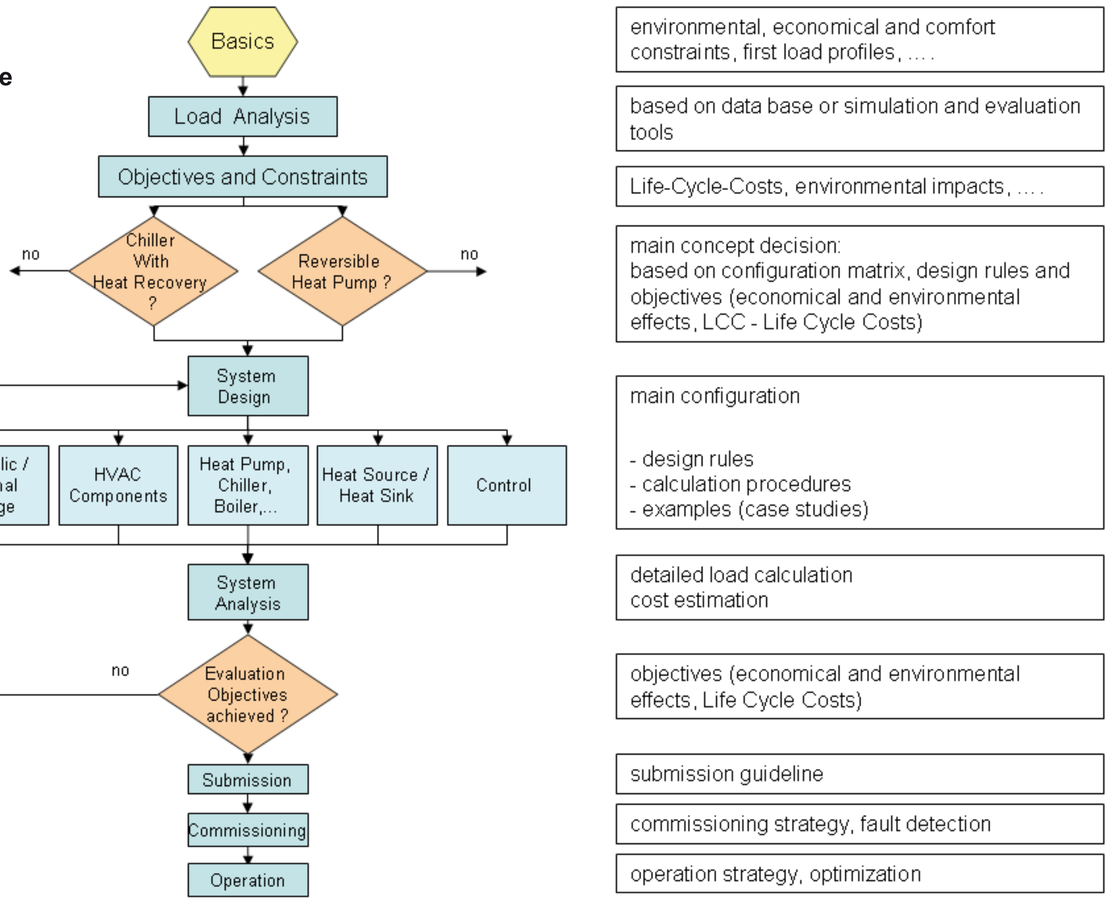
Figure 4. Block-diagram of the AHPSAT design tool.



FAST : A web tool has been developed in the aim to give a quick evaluation of the potential of reconverting a chiller in a reversible unit in commercial buildings. This tool is addressed to stakeholders, HVAC consultants, architects and installers. This tool can be used in retrofit buildings but also in the case of new buildings.

The online tool allows the user to define in few clicks the main parameters concerning the building, the climate, the HVAC system installed and its current performance, the heat pump performance to install and the heating consumption of the building. Some default values for economic and environmental parameters are

Figure 5 Scheme of the design process developed within the project.



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provided to the user but they can be changed at any time.

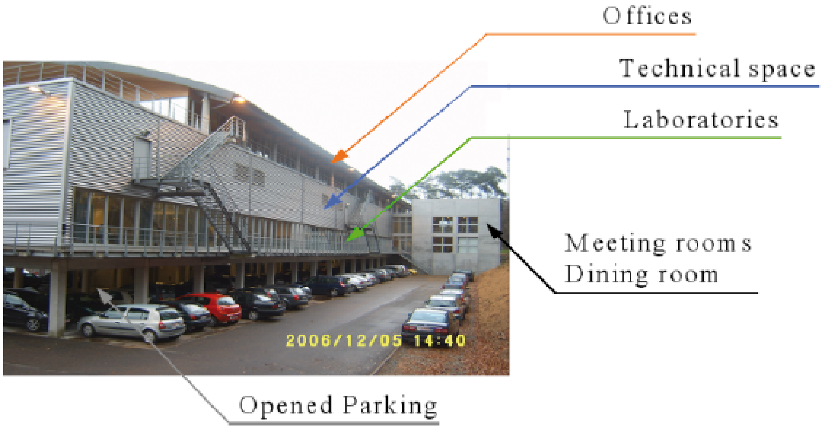


Figure 6. Laboratory building in Liège, Belgium.

