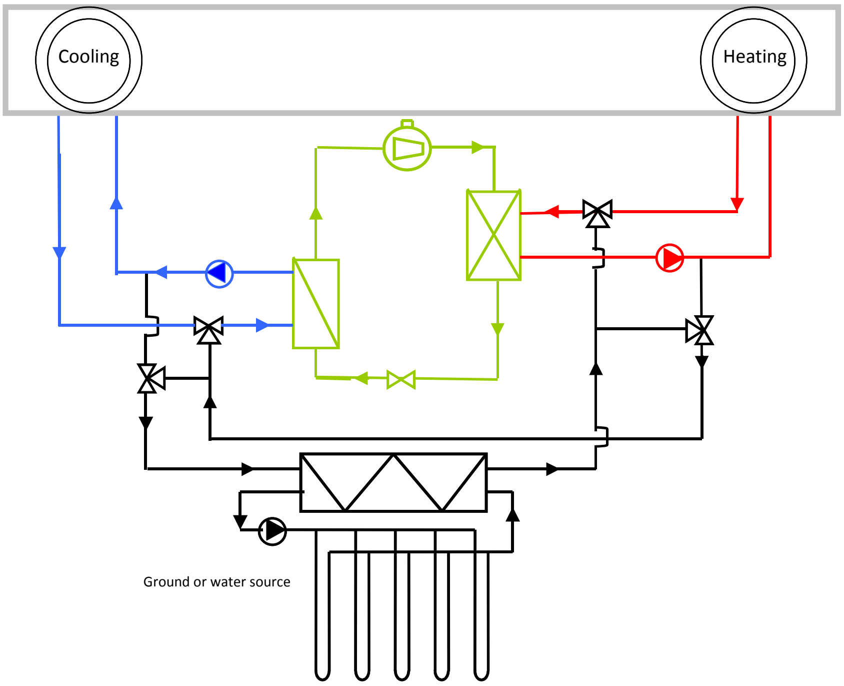
IEA-ECBCS ANNEX 48
Reversible Air-Conditioning

International Energy Agency
Energy Conservation in
Buildings and Community
Systems Programme

Review of heat recovery and heat pumping solutions



Main Authors :
Stéphane BERTAGNOLIO, Université de Liège, Belgium
Pascal STABAT, Mines ParisTech, France

Co-authors:
Marcello CACIOLO, Mines ParisTech, France
David CORGIER, CEA INES, RDI, France

Internal Reviewers :
Paul BYRNE, INSA Rennes
Jean LEBRUN, JCJ, Belgium
Vincent LEMORT, Université de Liège, Belgium
Wolfram STEPHAN, IEG, Germany

Date : 2011-05-24

Foreword

This document reports on a piece of work carried out in Subtask 1 "***Analysis of building heating and cooling demands and of equipment performances***" of IEA Annex 48 and is based upon the contribution of the participating countries.

This publication is an official Annex Report. It presents a survey of the technical solutions available to achieve reversibility or recovery-based heat pumping solution.

It is aimed at building and HVAC designers as well as at researchers in the field.

Philippe ANDRE
Editor

Operating agents :
Jean LEBRUN, Laboratoire de thermodynamique – Campus du Sart-Tilman B49 (P33) B-4000 Liège (j.lebrun@ulg.ac.be)
Philippe ANDRE, Département des sciences de l'environnement – Avenue de Longwy, 185 B6700 Arlon (**p.andre@ulg.ac.be**)

Subtask leaders :
Dominique MARCHIO, Pascal STABAT, Ecole des Mines de Paris, France, 60 boulevard Saint Michel, 75272 Paris Cedex 06 (**dominique.marchio@ensmp.fr**, **pascal.stabat@ensmp.fr**)

Preface

International Energy Agency

The International Energy Agency (IEA) was established in 1974 within the framework of the Organization for Economic Co-operation and Development (OECD) to implement an international energy program. A basic aim of the IEA is to foster cooperation among the twenty-five 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 Conservation in Buildings and Community Systems

The IEA sponsors research and development in a number of areas related to energy. The mission of one of those areas, the ECBCS - Energy Conservation for Building and Community Systems Program, is to facilitate and accelerate the introduction of energy conservation, and environmentally sustainable technologies into healthy buildings and community systems, through innovation and research in decision-making, building assemblies and systems, and commercialization. The objectives of collaborative work within the ECBCS R&D program are directly derived from the on-going energy and environmental challenges facing IEA countries in the area of construction, energy market and research.

ECBCS addresses major challenges and takes advantage of opportunities in the following areas:

- exploitation of innovation and information technology;
- impact of energy measures on indoor health and usability;
- integration of building energy measures and tools to changes in lifestyles, work environment alternatives, and business environment.

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 ((*) indicates work is completed):

Annex 1: Load Energy Determination of Buildings (*)
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 (*)
Annex 8: Inhabitants Behaviour with Regard to Ventilation (*)
Annex 9: Minimum Ventilation Rates (*)
Annex 10: Building HVAC System Simulation (*)
Annex 11: Energy Auditing (*)
Annex 12: Windows and Fenestration (*)
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 (*)
Annex 18: Demand Controlled Ventilation Systems (*)
Annex 19: Low Slope Roof Systems (*)
Annex 20: Air Flow Patterns within Buildings (*)
Annex 21: Thermal Modelling (*)
Annex 22: Energy Efficient Communities (*)
Annex 23: Multi Zone Air Flow Modelling (COMIS) (*)
Annex 24: Heat, Air and Moisture Transfer in Envelopes (*)
Annex 25: Real time HEVAC Simulation (*)
Annex 26: Energy Efficient Ventilation of Large Enclosures (*)
Annex 27: Evaluation and Demonstration of Domestic Ventilation Systems (*)
Annex 28: Low Energy Cooling Systems (*)
Annex 29: Daylight in Buildings (*)
Annex 30: Bringing Simulation to Application (*)
Annex 31: Energy-Related Environmental Impact of Buildings (*)
Annex 32: Integral Building Envelope Performance Assessment (*)
Annex 33: Advanced Local Energy Planning (*)
Annex 34: Computer-Aided Evaluation of HVAC System Performance (*)
Annex 35: Design of Energy Efficient Hybrid Ventilation (HYBVENT) (*)
Annex 36: Retrofitting of Educational Buildings (*)
Annex 37: Low Exergy Systems for Heating and Cooling of Buildings (LowEx) (*)
Annex 38: Solar Sustainable Housing (*)
Annex 39: High Performance Insulation Systems (*)
Annex 40: Building Commissioning to Improve Energy Performance (*)
Annex 41: Whole Building Heat, Air and Moisture Response (MOIST-ENG) (*)
Annex 42: The Simulation of Building-Integrated Fuel Cell and Other Cogeneration Systems (FC+COGEN-SIM) (*)
Annex 43: Testing and Validation of Building Energy Simulation Tools (*)
Annex 44: Integrating Environmentally Responsive Elements in Buildings
Annex 45: Energy Efficient Electric Lighting for Buildings
Annex 46: Holistic Assessment Tool-kit on Energy Efficient Retrofit Measures for Government Buildings (EnERGo)
Annex 47: Cost Effective Commissioning of Existing and Low Energy Buildings
Annex 48: Heat Pumping and Reversible Air Conditioning
Annex 49: Low Exergy Systems for High Performance Buildings and Communities
Annex 50: Prefabricated Systems for Low Energy Renovation of Residential Buildings
Annex 51: Energy Efficient Communities
Annex 52: Towards Net Zero Energy Solar Buildings
Annex 53: Total Energy Use in Buildings: Analysis & Evaluation Methods
Annex 54: Analysis of Micro-Generation & Related Energy Technologies in Buildings
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 (*)

Participating countries in ECBCS:
Australia, Austria, Belgium, Canada, P.R. China, Czech Republic, Denmark, Finland, France, Germany, Greece, Italy, Japan, Republic of Korea, the Netherlands, New Zealand, Norway, Poland, Portugal, Spain, Sweden, Switzerland,Turkey, United Kingdom and the United States of America.

What is Annex 48?

Environmental concerns and the recent increase of energy costs open the door to innovative techniques to provide heating and cooling in buildings. Among these techniques, heat pumps represent an area of growing interest. Heat pumping is probably today one of the quickest and safest solutions to save energy and to reduce CO_2 emissions. Substituting a heat pump to a boiler may save more than 50% of primary energy, if electricity is produced by a modern gas-steam power plant.

The heat pump market was, till now, concentrated on residential buildings. A growing attention is now given to new and existing non-residential buildings where heating and cooling demands co-exist. In many non-residential buildings, an attractive energy saving opportunity consists in using the refrigeration machine for heat production. This can be done by condenser heat recovery whenever there is some simultaneity between heating and cooling demands. When there is no simultaneity, reversibility has to be looked for.

What are the main aims of Annex 48 ?

The aim of the project is to promote the most efficient combinations of heating and cooling techniques in air-conditioned buildings, by means of heat recovery and reversible systems. The main goals are:

- To allow a quick identification of heat pumping potentials in existing buildings;
- To help designers in preserving the future possibilities and in considering “heat pumping” solutions;
- To document the technological possibilities and heat pumping solutions;
- To improve commissioning and operation of buildings equipped with heat pump systems;
- To make available a set of reference case studies.

Which tasks are covered by Annex 48 ?

Five tasks are being performed :

Subtask 1 : Analysis of building heating and cooling demands and of equipment performance.

- Classification and characterization of existing building stock;
- Characterization of existing HVAC systems;
- Evaluation of the potential of heat recovery and heat pumping systems, in order to save energy and reduce CO_2 emissions;
- Development and use of simulation models to identify the heating and cooling demands and the best heat pumping potentials.

Subtask 2 : Design

- Development of a design handbook for heat pump systems.
- Development of innovative design tools addressed to architects, consulting engineers and installers, in such a way to reach a global optimisation of the whole HVAC system.

Subtask 3 : Global performance evaluation and commissioning methods

- Development of evaluation methods devoted to heat pump solutions
- Tests with synthetic data and with measured data
- Development of computer-based tool for heat pump system operation

Subtask 4 : Case studies and demonstration

- Documentation of reference case studies
- Use of case studies to test the methods and tools developed in the annex
- Conversion of most successful case studies into demonstration projects.

Subtask 5: Dissemination

- website
- paper work (leaflet, handbooks),
- workshops, seminars and conferences.

Participants:

Université de Liège, Belgique

J.Lebrun
Co-operating Agent
S.Bertagnolio
Laboratoire de Thermodynamique
Campus du Sart-Tilman B49 (P33)
B-4000 Liège
mail : j.lebrun@ulg.ac.be
stephane.bertagnolio@ulg.ac.be
web : www.labothap.ulg.ac.be

P.André
Co-operating Agent
Département des sciences de l’environnement
Avenue de Longwy, 185
B-6700 Arlon
mail : p.andre@ulg.ac.be
web : http://www.dsge.ulg.ac.be/arlon/

CEA – INES, France

D. Corgier, V; Renzi
Co - Leader of Subtask 1
CEA – INES RDI
Laboratoire d'Intégration Solaire
Savoie Technolac - BP 332
50 Avenue du Lac Léman
F - 73377 Le Bourget du Lac
mail : david.corgier@cea.fr
virginie.renzi@cea.fr
web : www.cea.fr

Mines ParisTech, France

D.Marchio, P.Stabat
Co - Leaders of Subtask 1
Centre Énergétique et Procédés -
Mines ParisTech
60 Bd St Michel
F - 75272 Paris Cedex 06
mail :
dominique.marchio@ensmp.fr
pascat.stabat@ensmp.fr
web : www.cep.ensmp.fr

Greth, France

B. Thonon
Leader of Subtask 5
Greth
Savoie Technolac - BP 302
50 Avenue du Lac Léman
F - 73377 Le Bourget du Lac
mail : bernard.thonon@greth.fr
web : www.greth.fr

Georg-Simon-Ohm-Hochschule Nürnberg, Germany

W. Stephan
Co – Leader of Subtask 2
Ieg Intstitut für Energie and Gebäude
Kesslerplatz 12
D – 90489 Nürnberg
mail : wolfram.stephan@t-online.de

HLK Stuttgart GmbH, Germany

J. Schmid
Co – Leader of Subtask 2
HLK Stuttgart GmbH
Pfaffenwaldring 6A
D – 70569 Stuttgart
mail : joerg.schmid@hlk-stuttgart.de
web : www.hlk-stuttgart.de

TEB GmbH, Germany

M. Madjidi, T. Dippel
Co – Leaders of Subtask 2
Transferzentrum Energieeffizientes Bauen GmbH
Kehlstr. 27/1
D – 71665 Vaihingen/Enz
mail : info@madjidi.de
dippel@teb-online.de
web : www.teb-online.de

Politecnico di Torino, Italy

M. Masoero
Leader of Subtask 4
Politecnico di Torino
mail : marco.masoero@polito.it
web : www.polito.it

INSA Rennes, France

P. Byrne
Laboratoire de Génie Civil et de Génie Mécanique
Equipe Matériaux et Thermo-Rhéologie
20, Avenue des Buttes de Coësmes
CS 70839
F - 35708 Rennes Cedex 7
mail: paul.byrne@insa-rennes.fr
web: www.insa-rennes.fr

Table of contents

I. Introduction

The use of reversible heat pumps and the heat recovery on chiller condenser appear to be as the quickest and safest solutions to save primary energy and to reduce CO_2 emissions in commercial buildings. The penetration of heat pumps on the European market has increased during these last years in the tertiary sector (**Figure 1**). The treated area on Figure 1 is defined based on the sold units with a capacity higher than 17.5 kW.

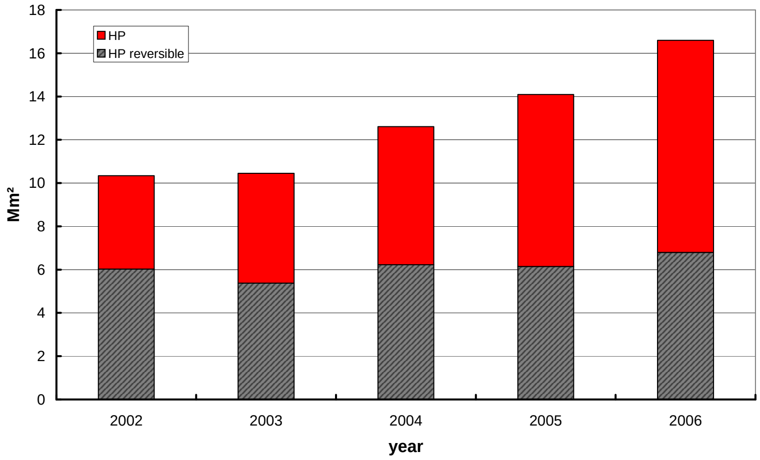


Figure 1: Heat Pump penetration in tertiary sector in Europe-15 during these last years in millions of square meters

One of the aims of IEA ECBCS Annex 48 is to identify the most attractive opportunities of heat recovery and reversibility in HVAC applications.

This document describes the different typologies of vapour compression systems that can be used in office and heath care buildings for both heat and cold production, through reversibility and heat recovery.

The document is split in two parts: the first one makes an overview of the solutions and the second one is a catalogue of description sheets (one for each technique).

II. Overview of technical solutions

1. Heat sources and heat sinks

Using heat pumps to heat and/or to cool a building requires having heat sources and sinks at one disposal. The heat source is the medium from which the heat is extracted by the evaporator of the heat pump. The heat sink is the medium where the heat is rejected by the condenser of the heat pump. Heat source and sink are selected according to the availability of the sources, the climate, the costs and the choices of heat/cold distribution into the building.

A classification of common heat sources and sinks is proposed by ASHRAE [ASHRAE, 2004]. This classification is detailed hereafter.

1.1. Air as heat source/sink

Two solutions are currently envisaged when using air as heat source/heat sink :

- Outdoor air;
- Ventilation exhaust air.

	Heat Source	Heat sink	Availability	Temperature	Limitations
Outdoor Ambient Air	Good, but efficiency and capacity decrease with decreasing outdoor air temperature	Good, but efficiency and capacity decrease with increasing outdoor air temperature	Universally and continuously available	Extremely variable temperature	Defrosting and additional heat production systems usually required
Ventilation Exhaust Air	Excellent and allowing constant capacity and efficiency	Fair and allowing constant capacity and efficiency	Excellent location relatively to needs and excellent coincidence with needs	Very constant temperature all along the year	Insufficient for typical loads

Outdoor air is very commonly used as heat-source and heat-sink in heat pump systems. The main disadvantage of the outdoor air is its very variable temperature. During winter, in heating mode, low outdoor temperatures limit the capacity of the heat pump and decrease its performances. During summer, in cooling mode, high outdoor temperatures reduce the performances and the capacity of the heat pump. Moreover, in winter, below more or less 6°C of outdoor air temperature, some defrosting is usually reqired and decreases the COP of the heat pump.

Ventilation exhaust air represents a very interesting heat source, because of its good availability, its good coincidence with needs and its very constant temperature. Condensing the water contained in extracted air allows recovering a part of the latent energy and increases the heating capacity. In cooling mode, condenser heat can also be easily rejected in the exhaust air, which is often at lower temperature than outdoor air.
However, exhaust ventilation rates are restrictive in terms of heating and cooling capacities, so that an additional heat source or sink can be required.

Both solutions are currently used in buildings; the related technology is mature and available. Finned coils are currently used and supplied by glycol water (to prevent freezing), or directly by the refrigerant (“direct expansion coils” or “DXcoils”).

Installation, operation and maintenance costs are usually low to moderate for both solutions.

1.2. Water as heat source/sink

Water used as heat source or sink may come from different origins :

- Ground water;
- Lakes, rivers or oceans;
- Closed water loops;
- Waste water
- Condensing water.

	Heat Source	**Heat sink**	**Availability**	**Temperature**	**Limitations**
Ground Water	Excellent	Excellent	Poor to excellent, availability depending of location	Generally excellent and very stable temperature level	Accessibility and required permits, risk of fouling
Surface Water (lakes, rivers, oceans)	Excellent when sufficient quantity or flow rate	Excellent when sufficient quantity of flow rate	Quite rare but continuously available	Usually satisfactory temperature level and variation	Often regulated or prohibited; risk of fouling
Closed loops	Good but loop may need additional heat	Good but loop may need heat rejection	Excellent if designed as such	Excellent if designed as such	Most suitable for large installations
Waste Water	Fair to excellent	Fair to excellent	Variable availability, may be adequate in some types of buildings	Excellent and very constant temperature level	Uncommon and rarely used; risk of fouling, corrosion…
Condensing (cooling towers, refrigeration systems)	Excellent	Poor to good	Variable with the cooling loads	Variable	suitable only if heating need is coincident with heat rejection

Ground water is certainly one of the most interesting media for heat pumping. This solution is characterized by very good and constant temperature level. Its "intermediate" temperature allows both efficient heat rejection and efficient heat pumping. The main limitations are related to the accessibility (depending of location) and to the risk of contamination of groundwater.
Installation costs may be reduced in case of using existing wells. Operation and maintenance costs are generally low.

Lakes, rivers and oceans are very good heat sources and sinks, due to their very constant temperature and their continuous availability. Several techniques can be used, for example:

- The water is pumped and directly circulated through a loop supplying the heat pump evaporator;
- A closed loop of glycol water is installed on the bottom of the "water body" (lake, river or ocean) and transfers heat from the water body to the heat pump evaporator.

The main limitations of these two solutions are the very limited number of locations where large water bodies are available and where it is authorized to use them as heat source/sink. The installation and maintenance costs of these solutions depend on the location and on the risk of fouling.

An internal closed water loop can be used to transfer heat to and from the different zones of the building through small local water-to-air reversible units.
This water loop can be connected to different heat sources/sinks, as outdoor air or ground, to allow heat rejection or heat pumping. In case of simultaneous heating and cooling demands inside the building, the heat rejected by the local units working in cooling mode is, at least partially recovered by the other units working in heating mode and the external source/sink can be only partly used. Installation, operation and maintenance cost are low to moderate.
This system presents very high potentials for large buildings characterized by simultaneous heating and cooling demands and will be described further.

