Case Study summary

IEA-ECBCS Annex 48

Heat Pumping and Reversible Air Conditioning

French Case Study N°3: Heat pump for simultaneous heating and cooling

Contribution of INSA Rennes

Introduction

This case study deals with the design, construction, testing and simulation of a heat pump for simultaneous heating and cooling (HPS).

Apart from producing hot and cold water with same energy consumed by the compressor, the HPS can work in heating only or cooling only modes, using air as a free source.

In heating mode, some energy recovered by subcooling is first stored in a water tank and used subsequently as a source for evaporation. This enables to increase the average performance during winter and to run an innovative defrosting sequence at the air evaporator.

A R407C prototype has been build to validate these concepts.

A simulation study enabled to evaluate the annual performance.

Summary

- Location: Rennes, France
- Building sector: office and residential buildings
- Gross net area: up to 2 000 m²
- Simulation:
  - Net area: 1 440 m²
  - Heat pump nominal heating capacity: 43 kW
  - U-value external walls: 0,307 W/(m²K)
  - U-value windows: 1,400 W/(m²K)
- Prototyping:
  - Prototype nominal heating capacity: 15 kW
  - Specificities: simultaneous heating and cooling, thermosiphon defrosting technique

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Background

The aim of the study is to design a heat pump for simultaneous heating and cooling (HPS) for smaller office and residential buildings. During summer, simultaneous needs in heating and cooling appear for Domestic Hot Water (DHW) and space cooling. During mid-season, needs in heating at the north and cooling at the south can appear simultaneously in the same glass-fronted building.
IEA ECBCS Annex 48 project aims to make air conditioning as reversible as possible. Simultaneous production is the most “reversible” process for a heat pump. This heat pump also follows the second objective which is “intending to make the best use of the currently available technology”.

Technical concepts

Possibility of heating and cooling simultaneously:

The HPS can work under three modes to produce hot and/or cold water:

- Heating mode: ambient air at evaporation / water at condensation
- Cooling mode: water at evaporation / ambient air at condensation
- Simultaneous mode: water at evaporation / water at condensation

A programmable controller chooses the appropriate modes to satisfy the building needs.

Hot and cold water tanks are connected to the condenser and the evaporator to increase the operating times of the heat pump, especially in the simultaneous mode.

Classic winter sequence:

During winter, the cooling demand can be inexistent. The cold water tank is then used as a short-time heat storage. The sequence alternates between heating and simultaneous modes. The sequence begins by the heating mode engaging the water condenser, the air evaporator and the subcooler. The cold water tank is heated, typically from 5 to 15°C, by the refrigerant subcooling energy. Then the HPS switches to the simultaneous mode and uses the energy stored in the cold water tank as a cold source for the water evaporator. The cold water tank temperature decreases from 15 to 5°C.

In the simultaneous mode, the evaporating temperature is higher than in the heating mode from the moment that ambient air is colder than the short-time heat storage tank water. Therefore, using the simultaneous mode for a moment during the winter sequence enables to produce hot water continuously with improved average system performance compared to standard air-source heat pumps. Besides, in the simultaneous mode, the air evaporator is not used for evaporation and can be defrosted using a two-phase thermosiphon.

Thermosiphon defrosting technique:

In the heating mode, under cold outside air temperatures, the fins of the air evaporator get frosted. Before frost thickness becomes critical, the cold tank temperature has raised 15°C and the simultaneous mode has been engaged. In this mode, the air coil is automatically defrosted by a two-phase thermosiphon formed between the two evaporators. A supplementary flow of vapour comes out of the water evaporator and migrates towards the air evaporator where the temperature, and thus the pressure, is lower. The refrigerant exchanges latent heat with the frosted fins and condenses and flows back to the water evaporator by gravity.

Technical data of the unit

Compressor

- Brand: Copeland
- Type: Scroll
- Ref: ZB38KCE-TFD
- Swept volume: 14.5 m^3/h
- Nominal cooling capacity (Tev = 0°C / Tcd = 40°C) 11.5 kW

Water heat exchanger

- Type: plate heat exchanger
- Condenser: 50 plates, 2.45 m^2
- Evaporator: 34 plates, 0.8 m^2
- Subcooler: 14 plates, 0.16 m^2