In AHPSAT, these options are evaluated using, as input data, hourly profiles of heating and cooling demands. The secondary system is not included in the calculation. Simple control strategies ate defined, allowing to switch from the heat pump system to the classical system (if present) and from the heating mode to the cooling mode, when applicable.

A significant part of the work consisted in developing a detailed design methodology for this kind of technical system.

By nature, the technical solutions involving reversible and/or recovery-based heat pumps are more complex than usual systems; mostly if reversible, hydraulic connections are more complex requiring a good design and an appropriate commissioning; control issues are important as well and may generate complex problems. Global performances are strongly depending upon the boundary conditions on both sides of the machine and on all "secondary" (fans, pumps…) consuptions. Therefore, a careful design and commissioning procedure has to be followed in order to get sufficient performances.

The design sequence (Figure.5) elaborated in the project includes the following steps:

- collection of basic information
- load analysis
- main concept decision
- life cycle costs and environmental impacts preliminary assessment
- detailed system design
- detailed system analysis
- commissioning strategy and fault detection
- operation

The design sequence elaboration as well as observations on the cases studies pointed out the following observations:

- Control aspects and hydraulic issues are essential to guarantee the success of such sensible energy systems.
- Selection and sizing of storage systems are important steps
- Dynamic simulation is recommended to assess the performance of such sensible systems
- An appropriate commissioning is mandatory to get reliable performance and to achieve the expected savings.

The following system types are covered by the case studies:

Reversible systems

- Reversible air-to-water HP system
- Reversible water-to-water HP system
- Reversible water-to-brine ground-coupled HP system
- Reversible groundwater HP system
- Reversible surface water HP system
- DX ground-coupled HP system
- Exhaust air HP system
- Air-to-air HP system

Reversible systems with heat recovery

- Reversible air-to-water HP system
- Ground coupled HP system with heat

Figure 7. Office building in Lyon, France.

Figure 8. Office building in Germany .

Figure 9. Administrative building in Regione Piemonte, Torino, Italy.

recovery
- Groundwater HP system with heat recovery
- Surface water HP system with heat recovery
- Split / multi-split / VRF
- Water-loop HP system

System with heat recovery

- Water-cooled chiller with heat recovery
- Dual condenser chiller
- Temperature amplifier

The selected cases studies cover most important heat pumping solutions. Some case studies led to the comparison, by simulation, of several solutions. Some pictures from the case studies are shown below (Figure. 6, 7, 8 and 9).

The case studies provide a lot of very useful information, but none of them can be yet considered as a convincing demonstration project: the practical conclusion in almost each case seems to be: "it should work or it would have worked, if…"

The following facts and ideas can be extracted from these case studies:

- Heat pumping is, unfortunately, in all cases an expensive technique which should not be introduced in any new or retrofitting project before having reduced already as much as possible all energy wastes.
- In an existing system with water-to-water chillers and cooling towers, it would be cost and energy effective to introduce some water-to-water heat pump (or "templifiers") in order to recover the condenser heat and to up-grade it until the temperature level required by the heating system.
- An existing air-to water chiller can be made reversible or have a water-cooled condenser added in such a way to allow some heat recovery.
- Both reversibility and heat recovery would be made more efficient if taking profit of all heat transfer areas already available in the system. This require some change over: (large) cooling coils of air handling and terminal units can be very well "re-used" in heating mode.
- Steam humidification could be performed with the help of a second heat pump stage; this one could use the humidification steam as working fluid (no condenser required: compressed steam would be directly used for air humidification).
- Panel heating and cooling is an attractive option, but not applicable in any sort of building; it also deserve a careful design and use of the control system specially with high inertia structures like TABS.
- Manufacturers should optimise more and more their machines for the heating, better

than for the cooling, mode. This is not yet the case and most systems are, unfortunately, less efficient in heating than in cooling mode.

- Commissioning of (conventional and unconventional) systems stay insufficient.

Results

The main results obtained during this project can be summarized as follows.

An improved knowledge of the different technical solutions allowing implementing heat pumping solutions in tertiary buildings was reached. A classification was defined, allowing to clearly allocate an example of project to a category, whatever the complexity of the system could be. Many solutions are feasible, depending upon the exploited ambient source: air, water, ground, exhaust air. The advantages and drawbacks of each solution were identified.