In some applications, waste water can be used as excellent heat source/sink. The main limitation of this system comes from the limited availability of waste water in large office buildings and from fouling problems. However, availability can be adequate in case of health care buildings, characterized by very important domestic hot water consumption. Currently, this solution is rarely used.

1.3. Ground as heat source/sink

The ground can be used as heat source/sink by means of three main types of ground heat exchangers:

- *vertical ground heat exchangers*
    - very constant temperature heat source/heat sink (+)
    - required ground area is very reduced (+)
    - cost and possibly difficult drilling (-)
- *horizontal ground heat exchangers*
    - lower cost (+)
    - influence of the outdoor air temperature is important at low depth (-)
    - required ground area is large (-)
- *buried direct expansion (DX) heat exchangers*

	Heat Source	Heat sink	Availability	Temperature	Limitations
Ground closed loops	Good but performance depends on soil properties	Good but performance depends on soil properties	Depends on soil suitability, generally continuously available	Usually good and very constant temperature level, especially for vertical systems	High initial cost
Direct expansion Ground heat exchanger	Very good but performance depends on soil properties	Very good but performance depends on soil properties	Depends on soil suitability, generally continuously available	Temperature level depending on design but generally constant	High initial costs, Risk of leakage, requires large refrigerant quantities

The soil composition has a great influence on its thermal properties and on the overall performances. The thermal diffusivity of the soil (thermal conductivity divided by the product of the density and specific heat) is the predominant factor of the heat transfer in the ground. The thermal conductivity and the thermal capacity are also influenced by the soil moisture.

Currently, ground closed loop systems are widely used. Water or Brine circulates in buried closed loops. Two types of loops are available:

- Vertical ground heat exchangers; consisting of a U-tubes installed in vertical boreholes up to 100-120 meters depth.

- Horizontal ground heat exchangers; consisting of long single or multiple serpentine heat exchangers pipes buried 1 to 2 meters below the surface.

The first solution is more expensive, due to drilling, but ensures quite constant temperature level of the heat source/sink. The horizontal ground heat exchangers require a large area (1.5 to 2 times the heated area) and can be influenced by the varying outdoor temperature. This second solution is cheaper, but is generally characterized by lower efficiencies.

In case of direct expansion exchangers, there is no intermediate buried loop and the refrigerant circulates directly in the buried pipes (generally in horizontal pipes). The temperature level depends of the design of the exchanger. The main limitation of this system is the risk of refrigerant leakage. Due to soil contamination risks, this solution is less current.

1.4. Solar Energy as heat source/sink

	Heat Source	Heat sink	Availability	Temperature	Limitations
Solar Collectors	Fair	-	Universal but highly intermittent availability	Extremely varying temperature level	Additional source or storage system usually required

Solar energy may be used as the primary heat source or in combination with other heat sources. The main advantage of this system is that, during functioning periods, the heat source temperature is higher than other common sources (ground, outdoor air,…). Compared to a classical solar heating system without heat pump, the efficiency of the collector is increased by means of a low temperature level required.

As for ground use, two types of solar collectors are available:

- direct expansion collectors in which the refrigerant evaporates;
- indirect collectors, with water, air or brine circulation.

The main limitations of this system are its limited capacity and the intermittent functioning.

Using solar collectors as heat sink is only possible during night; then, infrared radiation in clear sky conditions may help…

1.5. Industrial Process as heat source/sink

	Heat Source	Heat sink	Availability	Temperature	Limitations
Process heat or exhaust product	Fair to excellent	Often impractical	Depending on the process	Depending on the process	May be costly, depending on the application

If available, heat rejected by industrial processes could be a very convenient heat source. Of course the temperature level and variation depend on the process considered. The main limitations are technical (space available, location of the heat rejection relatively to the heat demand…) or economical.

2. System classification

The term “heat pump” can refer to heat pump units or to heat pump systems, as defined in appendix 2.

2.1. Heat pump units

For *heat pump units* the following denomination, according to the outdoor/indoor heat transfer medium is proposed (see appendix 2 for more information):

Table 1: Classification of heat pump units

Packaged units
Air-to-water heat pump (*Air-cooled chiller*) Water-to-water heat pump (*Water-cooled chiller*) Water/air-to-water heat pump (*Dual condenser chiller*) Water-to-air heat pump Air-to-air heat pump Brine-to-water heat pump Brine-to-air heat pump
Roof-top unit
Direct expansion (DX) units
Split type
VRF
Direct expansion (DX) Ground-coupled heat pump

Units are called reversible if they are equipped of a refrigerant changeover that can reverse the cycle.

According to Table 1 the term “chiller” can be used instead of the corresponding term “heat pump”, in order to emphasise that the primary purpose of the unit is cooling, e.g. when the unit is sized on the base of the peak cooling load.

Roof top units and direct expansion ground-coupled heat pump units are excluded from this document, since they are generally not used in office and health care buildings.

2.2. Heat pump systems

Heat pump systems are composed of one or more heat pump units and other components (see appendix 2 for more information). They can be split into three main categories:

- *Reversible systems without heat recovery*: alternate heating and cooling production;
- *Non-reversible systems with heat recovery*: designed mainly for cooling, they can recover heat at condenser side while producing cooling at evaporator side;
- *Reversible systems with heat recovery*: alternate or simultaneous heating and cooling production.

Each category can be subdivided according to heat source and sink (see section 1):

- Outdoor air, directly or by means of a cooling tower (section 1.1 and 1.2)
- Exhaust air (section 1.1)
- Geothermal sources: ground or groundwater or surface water (section 1.2 and 1.3)

Systems using solar or industrial heat sources (section 1.4 and 1.5) are excluded from this document, as they are not of current use in tertiary office and healthcare buildings.
At the end, the different systems can be categorized according to:

- the type of change-over (refrigerant change-over in the heat pump unit, water or air change-over in the distribution system);
- the distribution fluid
- the building (type and size)
- the heat source / sink (direct of by means of a water loop).

Table 2 proposes a classification of heat pump systems that will be examined in detail in chapter III.

Nomenclature	*Heat pump unit type*	*Heat source / sink*	*Reversibility*	*Heat recovery*	*Change-over*	*Distribution to the heat source/sink*	*Distribution fluid to the building*
· *Reversible systems without heat recovery*							
Reversible air-to-water heat pump system	Reversible air-to-water	Outdoor air	Yes	No	Refrigerant	Direct	Water
Reversible ground coupled heat pump system	Reversible brine-to-water	Ground	Yes	No	Refrigerant	Brine	Water
Reversible groundwater (surface water) heat pump system	Reversible brine-to-water	Groundwater, surface water	Yes	No	Refrigerant	Open/closed water loop	Water
Exhaust air heat pump system	Reversible air-to-water	Extracted air	Yes	No	Water	Direct	Water
Air-to-air dual duct heat pump system	Air-to-air	Extracted air	Yes	No	Air or refrigerant	Direct	Air
Mono-split / Multi-split	Split type	Outdoor air	Yes	No	Refrigerant	Direct	Refrigerant
· *Non-reversible systems with heat recovery*							
Water-cooled chiller with heat recovery	Water-cooled chiller	Outdoor air (cooling tower)	No	Yes	-	Water loop	Water
Dual condenser chiller	Dual condenser chiller	Outdoor air or/and water	No	Yes	-	Direct	Water
"Templifier"	Non reversible Water-to-water	Water	No	Yes	-	Direct	Water
· *Reversible systems with heat recovery*							
Reversible water/air-to-water heat pump system	Reversible water/air-to-water	Outdoor air	Yes	Yes	Refrigerant	Direct	Water
Reversible (ground coupled, groundwater or surface water) heat pump system with heat recovery	Non reversible water-to-water (water-cooled chiller)	Ground, groundwater, surface water	Yes	Yes	Water	Two separate water loops	Water
VRF	VRF	Outdoor air	Yes	Yes (3-tubes)	Refrigerant	Direct	Refrigerant
Water-loop heat pump system	Decentralized reversible water-to-air	Boiler / Outdoor air (cooling tower)	Yes	Yes	Refrigerant	Water loop connecting the local heat pumps and the heat source / sink	
		Ground, groundwater, surface water					

Table 2: Classification of heat pump systems

3. System selection

In order to select appropriately a heat pump system, a preliminary analysis should be carried out to identify the main parameters that affect the choice of the system:

- ***Building size***: According to their size (air-conditioned surface), some HVAC systems would be preferred to other ones.

For instance Multi split and VRF systems are often used in the retrofit of small buildings, since they are compact, easy-to-install and cost-effective. However, they have a limited capacity (<200 kW in heating) and the pipe length between the central unit and the terminal units is limited.

- ***Heat source/sinks***: The best heat sources/sink are those with stable temperatures.

The heat pumps on ground or water source offer the best performance but these sources are not available everywhere and drilling authorization may be required.
The choice of moderate temperature emitters should be preferred such as radiant panels (see appendix 1).

- ***Design heating and cooling loads***: The ratio between the design heating load (P_h) and the design cooling load (P_c) is an important parameter in choosing a system. According to the building thermal characteristics, the building use and the climatic zones, the design heating and cooling loads are more or less balanced.

If $P_h << P_c$, the reversibility is interesting, provided that the cooling production equipment is split in several units, some for heating and cooling and the other ones for cooling only; otherwise the heat pump will be oversized. If $P_h >> P_c$, the reversibility is interesting provided that the heating production equipment is split in several units, some for heating and cooling and the other ones for heating only.

- ***Simultaneity of heating and cooling demands:*** Simultaneity of heating and cooling demands is frequent in some cases, as in buildings with different exposures, buildings composed of "hot" core and "cold" peripheral zones, buildings with rooms requiring close environmental control, with large data centres, with swimming pools/ice rink or with refrigerated warehouse…

The buildings with high simultaneous heating and cooling demands can take advantage of heat pumps systems with heat recovery. The use of reversible heat pumps without any heat recovery should be combined with a back-up system.

- ***Domestic hot water:*** In buildings with high domestic hot water demand *and* high cooling demand, such as hospitals, the heat recovery on condenser for HDW can be interesting.

In order to reduce the energy consumption in buildings, when using heat pumping technology two aspects must be considered carefully:

- ***System sizing:*** Heat pump oversizing means higher installation costs and, possibly also lower seasonal efficiency, due poor part-load performance. Sizig rules were developed in the frame of this project
-
- ***Part load performance:*** it is important to choose the most efficient chillers, not only at standard conditions, but also at part load. EUROVENT certification certifies many HVAC equipments (www.EUROVENT-certification.com). The EER and COP of the certified reversible chillers are generally available. A selection guide is also provided (http://www.thelcon.gr/Default.aspx).

In HVAC, a chiller operates more than 95% of the time at part load. This is taken into account through a new index, named ESEER (European Seasonal Energy Efficiency Ratio).
To date, there is not yet a similar standardized index in heating mode.

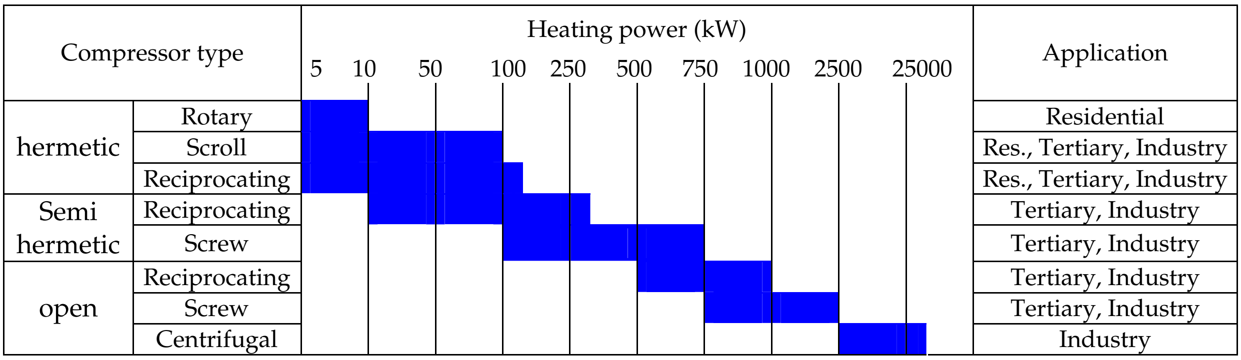
Guidelines for the choice of the compressor type

According to the heating power, several compressors types are available (Table 3).
While the reciprocating compressors have been, for a long time, the most common technology, the scroll compressors are more and more used. The success of scroll compressors is mainly due to its robustness and reliability (few moving parts), its low level of noise and vibration and good performance. Larger and larger heat pumps systems are manufactured by associating up to 8 compressors in parallel, which also provides very good part load performance. For a machine using one or two scroll compressors, another mean of capacity modulation is the on-off control, the multi-step control (the two scrolls can be disassembled by means of a pneumatic actuating system) or the control of the drive speed. The use of vapor injection, that is one of the most recent developments in scroll compressor technology, makes the machine even more adapted to heat pump application typically characterized by high temperature lift (difference between the condensing and evaporating temperatures).

Larger heat pumps commonly use screw compressors. The latter are also preferred for industrial applications because of their very high robustness. There are three main means of controlling the capacity of screw-type heat pumps: on-off control, speed variation, variation of the effective displacement of the compressors by means of sliding valves. Screw compressors usually require larger mass fraction of oil (in comparison with scroll compressor) for lubrication and cool ing purpose. As a consequence, generally large oil separators are required.

The largest heat pumps employ centrifugal compressors. While the condenser of a scroll- or screw-type heat pump can be cooled either by water or by air, centrifugal heat pumps are limited to water cooled condensers. Heating capacity of such machines is controlled by speed variation and/or inlet guide vanes.

Table 3 : Technology of compressor according to the heating power range [AUZ, 2005]



Compressor type		Heating power (kW)										Application
		5	10	50	100	250	500	750	1000	2500	25000	
hermetic	Rotary	■										Residential
	Scroll	■	■	■								Res., Tertiary, Industry
	Reciprocating	■	■	■	■							Res., Tertiary, Industry
Semi hermetic	Reciprocating		■	■	■	■						Tertiary, Industry
	Screw				■	■	■					Tertiary, Industry
open	Reciprocating						■	■				Tertiary, Industry
	Screw							■	■			Tertiary, Industry
	Centrifugal									■	■	Industry

For more information about heat pump technology, detailed information is provided in [ASHRAE, 2004], [VRI, 1991], [AUZ, 2005]…

III. Typical Heat Pump systems

In the following section, the most common heat pump systems involving different heat sources, heat sinks, heat pump systems and control strategies are described. Each description sheet contains:

- Description of system working and characteristics, including reversibility and heat recovery opportunities;
- Operating modes;
- Advantages and drawbacks of the system;
- Typical performances and working ranges;
- Typical applications.

1. Reversible systems without heat recovery

1.1. Reversible air-to-water heat pump

1.1.1. System description, reversibility and heat recovery opportunities

The air-cooled chiller is the most present technology on the European air-conditioning market, representing 85 % of chillers sold in the commercial sector [EECCAC, 2003].

The system can be reversed by means of a refrigerant change-over (Figure 2), which inverses the flow passage into the two exchangers:

- In cooling mode, the air exchanger works as condenser, rejecting heat to outdoor air, while the water-exchanger works as evaporator, transferring cooling power to the distribution system.

- In heating mode the air exchanger works as evaporator, extracting heat from outdoor air, while the water exchanger works as condenser, transferring heating power to the distribution system.

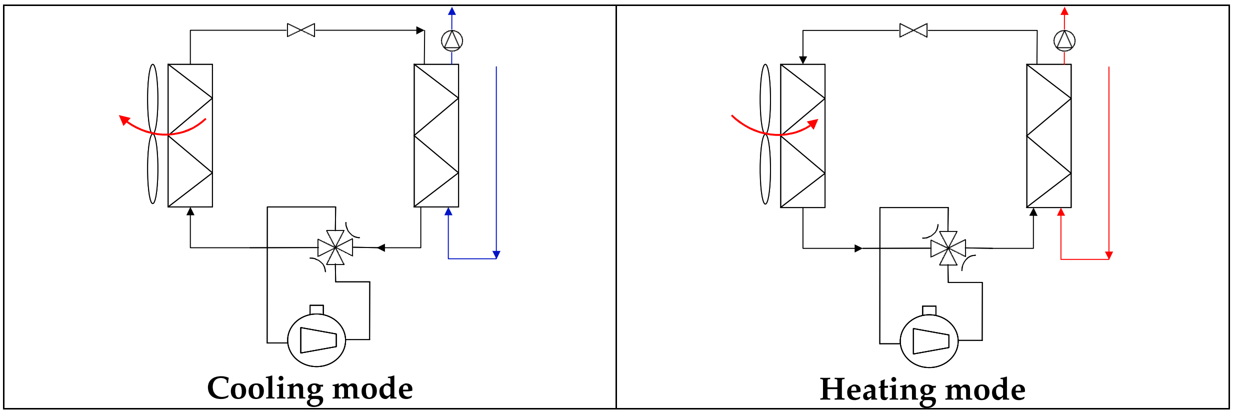


Figure 2: Air-cooled chiller with refrigerant change-over

Today, a large offer of reversible units is proposed, with investment costs comparable to non-reversible units.
Reversible air-cooled units are installed in most of the case in combination with a backup boiler, for the following reasons:

- To supply heating power when simultaneous heating and cooling loads are required: when the chiller works in cooling mode, it cannot provide any heating power;

- To complete heating power for low outdoor air temperatures, in case the air-to-water unit is not sized for low outdoor temperatures (the heating power at –5°C can be 30% lower than heating power at rating conditions);

- To supply the entire heating power when, (at very low outdoor temperature), the boiler has better performances than the air-to-water unit, or when the outdoor temperature is under the unit working range.

Typically, the air-to-water heat pumps have a limiting outdoor temperature (generally around –10°C), below which they cannot be operated. In addition, at very low outdoor temperature, the chiller COP degrades dramatically, and using the boiler could become preferable. The outdoor temperature limit depends on Heat pump COP, boiler efficiency and the objective (operation costs, CO_2 emissions, Primary Energy savings).

Reversible units can be connected to:

- A two-pipe water distribution system, in parallel with the backup boiler, if no simultaneity of heating and cooling loads is expected (Figure 3);

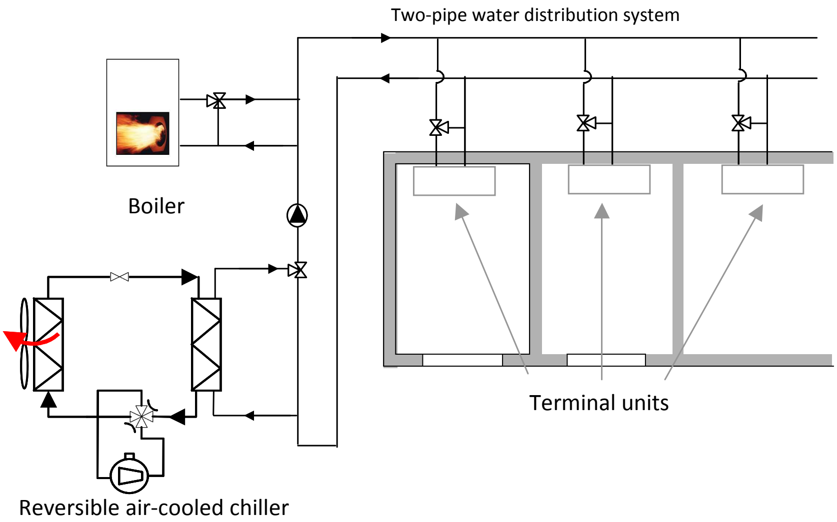


Figure 3: Reversible air-to-water unit, connected to a two-pipe distribution system in series with a boiler

- A four-pipe water distribution system, for buildings with simultaneous heating and cooling loads (Figure 4). Two main types of connection are possible:
    - as in conventional solution, the chiller is connected to the cold water pipes, while the boiler is connected to the hot water pipes. When only heating demand is present, the chiller switches to reversible mode, and the warm water circulates in the cold water pipes. In practice, this is only possible when the cold emission terminal units can be adapted for hot emission at low temperature as in a two-pipe configuration. The boiler is used only when heating demand is requested in some building zones whereas cooling demand is requested in other zones and when the heat pump heating capacity is insufficient.