Air heat exchangers

- Type: finned tubes, 68 m^2
- 6 rows of 30 tubes
- l = 750 mm , Ø = 10 mm

Working fluid

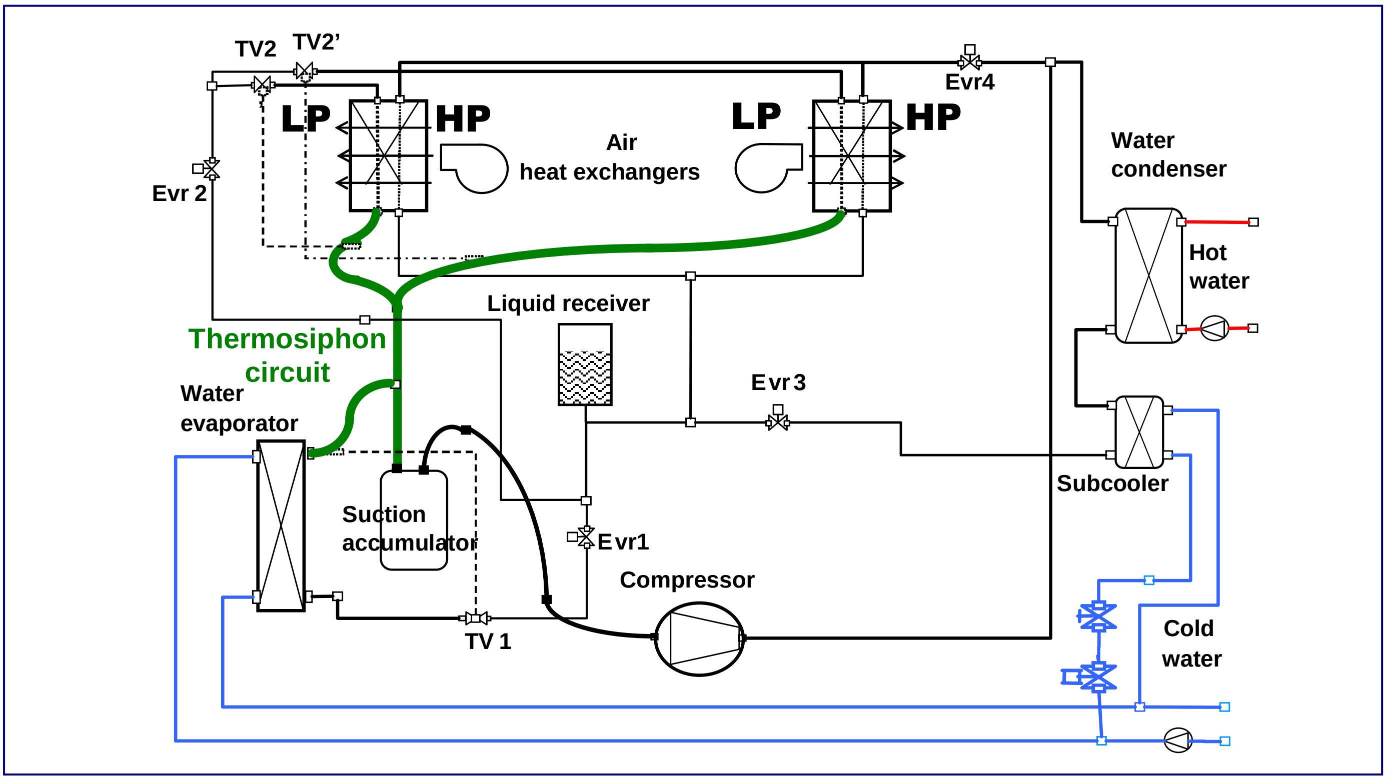
- R407C

Advantages

- Possibility to provide heating and cooling alternatively or simultaneously
- Dedicated heat exchangers
- Very interesting system when there is large and constant hot domestic water demand all along the year (health care institutions, hotels)
- Non penalizing defrosting
- Heat source/sink available everywhere
- Flexibility to cover a large variety of loading profiles
- Potential high performance and consequent low operation costs

Drawbacks

- Refrigerant circuit complexity
- Necessity of storage water tanks
- Higher installation cost
- Necessity of sophisticated control strategy