A specific design methodology was developed. This was mandatory to help to the success of projects where the HVAC solution, may appear sensible in many cases. The performance of heat pumping solutions is very sensitive to boundary conditions and to the technical realizations of principle solutions. It was shown in several cases that hydraulic and control issues were very important, if not crucial, aspects deserving a great attention from designers, installers and building operators.

The starting point of the development of a reversible heat pumping project is a good characterisation of the building heating and cooling demands. It was shown in the project that these demands had to be obtained ideally on an hourly basis. The most effective way to get these hourly demands profiles is to run a dynamic simulation model, which can be calibrated on the recorded energy consumptions, in the case of an already existing building. These consumptions are most often available on a longer time basis (eg. monthly values). Both sensible and latent demands have to be identified.

More generally, dynamic simulation has to be used in such projects, where the performance is depending on many factors and where storage and control issues have a great impact on the final result.

The selection of a heat pumping solution must be considered very early in a buiding/HVAC project. Indeed, low temperature solutions have to be privileged in the selection of the HVAC system. Should irreversible choices be made too early (like the sizing of heat exchangers), some heat pumping solutions may not be possible to consider.

Economical issues may influence the choice of such solutions as well.

Specific tools allowing comparing different options, right from the start of a project were developed.

The FAST tool was developed to be easy and quick to use and able to provide a very first assessment of the expected performance of a heat pumping solution for a given project. From general characteristics of the building, the tool retrieves an equivalent project from a database and extracts the performance of this project. All data required for that operation are usually available very soon in a project.

The AHPSAT tool requires more data and is designed to provide a model-based assessment of the performances of one or several heat pumping solutions, in comparison with the classical combination of a boiler and a vapour-compression chiller taken as reference. Performance indicators evaluated by the tool include energy performance (in terms of primary energy savings), environmental impact (in terms of CO_2 emissions) and economical aspect (in terms of total costs of the system roughly evaluated). This evaluation tool only takes the primary energy system into account.

For deeper analysis, a detailed dynamic simulation, using a tool as TRNSYS can be used to give a more complete view of the performance, including the impact of the secondary components and of the associated control system.

Impact

Theoretical calculations show that in good circumstances, a high potential for primary energy savings exists.

In the moderate climates of mid latitudes of Europe, where most of the Annex participants were located, the constraints of the climate make the unique heat recovery option of marginal interest: demands are not very often simultaneous and when they are, the heat demand is higher than the cooling demand, making the energy recoverable at the condenser too small to have a substantial useful effect.

Only for buildings where an important heating demand is still observed in summer (like in hospitals and rest homes), the unique recovery option offers interesting savings.

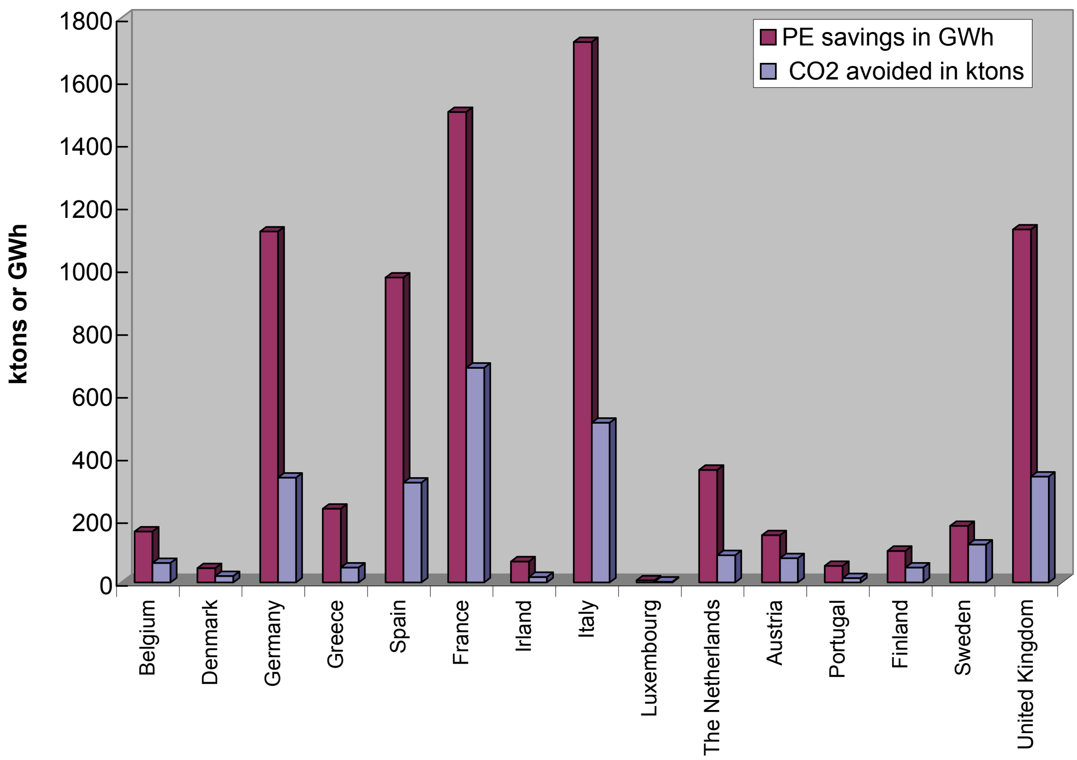
Reversibility (combined or not with heat recovery) appears to be a much more valuable option.