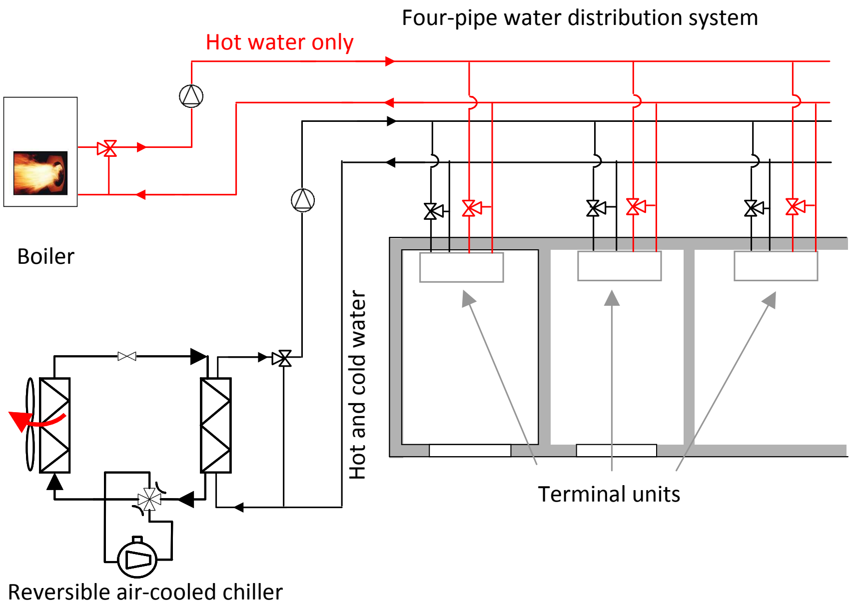


Figure 4: Reversible air-to-water unit, connected to a four-pipe distribution system via the cold water distribution

- the chiller is connected to both the cold water and hot water pipes (Figure 5). In this case, the hot emission terminal units should be compatible with low water temperatures, characteristic of the reversible unit working in heating mode without boiler contribution. If they are not compatible, the boiler could be used continuously to raise the water temperature to the level needed, but that is only possible if working with very large temperature difference i.e. with very low flow rate. This last case should be avoided when possible, because continuous use of the boiler at low load could result in bad seasonal performance and to a reduction of saving potentials.

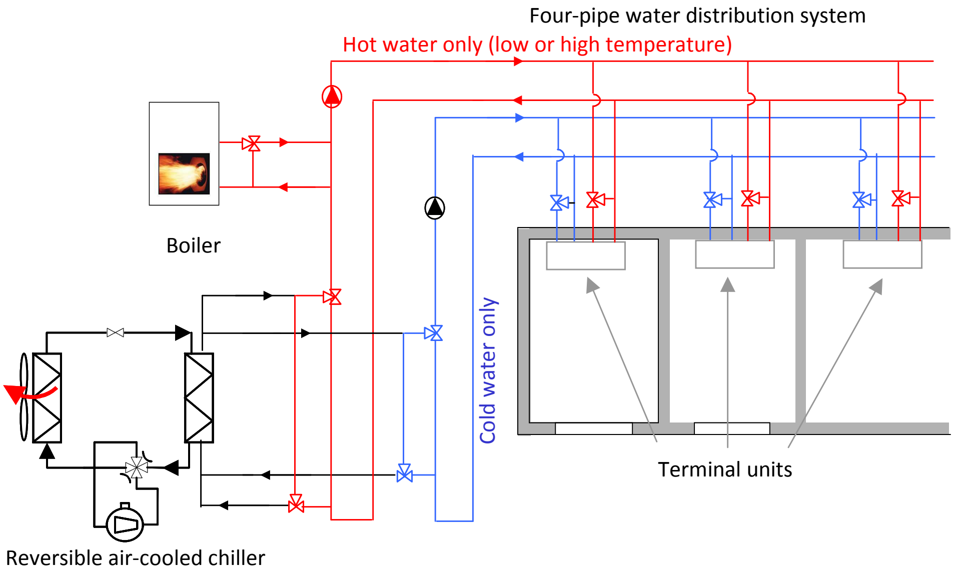


Figure 5: Reversible air-to-water unit, connected to a four-pipe distribution system via the hot water distribution

- An air-based distribution system. In analogy to the four-pipe water distribution system, there are two types of connections:
  - the chiller is connected to the cooling coil, and the boiler to the heating coil of the air handling units. The cooling coil works as heating coil when only heating load is demanded;
  - the chiller is connected to both coils.

Among the distribution units, radiant panels and dynamic chilled beams should be advantaged since they allow lower distribution temperatures in heating mode and higher ones in cooling mode, improving the efficiency of the heat pumps.

Heat recovery is typically not possible in simple air-to-water units. However, by adding a water exchanger, one can have either a water/air-to-water heat pump or a dual condenser chiller (section 2.2 and 3.1).

1.1.2. Operating modes

The system is cooling-driven. That means that the priority is given to cold generation, if there is a cooling demand. The boiler is used when cooling and heating demands are simultaneous (if the distribution system allows it), when there is only a heating demand, too large to be covered by the chiller in heating mode, or when the reversible chiller can not operate or has too bad performance due to low outdoor temperature.

Four operating modes of the system can be defined:

- If there is a cooling demand, the heat pump operates in cooling mode, according to this demand. All the heating demand is covered by the boiler;
- If there is no cooling demand and if the heating demand is into the limit of the heating capacity of the heat pump and if the heat pump performance corresponding to outdoor temperature is better than the boiler one, the heat pump operates in heating mode, regulating the load on the basis of the heating demand;
- If there is no cooling demand and the heating demand is outside the limit of the heating capacity of the heat pump, and if the heat pump performance corresponding to outdoor temperature is better than the boiler one, the heat pump provides heating at full load in heating mode, and the supplementary demand is covered by the boiler;
- If there is no cooling demand and the heat pump performance corresponding to outdoor temperature is worse than the boiler one, or if outdoor temperature is under the minimum operating temperature of the heat pump, the boiler covers all the heating demand.

1.1.3. Typical performance and working ranges

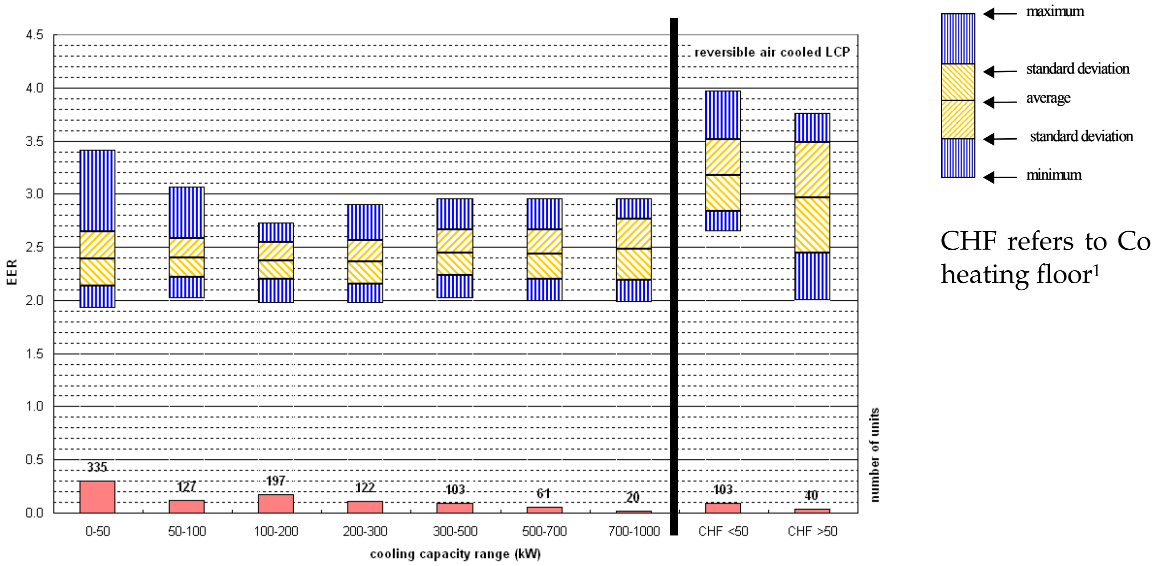
Typical nominal performances of air-cooled chillers can be obtained from the EUROVENT database. EUROVENT defines the standard rating conditions for air-cooled chillers as reported in Table 4. The conditions are different for standard air-conditioning and for cooling/heating floor (CHF) applications.

Table 4: Standard rating conditions for air-cooled chiller (EUROVENT)

Application	Temperature			
	Cooling		Heating	
	Evaporator	Condenser	Condenser	Evaporator
Standard air-conditioning	12 / 7 °C	35 °C	40 / 45 °C	7 °C
Cooling/heating floor	23 / 18 °C	35 °C	30 / 35 °C	7 °C

The certificated values are the cooling and heating nominal capacities, the nominal EER (cooling) and the nominal COP (heating).

Average EER and COP at rating conditions of reversible air-cooled chillers are summarized in Figure 6 and Figure 7.



CHF refers to Cool-heating floor[1]

Figure 6: EER of reversible air cooled LCP by range of cooling capacity based on EUROVENT data 2005

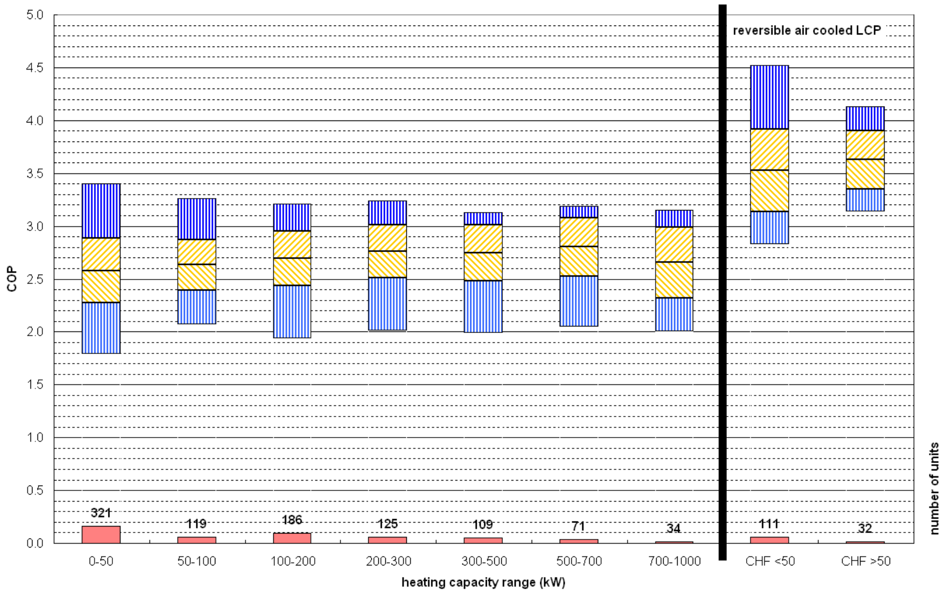


Figure 7: COP of reversible air cooled LCP by range of heating capacity based on EUROVENT data 2005

It can be noted that average values of COP are about 10% higher than EER at rating conditions. Heating capacities are also about 10% higher than the cooling capacities at rating conditions.

---

[1] The standard rating conditions in case of chillers on CHF are 23/18 °C for water and 35 °C for air which are more favourable conditions to obtain higher EER.

The average values of EER at rating conditions of EUROVENT certified air-cooled chillers (excluding the Cool Heating Floor, for which the rate conditions are more favourable) lie between 2.4 and 2.5, while the COP between 2.6 and 2.8.

The performances of air-to-water units at working conditions differ sensibly from the values at rating conditions because of three combined effects:

- *Outdoor air temperature variation.* The air temperature affects the air-cooled chiller performances varying the condensing temperature in cooling mode and the evaporating temperature in heating mode.
  In general, air-cooled chillers exhibit nearly linear variation of heating / cooling capacity and EER / COP with outdoor air temperature, in the typical heating and cooling operating temperature range, as shown in Figure 8.

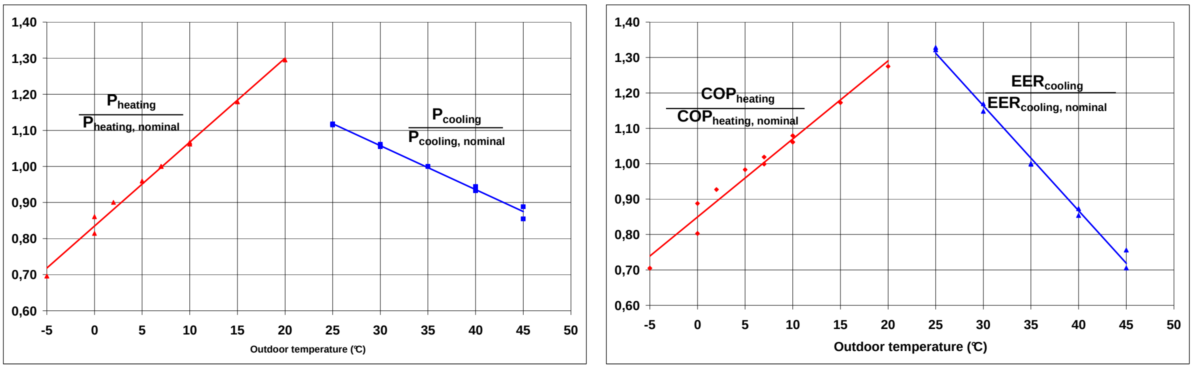


Figure 8: Typical performance variation of air-to-water reversible units as function of outdoor air temperature (catalogue data CARRIER - CIAT). Water temperatures are at rating conditions defined by EUROVENT.

  Additionally, in heating mode, at temperature near 0°C (typically starting from +4/+5°C), the effect of the defrosting cycles decreases further the chiller performance (roughly of 10% of the power and of the COP).

- *Distribution system water temperature:* The distribution water temperature affects the evaporating temperature in cooling mode and the condensing temperature in heating mode. As shown in Figure 9, in heating mode, an increment of the water temperature decreases the COP and increases the minimum operating temperature. On the contrary, in cooling mode, an increment of the water temperature increases the EER.

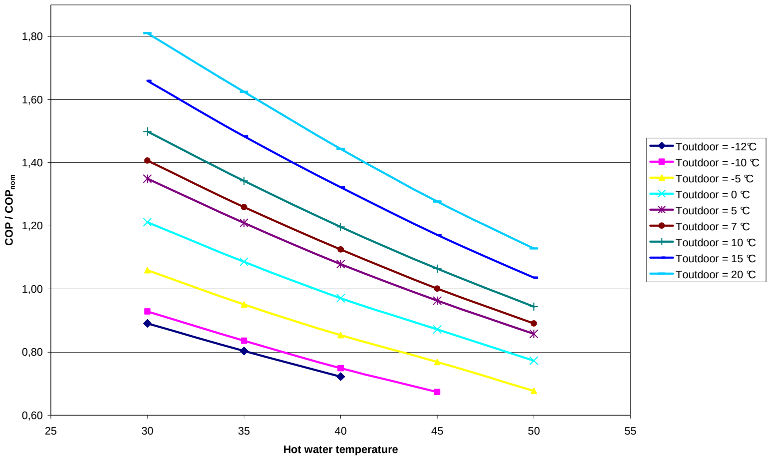


Figure 9: COP variation in heating mode of an air-cooled chiller versus outlet water temperature (catalogue data CIAT). Supply / exhaust temperature difference: 5°C.

- *Part load performance:* EER and COP provided by producer catalogues are measured at full load conditions. Either degradation or improvement of performance can occur in part load, depending on several factors. Unfortunately, producers tend to give little information about part load performance of their products.

For air-cooled chillers, EUROVENT has proposed a seasonal cooling index, the ESEER (European Seasonal Energy Efficiency Ratio), which takes into account both partial load performance and the effect of the variation of outdoor temperature in European Climates.

The ESEER is calculated on four working points, as follows:

$$ESEER = A \cdot EER_{100\%} + B \cdot EER_{75\%} + C \cdot EER_{50\%} + D \cdot EER_{25\%}$$

Table 5 shows the test conditions of the four working points and the weight coefficients defined for the air-cooled units.

Table 5: Test conditions and weight coefficients for ESEER definition

Part load ratio	Air temperature (°C)	Water outlet temperature (°C)	Weight coefficient:
100%	35	7	A = 0,03
75%	30	7	B = 0,33
50%	25	7	C = 0,41
25%	20	7	D = 0,23

Figure 10 shows that for a given EER, they are large difference of ESEER between products. The choice of the chiller should be preferably done based on ESEER since it is more representative of the real performance of the chiller on a year. In heating mode, the EUROVENT consortium has not yet established an analogue index.

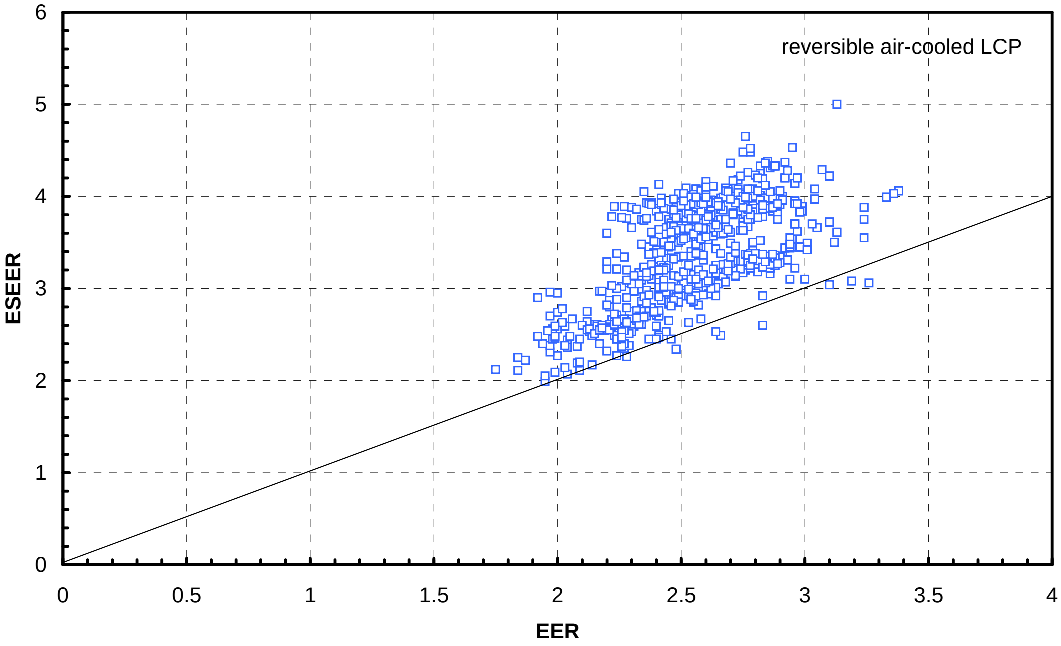


Figure 10 : ESEER versus EER for reversible air-cooled chiller from EUROVENT data (2008)

1.1.4. *Typical applications*

Reversible air-to-water units allow a very flexible use. They can be installed in new buildings and in renovation if a water or air distribution system is available.

In particular, their use is very interesting in existing air-conditioned buildings, when an air-cooled chiller and a boiler are already installed. In this case, an interesting retrofit action consists in using the chiller in reversible mode, rearranging the terminal units and the distribution system.

However, the change of the existing boiler for a smaller one should also be considered, as using continuously an aged boiler at low loads strongly decreases its seasonal performance.

1.1.5. Advantages

- Large offer of reversible units on the market, for all sizes
- Low investment cost
- As air is used as heat source/sink, the system can be installed in any building

1.1.6. Drawbacks

- Performance and capacity falls when the outdoor air is very cold in heating mode and when the outdoor air is very hot in cooling mode
- Simultaneous heating and cooling demands cannot be covered
- Auxiliary boiler is required
- Noise (outdoor fans)

1.2. Reversible geothermal (ground source, groundwater)/hydrothermal (surface water) heat pump (without heat recovery)

1.2.1. System description, reversibility and heat recovery opportunities

A reversible geothermal heat pump (GHP) is composed of a reversible water-to-water unit connected from one side to the building distribution system and from the other to a brine or water loop connected to the geothermal heat source / sink.