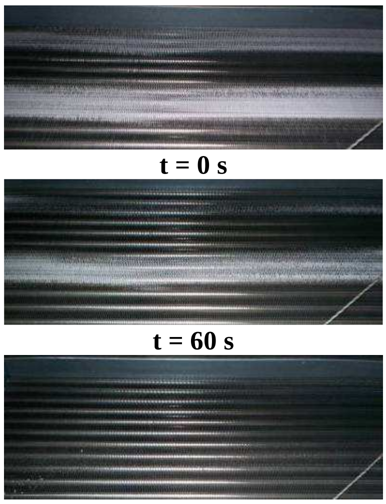
Scheme of the HPS prototype

Experimentation

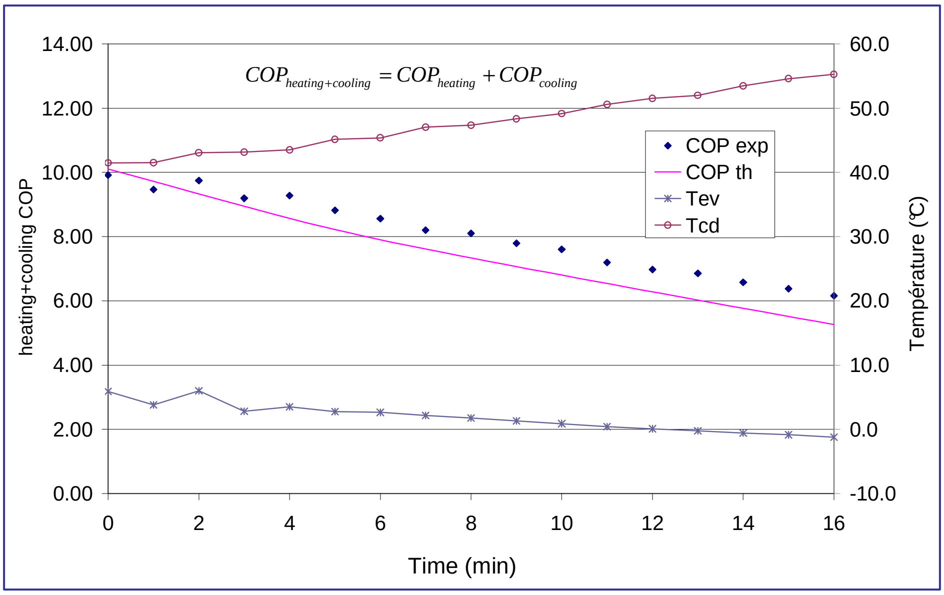
The experimental study focused on the validation of the concepts. The two-phase thermosiphon defrosting technique and the transitions between the modes of operation were successfully tested.

The performance of the plant was measured and compared to the data given by the selection software of the compressor manufacturer. Good accordance was found between experimental and theoretical data.

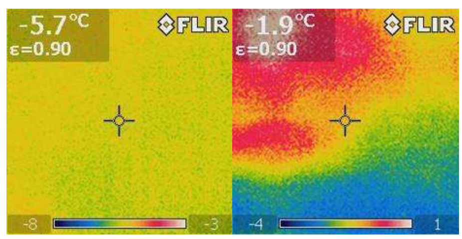
The non optimization of certain components of the plant (water evaporator, air coil) implied non significant results concerning seasonal performance.



The thermosiphon defrosting sequence lasts 120 s. When the HPS is stopped after a frosting phase, defrosting by the ambient air lasts 20 minutes



Experimental COP in simultaneous mode compared to compressor selection software values



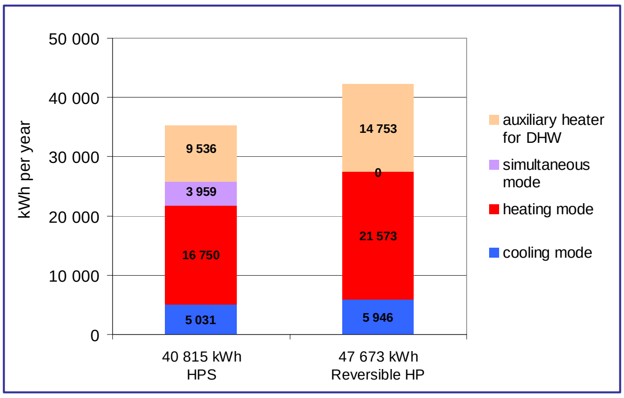
Before defrosting During defrosting
Thermographic pictures of the thermosiphon

Simulation

The operation of the HPS is modelled using TRNSYS software. The model is validated using the results of the experimental study.

Simulations are run to evaluate the average annual performance and the energy consumption of the system when coupled to the model of a 45-bedroom hotel, considered full or at 30% of occupation rate and situated in Rennes, Brussels and Marseille.

The results are compared to the ones of a standard reversible heat pump. Depending on the scenario, savings in electric energy consumption vary from 15 to 50% and annual performance improvement can reach 19%.



Electric energy consumption of a HPS and a standard reversible heat pump installed in a 45 bedroom hotel located in Rennes

Conclusion

A Heat Pump for Simultaneous heating and cooling has been designed in the aim of heating and cooling luxury dwellings, hotels and smaller office buildings and also producing domestic hot water. Running costs and greenhouse gas emissions can be diminished by using the same electric energy to produce hot and cold water simultaneously

This machine also proposes an answer to reduce the performance loss of air-to-water heat pumps under low ambient temperatures and especially during defrosting sequences by alternation between an air evaporator and a water evaporator. Defrosting is carried out without stopping the heat production.

A heat pump prototype has been build, tested, modeled and simulated. The concepts have been validated by the experiments. The prototype performance has been verified. The performance improvement compared to standard reversible heat pump has been shown by annual simulation.

A second prototype is to be build to evaluate the experimental annual performance and to characterize finely the two-phase thermosiphon defrosting technique. An optimized control strategy has to be defined to save energy.

This prototype goes further than reversibility in heat pumping technology since it produces thermal energy simultaneously for heating and cooling. The study concludes that some research is still to be accomplished in designing more efficient systems for future buildings.

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Literature

IEA-ECBCS Annex 48 website: http://www.ecbcs-48.org

Article: Byrne P., Miriel J., Lénat Y., Design and simulation of a heat pump for simultaneous heating and cooling using HFC or CO_2 as a working fluid. International Journal of Refrigeration, Vol. 32, pp. 1711-1723, novembre 2009

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IEA-ECBCS Annex 48 is a research project on reversible air conditioning systems in the tertiary sector. The project is accomplished in Energy Conservation in Buildings and Community Systems Programme of the International Energy Agency (IEA).

Internet: http://www.ecbcs-48.org