The realization of this potential is clearly depending on the technical solution which is used. Simulations indicate a good correlation between the potential performance (based upon building demands) and the expected savings (considering the primary and secondary HVAC system).

Moving to practice, a number of important issues have to be considered: sizing of the heat exchangers and of the storage devices if any, hydraulic considerations, control devices.
Overall, an appropriate commissioning of the whole system should be carried out.

Calculations based upon typical buildings allow an extrapolation of the expected savings at European level. An example of results is shown by Figure 10 for office buildings and Figure11 for health care buildings.

Figure 10. Annual primary energy savings and CO_2 emission reductions in air-conditioned office buildings in Europe-15 based on simulation results.



Project Outcomes

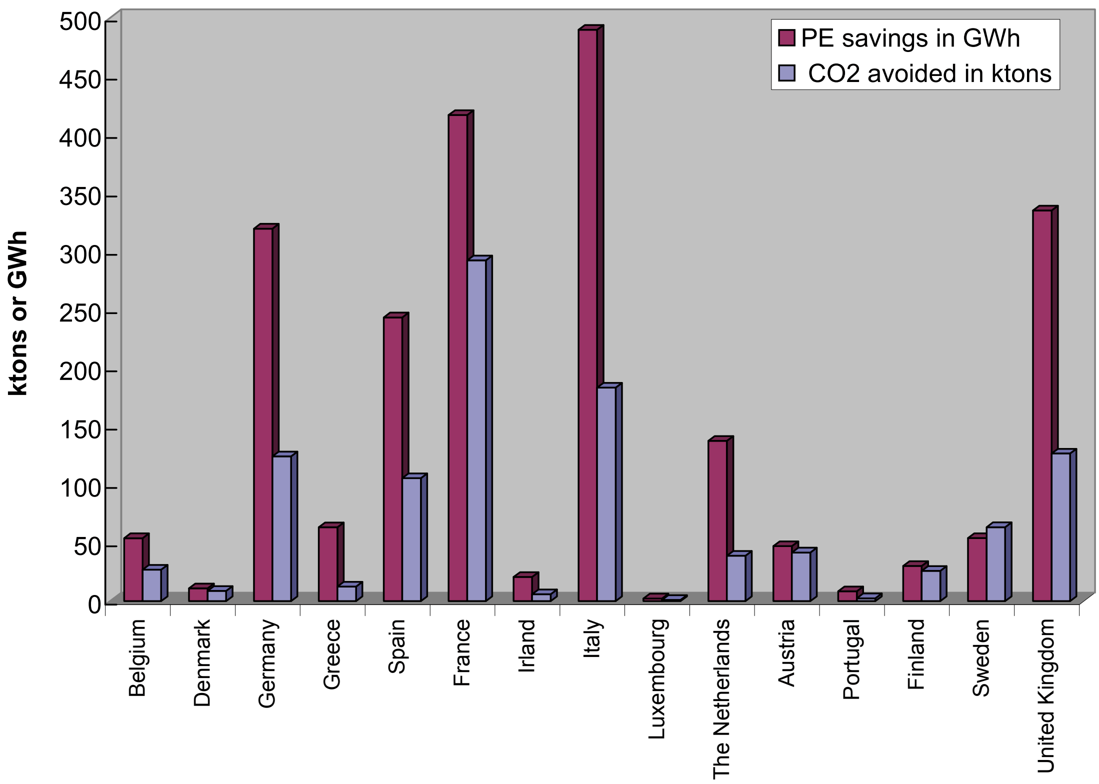


Figure 11. Annual primary energy savings and CO_2 emission reduction in air-conditioned health care institutions in Europe-15 based on simulation results.

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Italy Case Study N°5: A Shopping Mall with a Water Loop HP System, Université de Liège, 2011

Project Reports

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Project Participants

Category	Organisation
Belgium	University of Liège
France	CEA – INES RDI Centre Énergétique et Procédés -Mines ParisTech Greth INSA Rennes
Germany	Georg-Simon-Ohm-Hochschule Nürnberg HLK Stuttgart GmbH HLK Stuttgart GmbH
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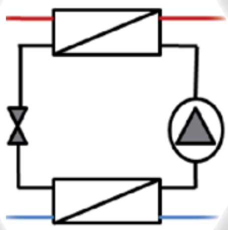

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