The system is reversed by means of a refrigerant changeover in the heat pump unit, which inverses the flow passage into the two exchangers:

- In cooling mode, the geothermal-side exchanger works as condenser, rejecting exceeding heat into the ground or the surface water via the water (or glycol-water) loop, while the water-exchanger works as evaporator, transferring cooling power to the distribution system.
- In heating mode, the geothermal-side exchanger works as an evaporator, absorbing heat from the geothermal heat source via the water loop, while the water exchanger works as condenser, transferring heating power to the distribution system.

In addition, if the geothermal source temperature is in the range of the building distribution temperature, the system can be designed to operate in free-chilling mode: the water loop by-passes the heat pump unit and is connected, by means of an additional heat exchanger, to the distribution system of the building. The heat exchanger size and the control strategy for the passage from the cooling mode to the free-chilling mode and vice-versa should be designed carefully, according to the geothermal source temperature level and to the building cooling load profile.

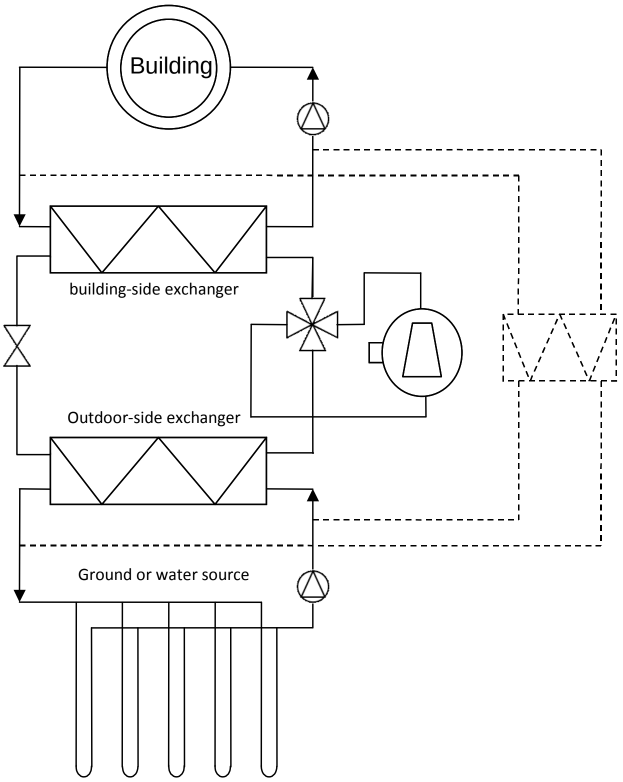


Figure 11: Reversible geothermal heat pump without and with free chilling

A deep geothermal closed loop behaves as a seasonal heat storage system:

- In summer, the heat pump is used in cooling mode and rejects heat in the ground or the groundwater through the loop;

- In winter, this heat is recovered from the ground or the groundwater through the loop.

In addition to these classical GHP systems, some hybrid systems are also developed. In hot climates, cold rejection in the ground is not always sufficient and an additional heat rejector (e.g. a cooling tower or a dry fluid cooler) must be coupled to the condenser of the heat pump to reject excess heat. In very cold climates, if the geothermal source is not a sufficient heat source an additional heat production system (e.g. a boiler) must be coupled to the GHP system.

In case of Ground Source Heat Pumps, two main types of ground heat exchangers exist: the vertical ground heat exchangers and horizontal ground ones. The installation costs of the horizontal boreholes are lower than vertical boreholes. However, in addition to their higher dependence to outdoor air conditions, the horizontal ground exchangers require a parcel of land which is 1.5 to 3.5 times greater than the building floor area, so that they are not very adapted to large buildings.
DX ground heat exchangers are not so popular, because of the leakage risks and are not used for large installation because of too important quantity of refrigerant which would be required.

1.2.2. Operating modes

Three operational modes are allowed, according to the building demand:

- Heating mode: the building side exchanger is used as condenser and the geothermal source provides the heat for the other exchanger, used as evaporator.

- Cooling mode: the building side exchanger works as evaporator, the other exchanger as condenser rejecting the heat in the geothermal sink by means of the water loop.
- Free-chilling mode: if there is an additional heat exchanger between the water loop and the building distribution system, the heat pump unit can be by-passed if the temperature level of the geothermal source is sufficient to provide the cooling demanded by the building.

1.2.3. Typical performances and working ranges

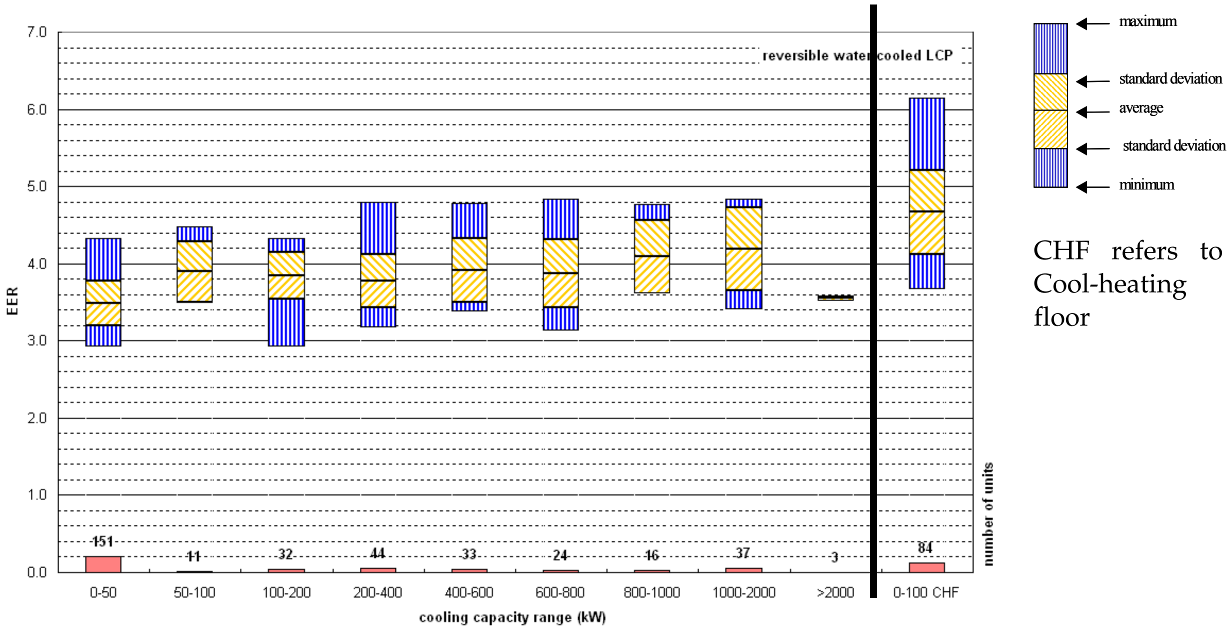
As for air-cooled chillers, typical nominal performances of water-cooled chillers can be found on the EUROVENT database.
EUROVENT defines the standard rating conditions for water-cooled chillers as reported in Table 6, for standard air-conditioning and cooling-heating floor water-cooled chillers.

Table 6: Standard rating conditions for water-cooled chiller (EUROVENT)

Application	**Temperature**			
	Cooling		**Heating**	
	Evaporator	Condenser	Condenser	Evaporator
Standard air-conditioning	12 / 7 °C	30 / 35 °C	40 / 45 °C	10 / * °C
Cooling/heating floor	23 / 18 °C	30 / 35 °C	30 / 35 °C	10 / * °C

* Measurement with the same water flow as in cooling mode

The certified values are the cooling and heating capacities, the EER and the COP at the rating conditions defined. Figure 12 and Figure 13 show the EER and COP of reversible water-to-water units in the EUROVENT database. Notice these values are for water and not for brine.



CHF refers to Cool-heating floor

Figure 12: Average EER of reversible water-to-water heat pumps by range of cooling capacity based on EUROVENT data 2005

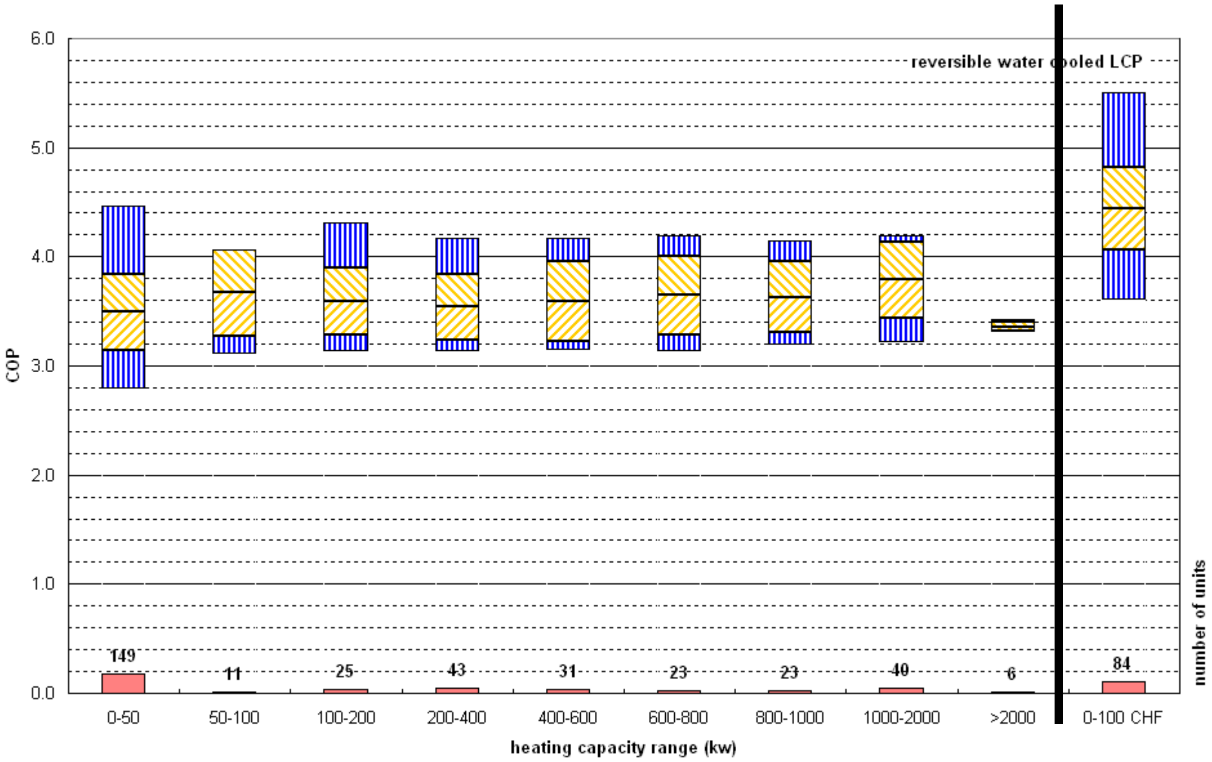


Figure 13: Average COP of reversible water-to-water heat pumps by range of heating capacity based on EUROVENT data 2005

Comparing Figure 13 and Figure 19 (section 2.1.3), it appears that reversible units have in average a bit lower EER than non reversible ones. On the other hand, as the units are coupled to a heat source characterized by a nearly constant temperature throughout the year, seasonal EER are generally higher than those of units coupled to a cooling tower (section 2.2). Use of free chilling can improve further the overall seasonal EER of the system.

Consequently, seasonal EER of this system can be expected to be higher than the corresponding SEER defined by EUROVENT (section 2.1.3). Despite that, EUROVENT does not define an alternative SEER definition for units destined to be coupled to ground or water source.

Similarly, seasonal COP is generally higher than the SCOP of reversible air-to-water units, as source temperature is more constant. Moreover, the unit can operate properly and with good performance even for low outdoor air temperatures, avoiding in most cases the necessity of a back-up boiler.

Particular attention must be paid to the additional electrical consumption due to water loop pumps. Indeed, system performance can be strongly improved by using variable speed pumps for the water loop and the distribution system.

1.2.4. Typical applications

Reversible geothermal heat pumps are generally well suitable for new buildings. Indeed, in renovation, it could be difficult to install the necessary underground exchangers.

As this kind of system do not generally allow heat recovery, the building should not have simultaneous heating and cooling demand, unless a back-up boiler or a second unit is installed for these situations.

For free chilling application, terminal units should operate with high distribution temperatures in cooling mode (e.g. radiant ceilings, chilled beams).

1.2.5. Advantages

- Low operation costs, as geothermal heat pump systems typically have lower energy and maintenance costs than outdoor air systems
- fairly constant temperature heat source/heat sink allow high heat pump performance
- No visible outdoor units and low noise
- Possibility of free chilling
- Various efficient and flexible hybrid systems can be built (e.g. GHP + boiler; GHP + cooling tower or dry fluid cooler, ...)

1.2.6. Drawbacks

- High installation cost
- Attention must be paid to the electrical consumption of pumps
- Surface and underground water sources are not largely available. In most countries, the use of underground water source is regulated
- Possibility of corrosion and fouling when dealing with geothermal waters
- Performance decreases when the geothermal source/sink temperature is too much disturbed by the presence of the heat exchangers or by the outdoor ambient temperature
- In case of ground source HP, the quality of the soil has a large influence on the performances of the system

1.3. Split and multi-split systems

1.3.1. System description, reversibility and recovery opportunities

Split systems are composed of a combination of an outdoor unit that contains the compressor, the outdoor air heat exchanger and the fan, and one or more indoor units that have the function of terminal distribution units. Different types of indoor units are proposed: floor standing units, ceiling-mounted units, cassette units. Each indoor unit is connected individually to the outdoor unit.

Mono-split systems (or mini-split) are the simplest type of split and are composed of one outdoor unit and one indoor unit and are generally suitable for room air conditioning.
Multi-split systems combine several indoor units connected to a single outdoor unit and are characterized by higher capacity and modularity. They have typically a maximum of 16 indoors units connected to each exterior unit.

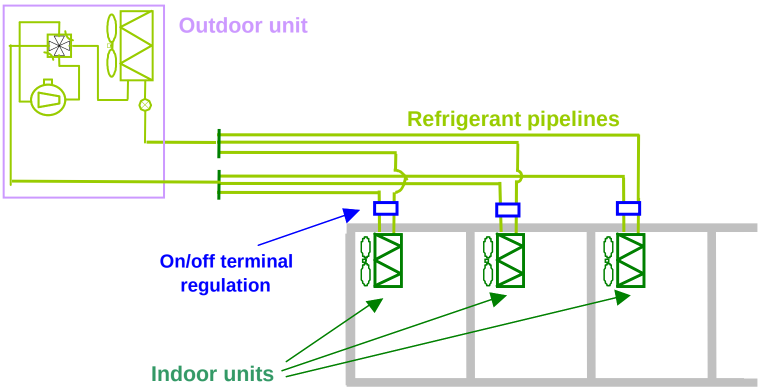


Figure 14: Multi-split system

Split systems are typically equipped with a central refrigerant changeover to switch from cooling mode to heating mode and vice-versa. In cooling mode, the outdoor unit works as a condenser and the indoor units as an evaporator, while in heating mode the functions are reversed. Ordinary split systems do not provide the ability to recover heat. Enhanced version of split systems (VRF), which allow heat recovery, are described in section 3.4.

Split systems do not provide ventilation, so a separate ventilation system is necessary.

1.3.2. Operating modes

Split systems can work in heating or cooling mode (Figure 15). The switch between operating modes is regulated by a central change-over located in the outdoor unit. The user has the possibility to regulate the indoor temperature of the room, usually by means of an ON/ OFF controller.

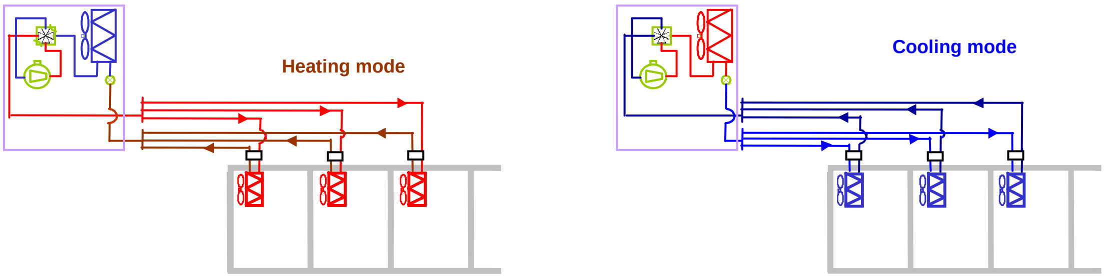


Figure 15: Operating modes of multi-split systems

In the basic version of split systems each outdoor unit is equipped of a unique compressor, with ON/OFF control, according to the cooling or heating demand.
However, today, even simple multi-split systems may be equipped with one or more compressors with electronic speed control, allowing a better part load performance.

1.3.3. *Typical performances and working ranges*

Typical size of split systems is in the range 1-12 kW; some models can reach 25 kW. The units are designed to work in heating mode even for very low temperatures, in order to avoid the necessity of a backup heating system.
EER and COP of split systems vary widely from manufacturer to manufacturer, depending on the type of technology adopted.
Nominal performances of split systems can be found on the EUROVENT database under the category "Comfort air conditioner". Standard rating conditions for this category defined by EUROVENT are reported in Table 7.

Table 7: Standard rating conditions for comfort air conditioners (EUROVENT)

	Indoor unit		**Outdoor unit**	
	Dry bulb	Wet bulb	Dry bulb	Wet bulb
Cooling	27 °C	19 °C	35 °C	24 °C
Heating	20 °C	15 °C	7 °C	6 °C

The certified values are the cooling and heating capacities, the EER and the COP at the rating conditions defined.
Typical values of COP at rating conditions range between 2.5 and 4.5, with an average value of about 3.5. The EER at rating conditions is between 2 and 4, with an average value of about 3 (EcoDesign, 2008).

Seasonal performance of the system depends strongly on part load performance and on control strategy.

1.3.4. *Typical applications*

Multi-split systems are usually installed in small buildings (typically less than 500 m^2). They are especially suitable in case of retrofitting, due to the small diameter of the refrigerant pipeline compared to water pipeline or to air duct.

1.3.5. *Advantages*

- Flexible and easy to install (adapted to retrofit)
- Compact and simple system
- Low installation cost

1.3.6. *Drawbacks*

- Limitation of the length of pipes (typically <50 m)
- Risk of leakage and problem of detection
- Indoor temperature fluctuations (with ON/OFF control)

1.4. Air-to-air dual duct heat pump

1.4.1. System description, reversibility and recovery opportunities

An air-to-air dual duct heat pump is a packaged system that can be used to heat or to cool the fresh air by recovering heat from the exhaust air.
The air-to-air heat pump plays the role of "active" heat recovery unit in a dual-duct balanced ventilation system.

The system is composed of three distinct sections:

- an indoor air section for the heating/cooling of the fresh air;
- an outdoor air section for the rejection/recovery of heat in the exhaust air;
- a control section housing compressors, control panel and automatic controls.

In heat pump mode, the unit recovers heat from the exhaust air to heat the fresh air.
In cooling mode, the fresh air is cooled and the heat is rejected on extraction side.

The fresh air fraction is controlled on both sides by two dampers. Units are also equipped with electrical heaters to ensure heating during defrosting cycles.

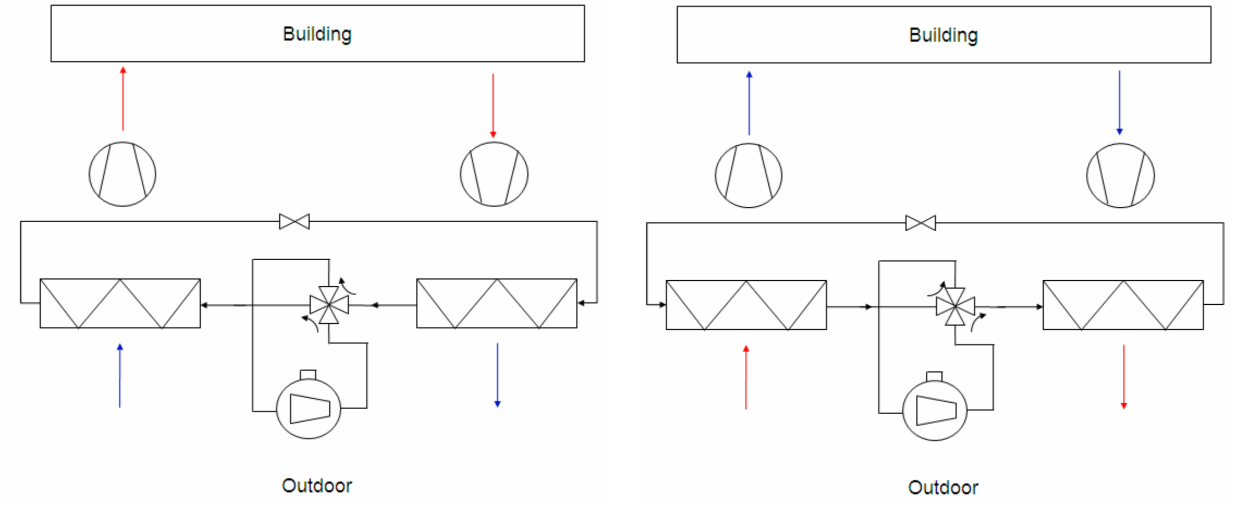


Figure 16: Air-to-Air Dual Duct Heat Pump (left: heating mode; right: cooling mode)

1.4.2. Operating modes

Three operating modes can be defined:

- Heating mode: the system heats the supply air. The exhaust air heat exchanger works as an evaporator.

- Cooling mode: the system cools the supply air. The exhaust air heat exchanger works as a condenser.

- Economizer (free cooling mode): ventilation only. The heat pump is switched off.

The system allows controlling the fresh air fraction, the supply airflow rate and the supply air temperature. Outdoor air can be mixed to exhaust air at the extraction side in order to increase the system capacity.

1.4.3. *Typical performance and working ranges*

Typically, units of this type are available for flow rates included between 5000 and 45000 m^3/h. The cooling and heating capacities are, respectively, 30 - 200kW and 30 – 230 kW. However, similar systems can be developed and adapted for larger scales.

In heating mode, the COP's announced by the manufacturer are quite high and can reach 5.5 in standard rating conditions (indoor DB/WB: 20°C/12°C and outdoor DB/WB: 7°C/6°C). These COP 's do not take into account the electrical consumptions of the supply and return fans. By taking the auxiliaries into account (supply and exhaust fans and control) the COP's decrease until around 3.5.

1.4.4. *Typical applications*

The system can be used as component of a complex air handling system, in substitution or in addition to a static heat recovery unit, in order to increase the exhaust air heat recovery.

1.4.5. *Advantages*

- Increased heat recovery from the extracted air with respect to static heat recovery units
- Compact factory-assembled packaged unit

1.4.6. *Drawbacks*

- Usually not sufficient to cover all the heating and cooling demand of an office building
- Additional pressure drop in the air handling unit and consequent fan consumption

1.5. Exhaust air heat pump system

1.5.1. System description, reversibility and recovery opportunities

Exhaust air is used as heat source in heating mode and as heat sink in cooling mode. The heat pump is not reversible but a changeover is made on the water circuit to allow heat pumping or heat rejection on the exhaust air side (Figure 17).

The exhaust ventilation air is an excellent heat source and also a fair heat sink for heat rejection. The use of an additional heat sink (cooling tower or secondary air-cooled condenser) is not always required.

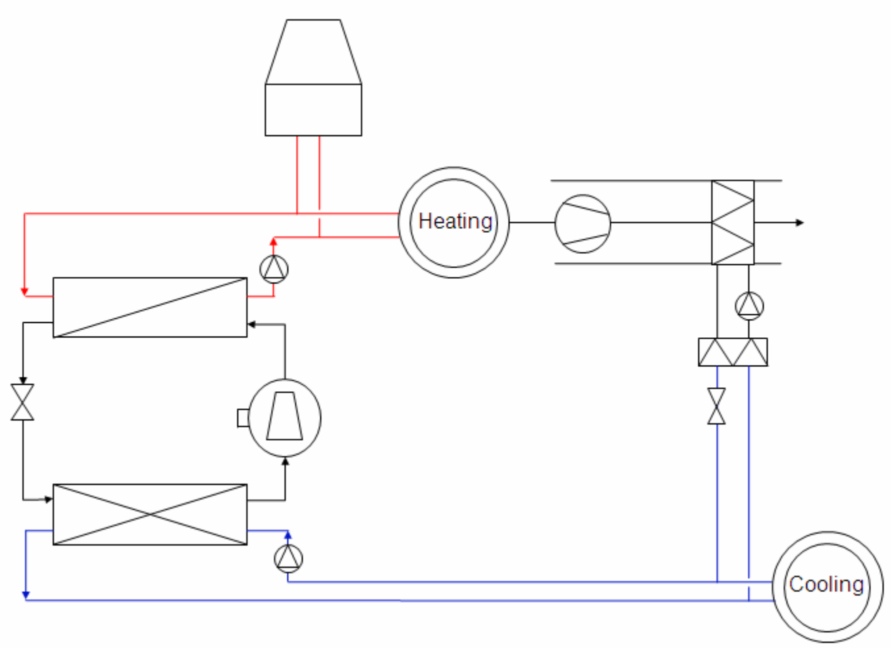


Figure 17: Use of ventilation exhaust air as heat source only

The heat recovery on ventilation exhaust air requires the use of classical air-water coils. These coils can be supplied by glycol water to prevent freezing when the ventilation is switched off. A classical plate heat exchanger can be used to couple the closed glycol loop to the water network(s). The coil must be designed to allow condensation and to work at very different temperature regimes if used as heat source and as heat sink.

In both cases, it must be noted that ventilation exhaust air is usually not a sufficient heat source to cover all the heating demand of the building. An additional heat source and/or a classical boiler have to be added to cover a larger part of the demand.

The coupling between an "active" heat pump and a "passive" heat recovery system (as cross-flow exchanger or glycol water recovery loop) has to be optimised to ensure complementary use between the two recovery systems.

The use of the heat sinks to reject excess heat should also be envisaged in this type of installation.

1.5.2. Operating modes

- Heating only: the water-heated evaporator is supplied with water heated in the heat-source air-water heat exchanger located on exhaust ducts. The heat pump is controlled to cover the heating demand of the building and the air-cooled condenser is not used.

- Cooling only: the water-heated evaporator ensures the production of chilled water. The air-cooled condenser is used to reject heat. The water-cooled condenser is not used.

- Cooling preponderant: the chilled water is produced on the evaporator side. The heat production is ensured by the water-cooled condenser and the air-cooled condenser rejects the excess heat.

- Heating preponderant: the water-cooled condenser ensures the production of heat. The air-cooled condenser is not used. The water-heated evaporator ensures the production of chilled water and is also supplied with water coming from the heat-source heat-exchanger to allow sufficient heat production.

1.5.3. Typical performance and working ranges

If coupled to an efficient water-to-water heat pump, the performances can be high. In both heating and cooling modes, the good and constant temperature level of the heat source allows good performance of the heat pump. Moreover, the use of larger heat transfer areas to heat the fresh air allows to work with low-temperature heating water and to increase the performance of the heat pump.

1.5.4. Typical applications

This system should be envisaged in the case of commercial or industrial buildings characterized by high ventilation rates.

1.5.5. Advantages

- Very constant temperature level of the heat source / heat sink
- Excellent availability and coincidence with needs of the heat source / sink
- Well adapted for retrofit if sufficient place

1.5.6. Drawbacks

- Limited capacity of the heat source and need of additional heat source or heat production system
- The addition of a supplemental coil in the return duct causes additional pressure drop on air side

2. Non-reversible systems with heat recovery

2.1. Water –cooled chiller with heat recovery

2.1.1. *System description, reversibility and heat recovery opportunities*

Water-to-water heat pumps are commonly used for cooling applications; they are coupled to cooling towers or to dry coolers for heat rejection. As these devices are generally not appropriate to be used as heat sources, water(cooling tower)-to-water heat pumps are usually not used in heating mode and are commonly referred to as water-cooled chillers.

Heat recovery is an attractive option for water-cooled chillers. Heat can be recovered by using a heat exchanger installed in the hot water loop or directly in the refrigerant loop. Therefore, this kind of system can produce heating and cooling simultaneously (Figure 18).

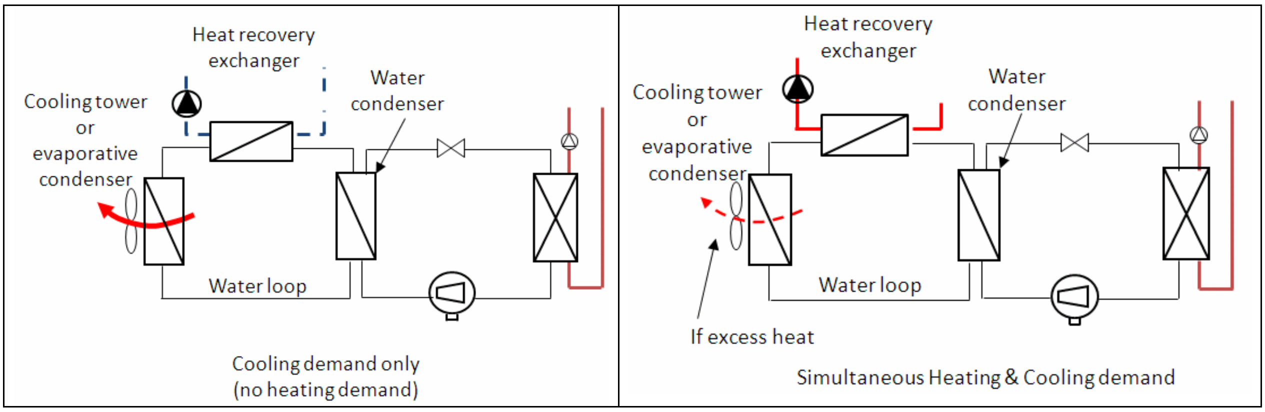


Figure 18: Water-cooled chiller with additional heat recovery exchanger in the water loop

As the heat pump can produce hot water only, when cooling power is required, a boiler is also required to:

- Cover the heating demand, when there is no cooling demand;
- Cover the peak heating demand;
- Raise the hot water temperature, if the hot emission terminal units need a temperature level higher than achievable by the heat recovery exchanger (typically 35 - 40° C).

2.1.2. *Operating modes*

The chiller is controlled in function of the cooling demand of the building.
The condenser heating power is partly transmitted to the heat recovery exchanger ,according to the heating demand, and partly dissipated by the cooling tower.

2.1.3. *Typical performances and working ranges*

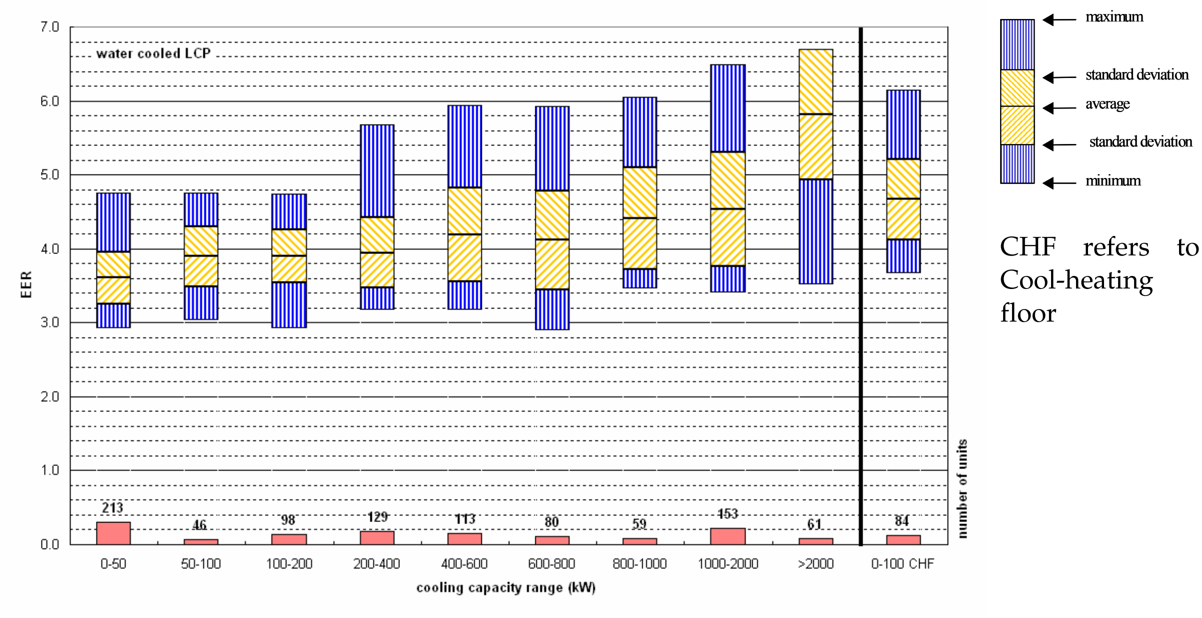
EUROVENT standard rating conditions are reported in Table 8, for standard air-conditioning and cooling-heating floor systems.

Table 8: Standard rating conditions for water-cooled chiller (EUROVENT)

Application	Temperature	
	Cooling	
	Evaporator	Condenser
Standard air-conditioning	12 / 7 °C	30 / 35 °C
Cool-heating floor	23 / 18 °C	30 / 35 °C

EUROVENT does not take the electrical consumption of the circulation pumps into account in the calculation of the EER and the COP at rating conditions.

The certified values are the cooling capacities and the EER at the rating conditions. Average EER at rating conditions of water-cooled chillers are summarized in Figure 19.



CHF refers to Cool-heating floor

Figure 19: **EER of water-cooled chillers by range of cooling capacity based on EUROVENT data 2005**

Water-cooled chillers show better performances than air-cooled ones. The average values of EER at rating conditions of EUROVENT certified water-cooled chillers, excluding CHF, lie between 3.6 and 4.6, according to the cooling capacity range.

Also for water-cooled chillers, EUROVENT has proposed a seasonal cooling index, the ESEER (European Seasonal Energy Efficiency Ratio). The method is the same as for air-cooled chillers, except the definition of the test temperatures.

The ESEER is calculated on the base of four working points, as follows:

$$ESEER = A \cdot EER_{100\%} + B \cdot EER_{75\%} + C \cdot EER_{50\%} + D \cdot EER_{25\%}$$

Table 9 shows the test conditions of the four working points and the weight coefficients defined for the water-cooled units.

Table 9: Test conditions and weight coefficients for ESEER definition

Part load ratio	Cooling water temperature (°C)	Distribution water temperature (°C)	Weight coefficient:
100%	30	7	A = 0,03
75%	26	7	B = 0,33
50%	22	7	C = 0,41
25%	18	7	D = 0,23

Figure 20 shows that, for a given EER, they are some differences of ESEER between products. The choice of the chiller should be preferably done based on ESEER since it is more representative of the real performance of the chiller on a whole year.

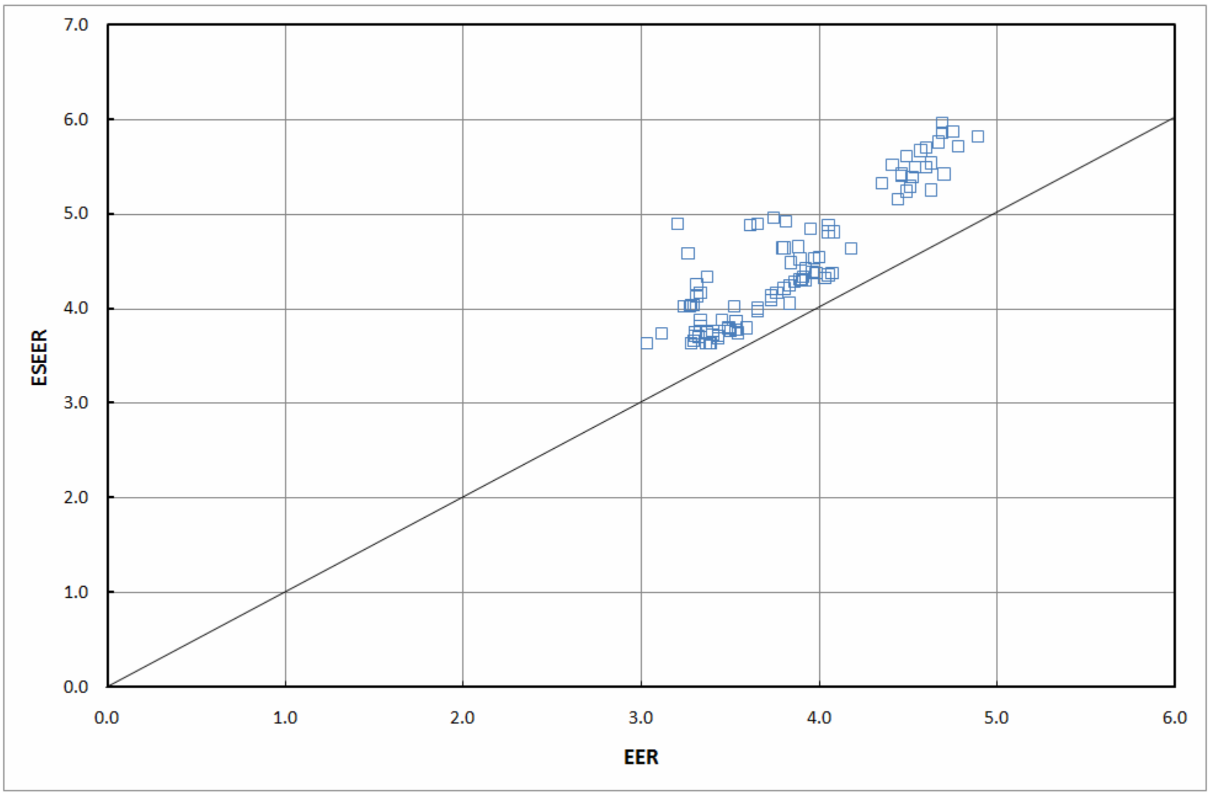


Figure 20: ESEER versus EER for reversible water-cooled chiller from EUROVENT data (2008)

2.1.4. *Typical applications*

Typically, a water-cooled chiller with heat recovery is an interesting option in the following applications:

- when there is a significant heating demand all along the year (domestic hot water production);
- when there is a significant cooling demand all along the year (data centers).

However, in most of European office buildings, there is too little simultaneity in heating and cooling demands to make attractive the condenser heat recovery.
Only some large office buildings with core zones surrounded by peripheral zones, may present a significant simultaneity in heating and cooling demands.

2.1.5. *Advantages*

- Large offer of packaged water-to-water units
- Higher EER than air-cooled units
- Possibility to produce simultaneously sanitary hot water and ambient cooling

2.1.6. *Drawbacks*

- No heating power is produced if there is no cooling demand, so that an auxiliary boiler must always be installed
- Risk of legionella and noise related to the use of the (wet) cooling towers

2.2. Dual condenser chiller

2.2.1. *System description, reversibility and recovery opportunities*

A double-bundle chiller is equipped with two independent water/refrigerant condensing circuits. One of the circuits is connected to the hot water network while the other one is connected to a heat rejection system. Therefore, simultaneous heating and cooling production is possible. This is a rather old and classical solution, but less used today, due to the use of new refrigerants.

The dual-condenser chiller consists in a chiller equipped with two independent condenser shells (one air-cooled condenser and one water-cooled condenser, or two water-cooled condensers). Both condensers are usually sized at nominal power.

When both condensers are connected in series, the recovery condenser is used as a de-superheater in order to provide a limited thermal power, but at high temperature.
When both condensers are connected in parallel, the heat output of the chiller can be freely distributed between the two heat exchangers.

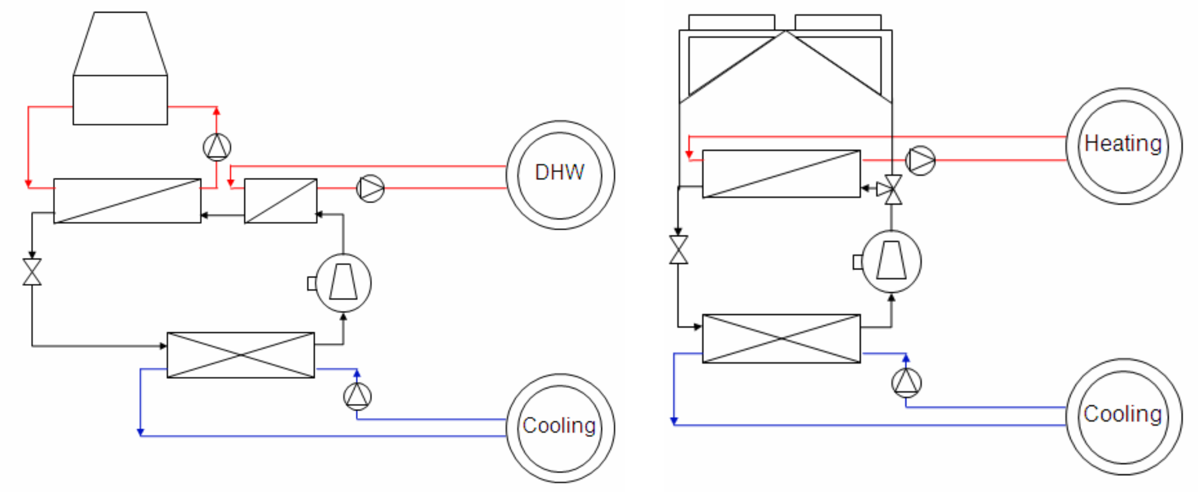


Figure 21: Series dual condenser chiller (left) and Parallel dual condenser chiller (right)

2.2.2. *Operating modes*

In case of condensers installed in parallel, the dual condenser chiller is controlled according to the chilled water demand. On the condenser side, a three-way control valve makes more or less water circulating through the water-condenser according to the heating demand, resulting in three operating modes:

- Total heat recovery: the heating demand is high and the refrigerant vapour is cooled in the heat recovery water-condenser. The secondary condenser pump/fan is stopped. The overall efficiency of the chiller is improved (better sub-cooling).

- Partial heat recovery: the heating demand is low and so only one part of the refrigerant vapour is condensed in the water cooled condenser. The condensation is completed in the secondary condenser.

- No heat recovery: the heating demand is null. The chiller operates classically. The heat rejection condenser evacuates all the heat produced by the chiller.

2.2.3. *Typical performance and working ranges*

The performances are similar to those of air-to-water heat pumps when they operate in cooling mode without recovery. In heat recovery mode, the performances of the unit with parallel condensers decrease because of the higher condensing temperature. In the case of condensers connected in series, performances stay quite constant, since the heat recovery condenser is used as desuperheater only. Since this system is adapted to heat recovery, its global seasonal performance is better when there is a significant simultaneity between heating and cooling demands.

2.2.4. *Typical applications*

Buildings with high simultaneity of heating and cooling demands and 4-pipe distribution network are appropriate. Data centers, buildings with high hot domestic water demand (hotels, health care institutions) and industrial buildings with cooling process offer the most attractive opportunities.

2.2.5. *Advantages*

- Low investment over-costs
- Quite simple installation in retrofitted buildings
- High performances achievable
- Possibility to produce sanitary hot water
- Increasing offer on the market

2.2.6. *Drawback*

- The control of the parallel condensers heat pump is more complex (distribution of the load among the two condensers)

2.3. Templifier

2.3.1. *System description, reversibility and recovery opportunities*

A templifier (temperature amplifier) is a non-reversible water-to-water heat pump which turns waste heat from a low temperature source into useful heat (Figure 22). For instance, the templifier can be connected to a water-cooled chiller in order to rise the temperature of the heat rejected from the condenser. The templifier makes possible using that heat for space heating or for production of sanitary hot water. Temperatures up to 70°C can be reached if necessary.

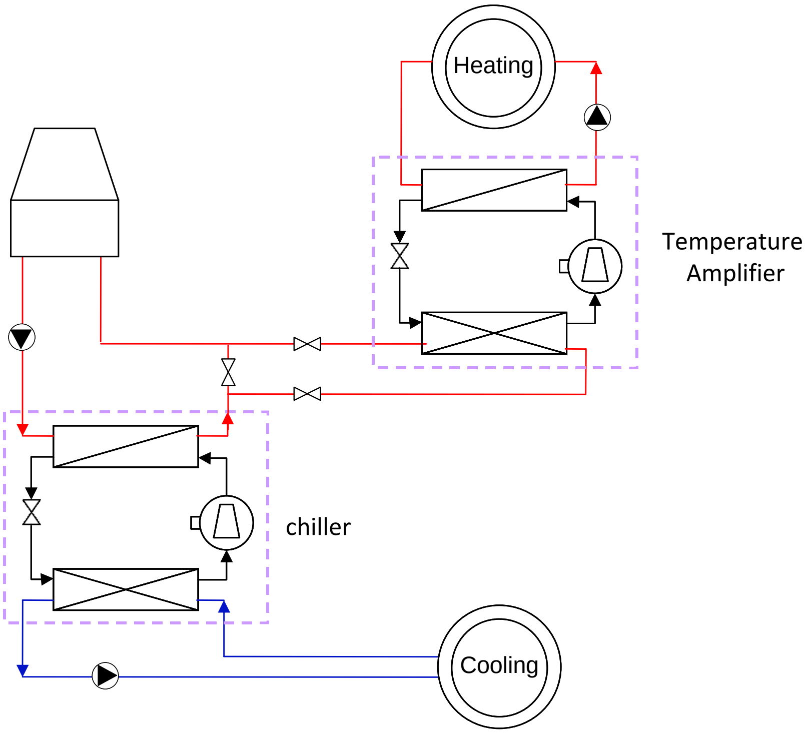


Figure 22: temperature amplifier

2.3.2. *Operating modes*

The operation of the templifier depends on the availability of the warm source and on the heating demand.
For space heating applications, a temperature sensor is usually located in the water circuit at condenser supply.
The water supply temperature is held constant and the exhaust temperature floats with the load. Thus, at low loads, the exhaust water temperature is lowered and the head imposed on the compressor is minimized. This maximizes the unit COP.
The capacity of the templifier must be controlled in part load in order to maintain high enough its evaporation temperature. An auxiliary heater is then required to maintain the temperature of hot water distribution.

2.3.3. *Typical performance and working ranges*

Performances are generally satisfactory…
The heating capacity ranges between 150 and 7000 kW.

2.3.4. *Typical applications*

A templifier can be connected to different warm sources such as cooling towers, solar collectors, groundwater.

This system can be installed in buildings with Space heating or/and Hot domestic Water demands and with long cooling season. High simultaneity between cooling and heating demands is required.

2.3.5. *Advantages*

- Quite simple installation in retrofitted buildings
- Warm source water temperatures to maximize the COP
- Possibility to produce domestic hot water

2.3.6. *Drawbacks*

- Long cooling season and high cooling internal loads are required
- Investment costs

3. Reversible systems with heat recovery

3.1. Reversible water/air-to-water heat pump

3.1.1. *System description, reversibility and recovery opportunities*

A reversible water/air-to-water heat pump is essentially a dual condenser chiller (section 2.2) with a refrigerant changeover to reverse the cycle. Therefore, both reversibility and heat recovery are possible.

When there is only heating (or cooling) demand, the water exchanger does not work and outdoor air is used as heat source (sink), as in a traditional air-to-water heat pump.
On the contrary, in case of simultaneous heating and cooling demands, one water exchanger works as evaporator, providing hot water, and the other as condenser, cooling the chilled water. The air exchanger absorbs or rejects heat in order to balance the system.

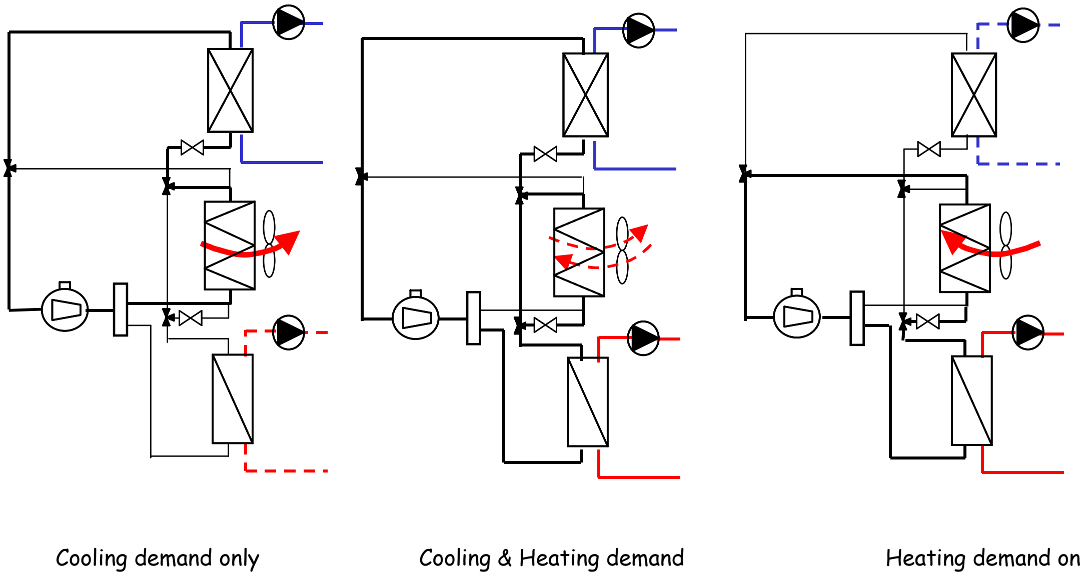


Figure 23: Modes of operation of a water/air –to-water heat pump

Reversible water/air-to-water heat pump is a relatively new concept that needs still some development to be reliably used.

There are few manufacturers that propose water/air-to-water heat pumps, due to the difficulties to provide a reliable control at part load.

3.1.2. *Operating modes*

1. Cooling only: the water evaporator is used to cool the chilled water. The air-cooled condenser is used to reject heat, as in air-cooled chiller
2. Heating only: the system produces hot water only, the refrigerant evaporation occurs in the outside coils as with an air-to-water heat pump
3. Heating and cooling balanced: the system produces hot and cold water simultaneously, the outside coils are not used
4. Cooling preponderant: the system produces cold water, the refrigerant condensation occurs alternatively in the water condenser and in the outside coil (modes 1 and 3)

5. Heating preponderant: the system produces hot water, the refrigerant evaporation occurs alternatively in the water evaporator and in the outside coil (modes 2 and 3)

6. Defrosting: the cycle is usually reversed in mode 1 to defrost the outside coil with a given periodicity

3.1.3. Typical performance and working ranges

The performance are similar to those of air-to-water heat pumps when they operate in cooling or heating only. According to simulations related to a case study in France [BYR 2009], the system performance is enhanced when there is heating and cooling demands simultaneously and optimal when the heating and cooling demands are balanced. A storage system enables to increase the simultaneous production time and thus the overall performance

3.1.4. Typical applications

Buildings with quite high simultaneity of heating and cooling demands such as glass fronted office buildings or hotels (high domestic hot water consumptions) and 4-pipe distribution network are adapted.

3.1.5. Advantages

- Heat source/sink available everywhere
- Combination of heat recovery and reversibility
- Flexibility to cover a large variety of loading profiles
- Possibility to provide heating and cooling alternatively or simultaneously
- Potential high performance and consequent low operation costs
- No need of an auxiliary heating generator if the system is correctly sized
- Very interesting system when there is large and constant domestic hot water demand all along the year (for example hotels or health care institutions)

3.1.6. Drawbacks

- Plant complexity
- Not fully mature technology
- Necessity of a relatively sophisticated control system
- Problems of operation at part load (dysfunctions)

3.2. Reversible geothermal heat pump system with heat recovery

3.2.1. *System description, reversibility and recovery opportunities*

A reversible geothermal heat pump system with heat recovery is an enhanced and flexible system for the alternative and simultaneous heating and cooling production.

The system is composed of a non-reversible water-to-water heat pump (water-cooled chiller), connected to the two branches of a four-pipe distribution system: the condenser is connected to the hot water pipe system and the evaporator to the cold water pipe system.
An additional water loop connects the two distribution systems to a heat exchanger, through which the excess of cooling or heating power is evacuated to the geothermal heat sink / source.
This is possible for instance if the temperature range of the geothermal source is in the range 12 – 30 °C, for a distribution system working with typical temperature levels of 7/12 °C and 35/30 °C.

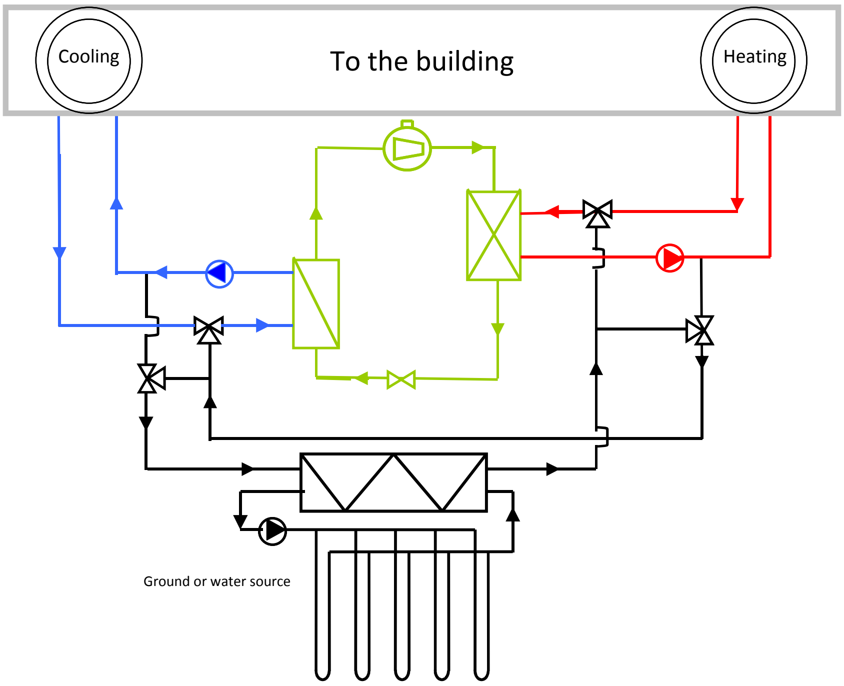


Figure 24: Principle of operation of reversible geothermal heat pump system with heat recovery

The geothermal heat exchanger can be of any type presented in section 1.2 and 1.3.

If the temperature of the geothermal source is sufficiently low, and if there is no heating demand, it is always possible to make such system working in free-chilling mode by bypassing the heat pump unit.

If the difference between the hot water and the cold water return temperatures is small (e.g. 5-10 °C), the four-pipe distribution system can be replaced by a three-pipe one, collecting the return hot and cold water in the same pipe and consequently reducing the complexity and the cost of the installation.

Cold and hot thermal storages can be added to the system.

3.2.2. *Operating modes*

Six operating modes can be distinguished:

1) *Heating only:* The system works in this mode when there is no cooling demand. The heat pump is controlled in order to cover the heating demand, and the geothermal source is used as heat source.

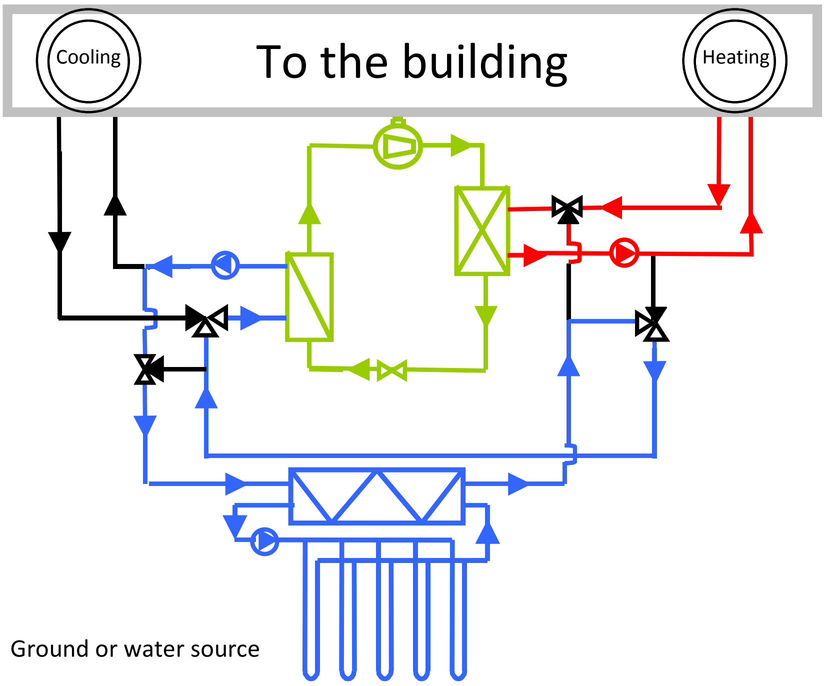


Figure 25: Reversible geothermal heat pump system with heat recovery: heating only operation

2) *Cooling only:* The system works in this mode when there is no heating demand. The control is achieved in order to cover the cooling demand and the geothermal source is used as heat sink.

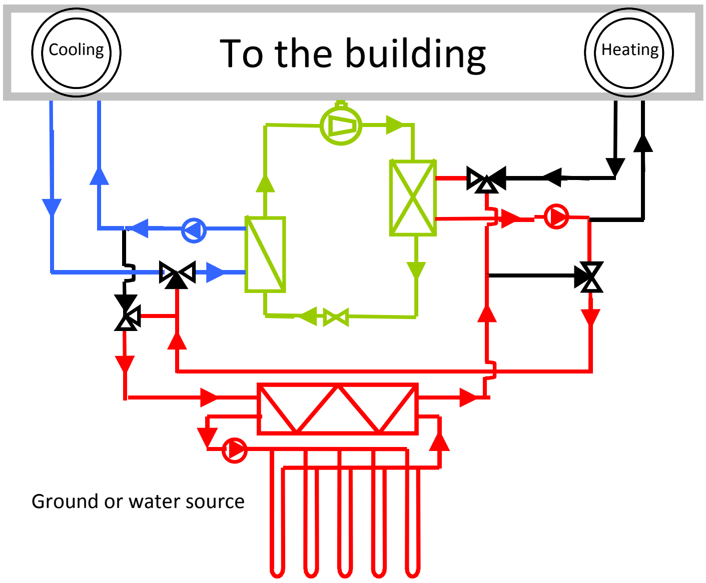


Figure 26: Reversible geothermal heat pump system with heat recovery: cooling only operation

3) *Free-chilling mode*: If there is only cooling demand, the heat pump unit can be by-passed if the temperature of the geothermal source is low enough to provide the cooling demanded by the building.

4) *Dominant heating demand:* The heating demand is predominant over the cooling demand.

5) *Cooling major:* The cooling demand is predominant over the heating demand.

6) *System balanced:* The cooling demand and the heating demand correspond exactly to the cooling and heating capacity available at the evaporator and the condenser respectively. In

this situation, the water body is not used, neither as heat sink nor as heat source. This operating mode is an ideal (and exceptional) limit between the mode 4 and 5.

3.2.3. Typical performance and working ranges

Water-cooled chiller performance is presented in section 2.1.3.

In comparison with a traditional water-cooled chiller coupled with a cooling tower, this system takes advantage of the relatively constant temperature of the water source compared to air, which allows better performance of the heat pump in both summer and winter seasons.

Additionally, as the system can satisfy virtually any combination of cooling and heating loads, the performance are particularly emphasised in the case of simultaneous heating and cooling demands (mode 4 and 5), and the overall coefficient of performance is higher than that one at rating conditions.

The peak of performance is reached in condition of thermal equilibrium of the system (mode 6). The overall COP, accounting both heating and cooling outputs, can theoretically reach up to more than two times the EER for cooling only.

Evidently, the seasonal COP value of the installation is much lower, and depends strongly on the load profile type (number of hours of simultaneity) and on the part load performance of the heat pump.

As this kind of system requires at least three autonomous water loops, electrical consumption for water pumping can represent a large part of the overall plant consumption. For a case study in France [NAV, 2007], the circulation pump consumption represented about 10 to 14% of the energy consumption, while heat pump consumptions represented about 24% to 28%. The use of variable speed circulation pumps can reduce the energy consumption.

3.2.4. Typical applications

Reversible geothermal systems with heat recovery are very advantageous when heating and cooling demands are often simultaneous. On the contrary, if the heating and cooling demands are seldom simultaneous, a reversible geothermal heat pump without heat recovery can be generally installed, reducing plant complexity and cost.

3.2.5. Advantages

- Flexibility to cover a large variety of loading profiles
- Possibility to provide heating and cooling alternatively or simultaneously
- Potential high performance and consequent low operation costs
- No need of an auxiliary heating generator if the system is correctly sized
- Very interesting system when there is large and constant domestic hot water demand all along the year (for example health care institutions)
- No visible outdoor unit
- Possibility of free chilling

3.2.6. Drawbacks

- Plant complexity
- High installation cost
- Surface and underground water bodies are not largely available. In most countries, the use of underground water source is regulated
- Attention must be paid to the electrical consumption of the circulation pumps
- Possibility of corrosion and fouling when dealing with geothermal waters
- Necessity of a relatively sophisticated control system
- In case of ground source, the quality of the soil has a large influence on the performances of the system

3.3. Water loop heat pump system

3.3.1. System description, reversibility and heat recovery opportunities

A water loop heat pump system is composed of several reversible water-to-air heat pump units, each serving a zone, connected to a closed water loop circulating throughout the building. Each heat pump unit uses the water loop as heat source/sink, rejecting or absorbing heat from it.

The water loop is maintained at a "neutral" temperature level, e.g. between 15 and 30°C, by means of a central heat source / sink. The central heat source is typically a boiler, while the central heat sink is typically a cooling tower. However, if possible, a geothermal loop field can be used as heat source and heat sink. Additionally, a central thermal storage system can be added to the system.

The basic water-loop heat pump system configuration is shown in Figure 27. The water-to-air heat pump units are used and controlled by their own thermostats as terminal units.

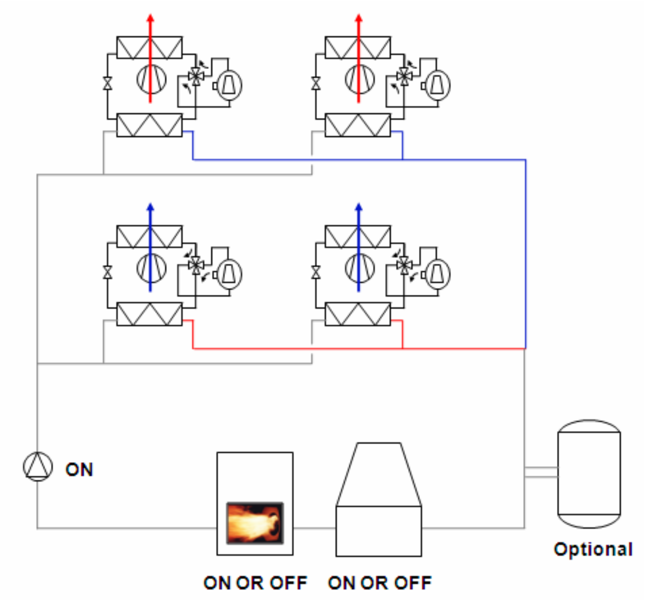


Figure 27: Closed water loop system

Hybrid configurations combining ground heat exchangers with classical heat source (boiler) and heat rejector (cooling tower or dry fluid cooler) are also studied and allow optimizing the sizing of the ground heat exchangers [HUG, 1990].

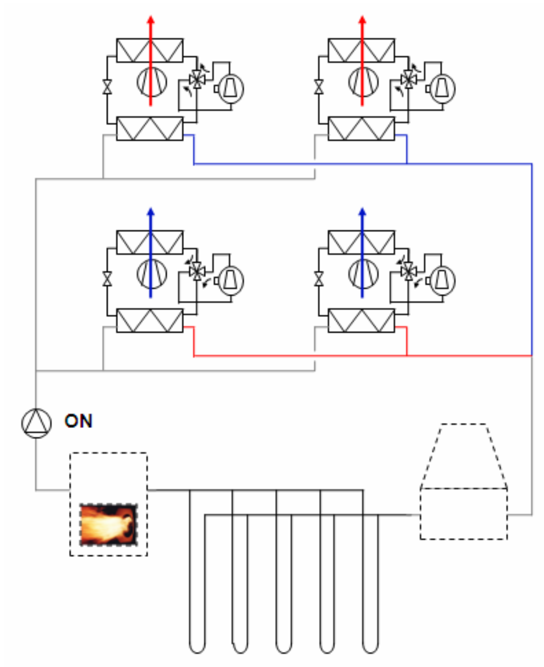


Figure 28: Hybrid Water Loop Heat Pump system

3.3.2. *Operating modes*

Closed-loop water source systems can operate in three modes depending on the building energy demand:

- In cooling mode (Figure 29), the system extracts heat from the indoor air in both core and peripheral zones. Since there is no heating demand in the building, the heat is rejected out of the building via a cooling tower or a dry cooler.

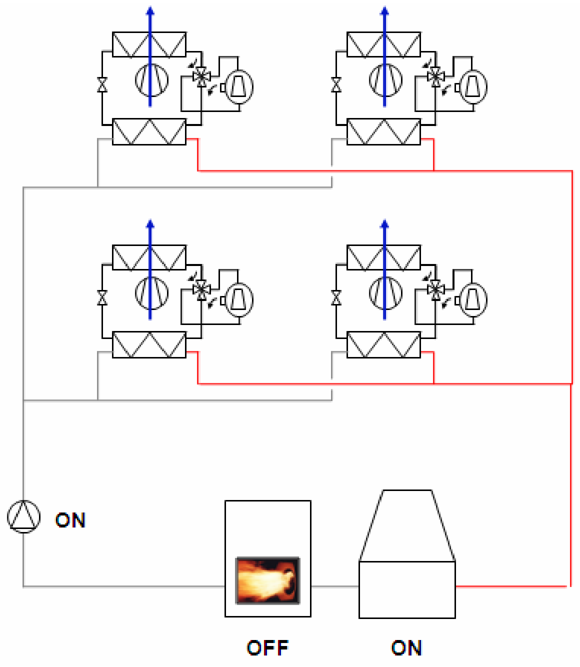


Figure 29: Closed water loop system - Cooling mode

- In heating mode, the system extracts heat from the low temperature water loop and injects it in the zones. A heater (fuel oil/gas/electric boiler or an air-to-water HP or GSHP…) provides the loop with heat in order to maintain the temperature in the loop. When both heating and cooling demands are well balanced, an electric boiler can be envisaged to reduce investment costs. This solution is economical only if the heater works only a few hours per year.

- For simultaneous heat and cold production, the water-air heat pump units extract heat from the zones where cooling is required (core zones) and inject it in the closed water loop. The heat is then extracted from the water loop by the heat pump units located in the zones where heating is required (peripheral zones). The water loop temperature stays quite constant if the heating and cooling zones are balanced. If not, the heat source or the heat rejector must be used to balance the system. Additional central heat storage can avoid the necessity of heat production or rejection even if the heating and cooling demands do not match perfectly.

3.3.3. *Typical performance and working ranges*

The low and constant level of temperature of the water loop ensures high COP to the heat pump units. Special attention must be paid to the electricity consumption of the auxiliaries (water loop pump and heat pump fans).

3.3.4. *Typical applications*

The water loop based system is well adapted to large buildings characterized by simultaneous and equivalent heating and cooling demands, i.e. buildings composed of “hot” core zones and “cold” peripheral zones.
The system is not interesting if a large amount of heat has to be rejected from or injected into the loop.

3.3.5. *Advantages*

- Individual room or zone control
- Heat and cold are provided exactly where and when required
- Easy maintenance
- High performance and subsequent low running cost, especially if coupled to a thermal storage systems and/or a geothermal source
- As the water loop is at a “neutral” temperature, pipe insulation is generally not necessary

3.3.6. *Drawbacks*

- High installation cost
- Not adapted to small office buildings
- Efficient only if large simultaneity of heating and cooling demands
- Attention to the circulating pump consumption

3.4. Variable Refrigerant Flow (VRF) systems

3.4.1. System description, reversibility and recovery opportunities

On the contrary of multipslit systems, where each inside unit is connected to the single outside unit individually, in VRF systems, inside units are connected to a refrigerant network and this system is typically a built-on-site system meaning design is adapted to every single building.
The term VRF refers to the ability of the system to control the amount of refrigerant flowing to each evaporator and to each condensor, enabling individualized comfort control, simultaneous heating and cooling in different zones, and heat recovery from one zone to another one.

VRF systems indoor units are connected to a 2-pipe or 3-pipe refrigerant network adapted to the building.

A two-pipe arrangement (Figure 30) generally permits heating in all of the indoor units or cooling in all the units similarly to multi-split systems. However, one manufacturer proposes a two-pipe system than can be used to provide simultaneous heating and cooling as well as heat recovery operations.

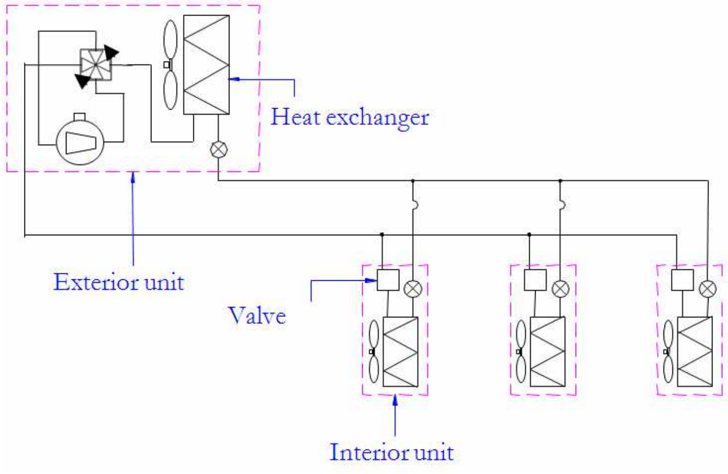


Figure 30: Two-pipe VRF system

More commonly, a heat-recovery VRF system is realized with a three-pipe distribution (Figure 31).

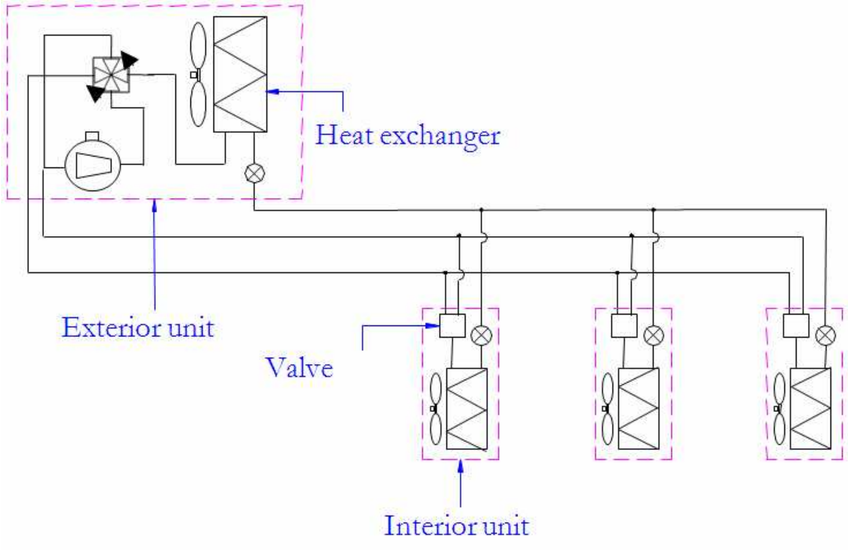


Figure 31: Three-pipe VRF system

Each external unit can be connected to up to 16 or 64 internal units, depending on manufacturer. The pipe length from the external unit to the internal units is limited (up to 400 meters in the best cases).

VRF systems are traditionally air-cooled. Consequently, external units have to be installed outdoor, so that the restrictions on refrigerant pipeline impose high pressure drops and design limitations. However, some manufacturers have recently proposed water-cooled VRF.

As multi-split systems, VRF systems do not provide ventilation; a separate ventilation system is necessary.

At the present time, the VRF market is rapidly increasing in Europe. Almost all the main air-conditioning equipment manufacturers have at least one VRF system in their catalogue. Therefore, there is a very large offer of VRF systems, making use of different technologies and with different degrees of complexity.

3.4.2. *Operating modes*

An inverter commanding the compressor and an electronically expansion valve continuously adjusts the flow of refrigerant to match to the load requirements of the indoor units.

There are basically four working modes:

- ➢ Cooling mode only: all indoor units work in cooling mode (Figure 32)
- ➢ Heating mode only: all outdoors units work in heating mode (Figure 33);
- ➢ Heat recovery mode with cooling demand > heating demand (Figure 34);
- ➢ Heat recovery mode with cooling demand < heating demand (Figure 35).
- ➢ Heat recovery mode with cooling demand = heating demand (Figure 36)

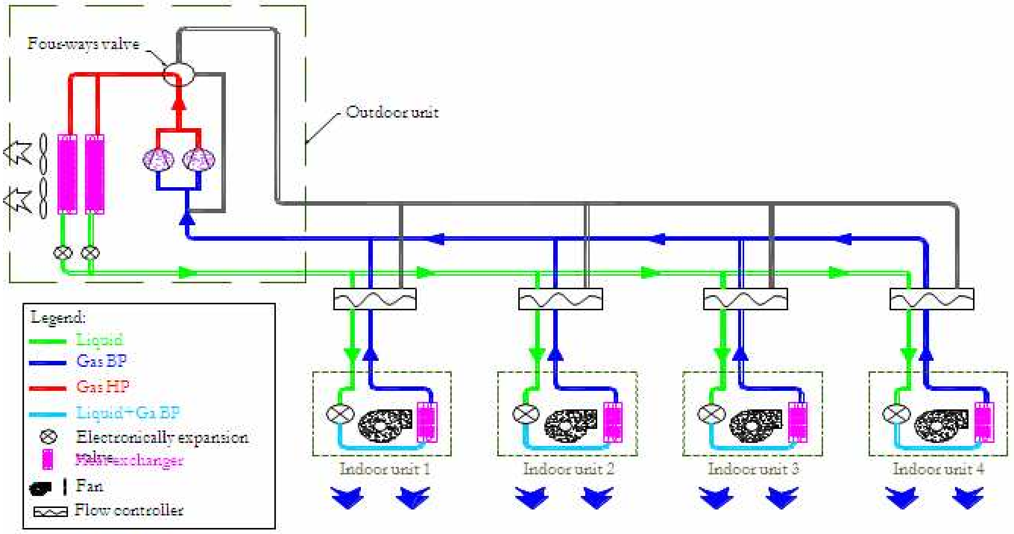


Figure 32: VRF system three-pipe, cooling mode only.

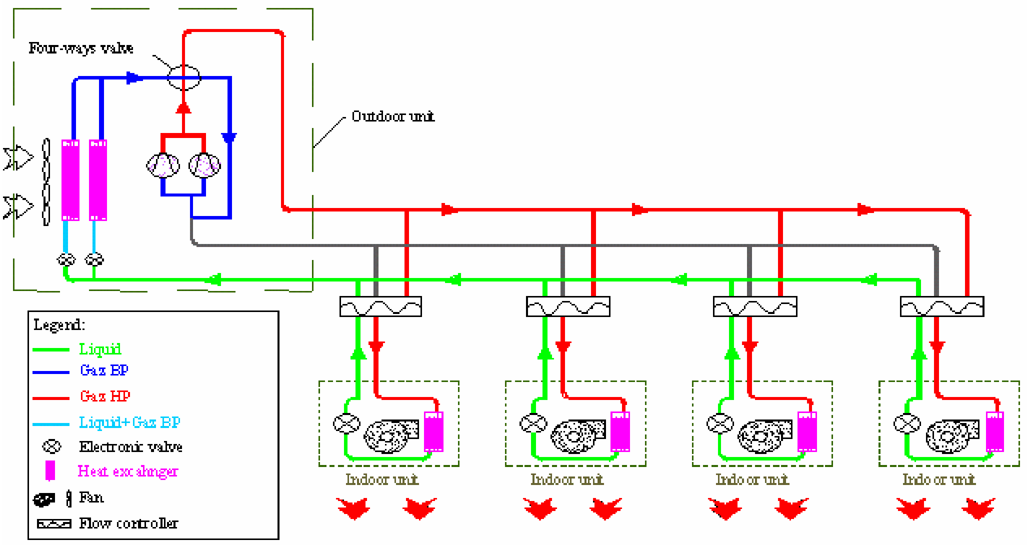


Figure 33: VRF system three-pipe, heating mode only.

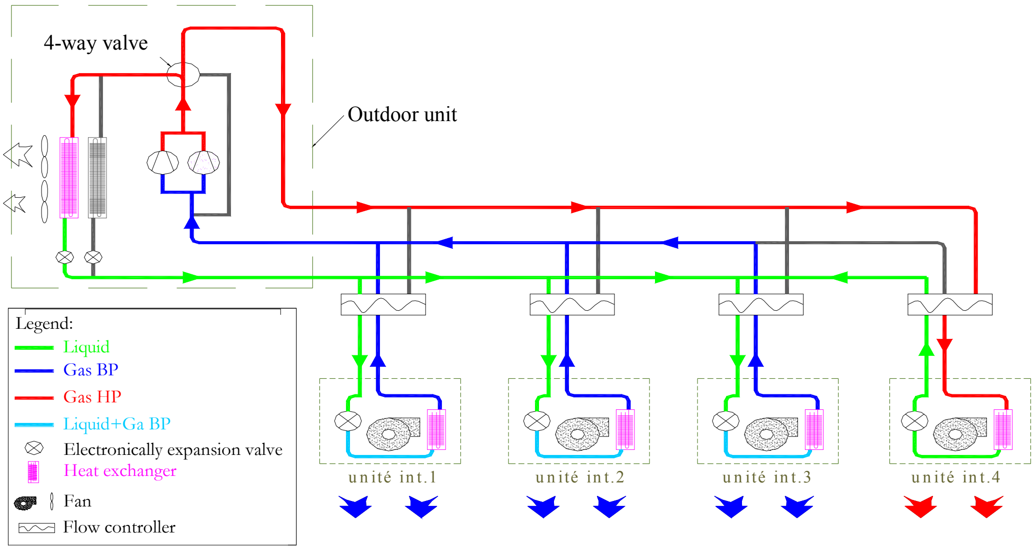


Figure 34: VRF system three-pipe, heat recovery mode (cooling > heating).

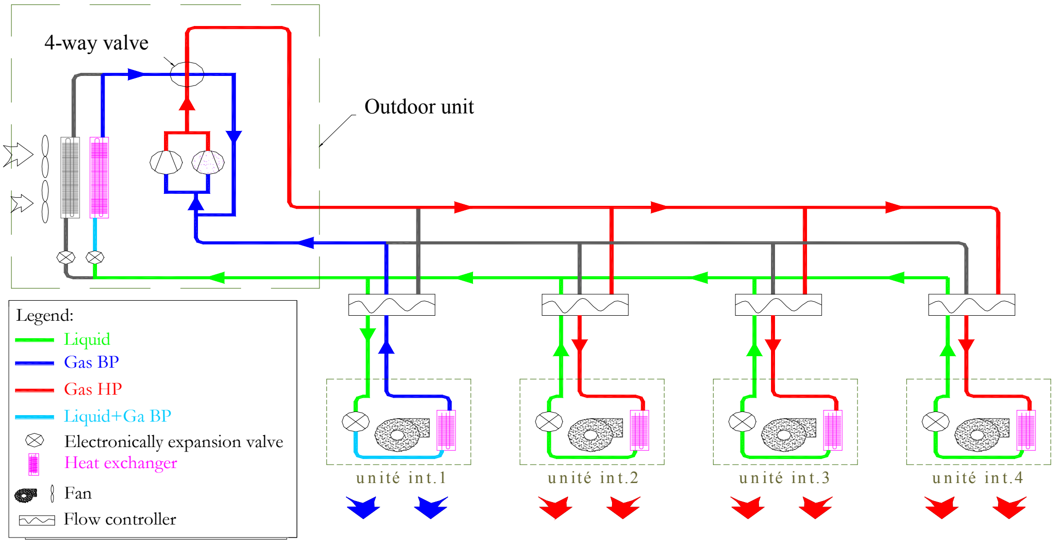


Figure 35: VRF system three-pipe, heat recovery mode (cooling < heating demand).

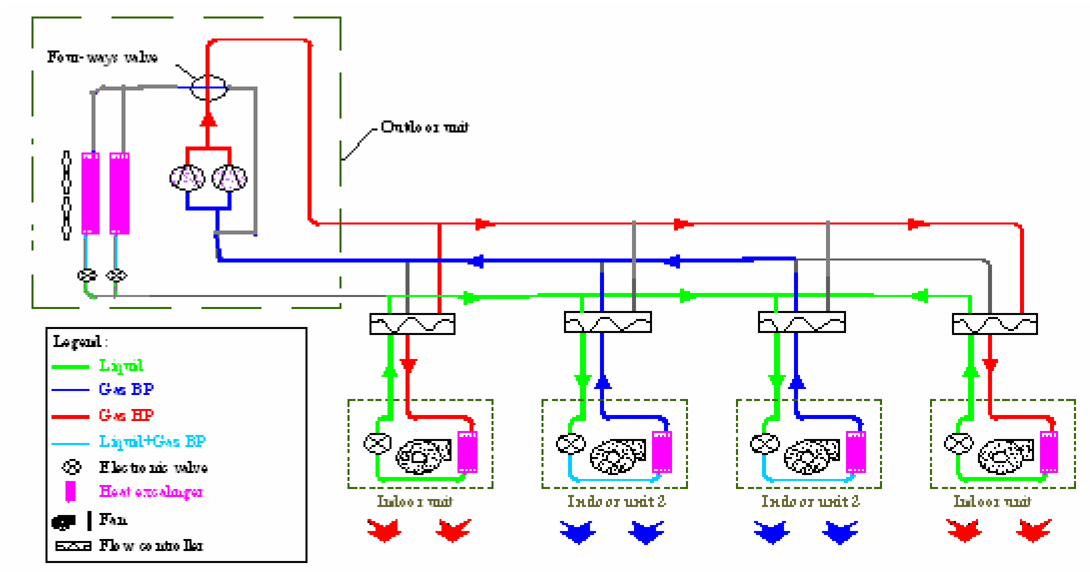


Figure 36: VRF system three-pipe, heat recovery mode (cooling and heating balanced).

3.4.3. *Typical performances and working ranges*

As VRF are typically built-on-site systems, the capacity and the performance vary widely from installation to installation, depending on the system configuration and piping arrangement.

Typically, the system capacity can reach 100 - 150kW.

Manufacturers usually provide information about COP and EER in their catalogues, but their values are not certified by EUROVENT, which has not yet defined a category for this kind of systems.

According to manufacturers catalogues, Variable Refrigerant Flow systems offer good rating EER and COP (between 3 and 5 in the standard conditions defined by EUROVENT for comfort air conditioners, see section 1.3.3). Moreover, the inverter technology, the use of multiple compressors and the electronic control should permit good performance even at very low loads.

Consequently, good seasonal efficiencies are expected from this kind of systems.

A good control strategy is pretty important for the good performance of VRF systems. For the outdoor unit, variable-capacity control is applied.

The commonly employed capacity control methods for compressor are: multiple compressor, and variable speed.

As for the control of indoor unit, two different methods are usually used to adapt the thermal capacity of each indoor unit to the cooling/heating demand.

Using cooling condition as an example :

1) ON/OFF operation of each indoor unit (by fully closing the expansion valve), maintaining a same superheating in ON periods. This control can be very easily realized: the expansion valve maintains the constant superheating at the exhaust of the indoor unit, until the room temperature reaches the lower limit of the control band; then the system closes the expansion valve. The disadvantages of this kind of control are fluctuations of the room temperature (which may affect the comfort) and fluctuations in refrigerant mass flow rate, which may affect the compressor performances.

2) Continuous adaptation of the heat transfer coefficient (AU) of the indoor unit. In this second control strategy, each expansion valve is adjusted to distribute the suitable refrigerant mass flow rate to each indoor unit, in order to fulfill the cooling demand (maintain the constant room temperature), instead of maintaining constant outlet superheating degree. With the different cooling loads, the superheating of each heat exchanger varies quite a lot, which also varies the heat transfer area ratio between the two-phase and superheating zones. Thus it changes the global heat transfer coefficient (AU) of the heat exchanger. And a liquid bypass (from the exhaust of the condenser to the inlet of the compressor) can be used to adjust the global superheating temperature at the inlet of the compressor to the proper value.

3.4.4. *Typical Applications*

VRF systems are typically used in medium-size buildings. They are often well adapted in case of building retrofit. VRF systems with heat recovery are well suited in buildings with high simultaneous heating and cooling demands.

3.4.5. *Advantages*

- The system maintains temperatures at a virtually constant and comfortable level without the typical fluctuations of a ON/OFF control system
- Easy-to-install and compact system (adapted to retrofit)
- Expected high performance and consequent low running cost
- Extremely rapid response time; i.e., rapid pull-down of set point conditions.
- Ability of heat recovery, adapted to buildings with simultaneous heating and cooling loads.
- Low maintenance cost

3.4.6. *Drawbacks*

- High installation cost
- Complexity and necessity of sophisticated control strategies, adapted to the building
- Limitation of the length of pipes (<150 m in general) and limitation of the vertical length of pipes (<35 m)

Table 10: Limitations of pipe length and elevation differences (unit: m)

System type		R22 system	R410A system
Cooling-only type	Length of pipes	<80	<200
	Elevation difference between outdoor and indoor unit	(-80, 36)	(-140, 64)
	Elevation difference between indoor units	<50	<100
Heat-pump type	Length of pipes	<80	<200
	Elevation difference between outdoor and indoor unit	(-33, 36)	(-56, 64)
	Elevation difference between indoor units	<20	<25

- Risk of leakage and problem of detection
- Noise of external units

CONCLUSIONS

Many solutions are available on the market.
Geothermal solutions appear as the most efficient solutions, but they are not applicable everywhere. Moreover, the investment costs are high.
The choice of the terminal units is important. The use of low distribution temperatures for cooling and of high temperatures for heating decreases deeply the HP performance.
Radiant panels are a good solution but their power is limited.
The performances of the auxiliaries (fans and pumps) should be checked; their total consumption can be even higher than the heat pump unit consumption.

REFERENCES

[AUZ, 2005] Pompes à chaleur – systèmes à compression de vapeur, AUZENET E et CLERC RENAUD M., Techniques de l'ingénieur BE9620, 2005

[ASHRAE, 2004] ASHRAE Handbook HVAC system & Equipment, American Society of Heating, Refrigerating and Air-conditioning Engineers, SI Edition, 2004

[EN 13779, 2007] "Ventilation for non-residential buildings – performance requirements for ventilation and room-conditioning systems", NF EN 13779, July 2007

[ECODESIGN, 2008] Preparatory study on the environmental performance of residential room conditioning appliances (airco and ventilation), Co-ordinator: Philippe RIVIERE, ARMINES, France

[EECCAC, 2003] Energy Efficiency and Certification of Central Air Conditioners (EECCAC), Final report, Co-ordinator: Jerome ADNOT, ARMINES, France, April 2003

[HUG, 1990] Hughes, P.J.1990. Survey of water-source heat pump system configurations in current practice, ASHRAE Transactions 96(1), 1021-1028.

[REC, 2001] « Manuel pratique du génie climatique; Vol. 3 : Ventilation, climatisation, conditionnement d'air », H. RECKNAGEL, E. SPRENGER, E.R. SCHRAMEK, PYC livres, 3ème édition, 2001

[REI, 1996] « Climatisation et conditionnement d'air modernes par l'exemple », REINMUTH F., traduction from German by J.L. Cauchepin, PYC livres, 1996

[NAV 2007] Chauffage et rafraîchissement de la CAF de Lyon : une réussite exemplaire, NAVETEUR J, BRUSS C., Revue générale du froid et du conditionnement d'air, décembre 2007

[VRI, 1991] Production de froid: technologie des machines industrielles, VRINAT G., Techniques de l'ingénieur, B 2365 Génie énergétique.

[BYR, 2009] Design and simulation of a heat pump for simultaneous heating and cooling using HFC or CO2 as a working fluid, Paul Byrne, Jacques Miriel, Yves Lenat, International Journal of Refrigeration, Volume 32, Issue 7, November 2009, Pages 1711-1723

APPENDIX 1: Distribution systems

In general, HVAC systems used in order to cool and heat buildings can be divided up into three main types:

- all-water systems
- all-air systems
- combined systems (with cooling and/or heating supplied both by air and by water)

For more information, refers to [ASHRAE, 2004].

1. All-water systems

All-water systems are designed to control the room temperature and sometimes also the humidity whereas ventilation systems are designed to maintain air quality and humidity only. Cooling and/or heating can be supplied to rooms in different ways: chilled beams, radiant panels, thermal activated building systems (tabs), fan coil units and induction units.

1.1. Induction units

In the induction units (Figure 37), ducted primary air is fed into a small plenum chamber where its pressure is reduced by means of a suitable damper to the level required at the nozzles. The plenum is acoustically treated to attenuate part of the noise generated in the duct system and in the unit. The primary air is delivered through nozzles as high velocity jets which induce secondary air to the heating/cooling coil(s).

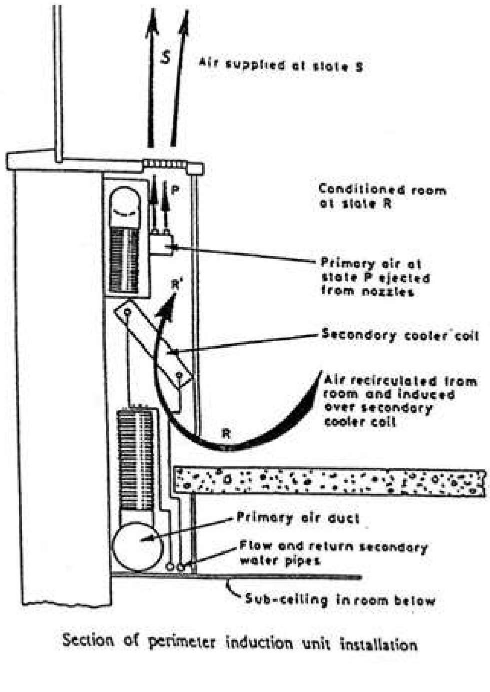


Figure 37: Induction unit

The induction system employs air ducts to convey treated air with higher pressure levels and of the right adjustable quantities to various cooling/heating coil units. These coil units are built in with induction nozzles such that when high pressure air goes through them, air room the room is inducted across the fin surface of the water-circulated coils. This inducted air stream is either cooled or heated after passing through the coil, and then mixed with the air coming out of the nozzle.

The right quantity of high pressure air is adjusted automatically in response to a thermostat located in the conditioned space.

The system is well suited to provide temperature control for individual spaces or zones.

1.2. Fan Coil Units

The basic elements of a fan-coil unit are a finned-tube coil and a fan. The fan blows air continuously through the coil which is supplied with either hot or chilled water. Fresh air may be delivered to the conditioned space through the fan coil unit or through another duct for humidification/dehumidification and air quality control.

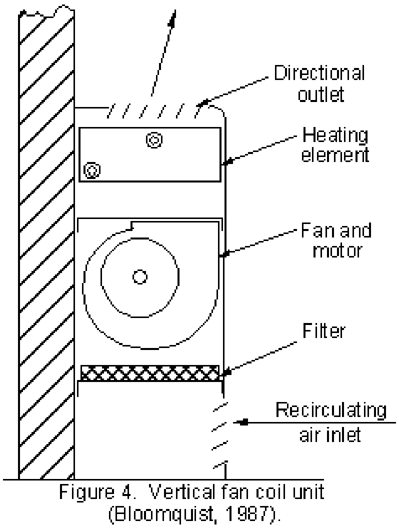


Figure 38: Vertical fan coil unit (Bloomquist, 1987).

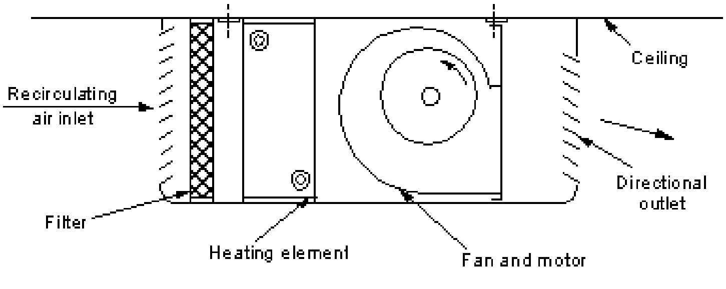


Figure 39: Horizontal fan coil unit (Bloomquist, 1987).

Two types of FCU are available: two pipe and four pipe. The two or four pipe designation refers to the water distribution system serving the terminal equipment. A two-pipe system includes only one supply line and one return line. As a result, it can supply only heating or cooling to the building at any particular time. Fan coil units connected to a two pipe system contain only one coil that serves as heating or cooling coil, depending upon the season.

The four pipe system includes a distribution system that contains both hot water supply and returns lines and chilled water supply and return lines. As a result, either heating or cooling can be delivered to any zone at any time. Heating coils in these units generally require much higher water temperature than two pipe system units.

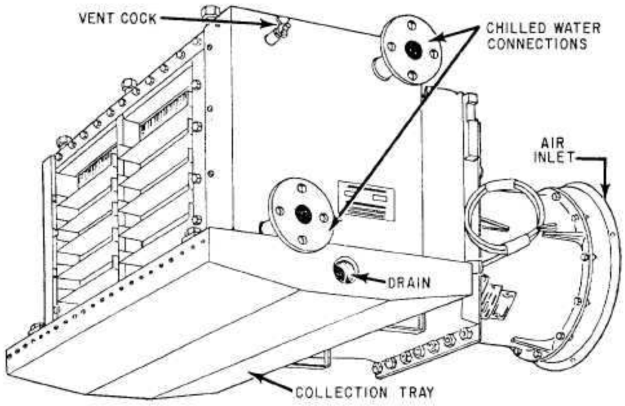


Figure 40: Fan coil unit

1.3. Radiant ceiling panels

The ceiling systems consist in a radiant surface connected with a closed circuit containing water. To avoid the risk of condensation in cooling mode, the water supply temperature of the ceiling panels must exceed the dew-point temperature of the zone..

This system is usually:
- Installed in the suspended ceilings of a room: the water - pipe circuits are distributed on the upper side of the panels which form the room's ceiling. The whole present a low thermal inertia and the metal panel is used as a decorative element. The cooling capacity of those systems usually varies
- Embedded in the ceiling slab (TABS): The pipes are embedded in the building's concrete slab. The peak cooling and heating requirements are reduced due to the high thermal inertia but a good control strategy is needed.

In both cases, heat/cold is transferred between the space and the panels through a combination of radiation and convection.

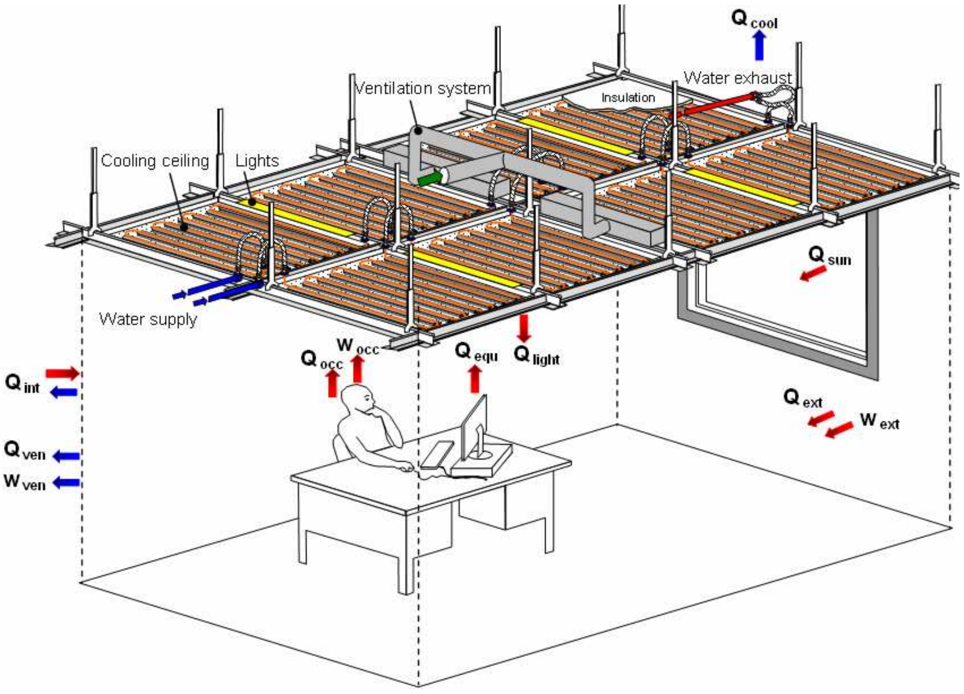


Figure 41: Heat loads of a cooling ceiling system

In cooling mode, the inlet temperature should be controlled to be as close as possible to the room's dew point temperature. Consequently, the cooling capacity of a radiant cooling system is generally limited by the minimum allowable temperature of the inlet water relative to the dew point temperature of the room air and the heat transfer area of the panel. Usually, the chilled water temperature regime is 15/17°C. The cooling capacity of such system can reach about 100 W/m² for a temperature difference of 10K between the average water temperature (16°C) and the room air temperature (26°C). The maximum specific capacity of a tabs system is between 25-35 W/m².

When using cooling ceiling systems to cool a room, the ventilation air has to be prepared in AHU for two main reasons:

- The cooling capacity of the ceiling system is usually not sufficient and pre-cooled air is necessary to maintain the temperature in the room;
- The room air humidity has to be strictly control to avoid any condensation on the ceiling. The relative humidity has generally to be comprised between 52 and 57% depending on the room air temperature.

It must be noted that the use of high temperature chilled water is well adapted to the use of passive cooling (providing cooling energy without any refrigerant cycle, but using auxiliary energy).

Different heating system can be coupled to a cooling ceiling system:

- All-air heating: the supply ventilation air is used for heating.
- Heating ceiling: the piping of the cooling ceiling system is used for heating. This can be done only with low temperature hot water (max 35°C) and is possible only in building characterized by a low heating demand (recent buildings);
- Classical heating system using static convectors or radiators (mainly for retrofit of buildings already equipped with static convectors or radiators).

1.4. Heating/Cooling Chilled Beams

These units may be "static" or "dynamic". "Static" chilled beams are supplied by free convection. "Dynamic" units are supplied in the same way as induction units. Usually, "dynamic" beams are reversible and may be also be used for heating. In cooling mode, the chilled water supply temperature is usually around 13°C to 16°C (with a temperature variation of about 2-3 K), i.e. 1.5°C to 2°C above the indoor air dew-point temperature (usually 10°C to 13°C). In heating mode, the hot water supply temperature is generally comprised between 35°C and 45°C. Depending on the operating conditions (primary air temperature and flow rate, room air temperature), the cooling and heating capacities can reach, respectively, 400 and 500 W/m for dynamic chilled beams. Passive beams heating and cooling capacities are usually comprised between 70 and 200 W/m.

Figure 42: Dynamic chilled beam

2. All-air systems

The design airflow rate in all-air systems is determined by the design cooling or/and heating requirement instead of the air quality requirements, if the load is greater than the requirements on the hygienic air change.

The two main types of all-air systems are the constant airflow system and the variable air flow system. There are many basic factors that have to be considered when choosing the system:

- An all-air system requires more space than an all-water system. The size of ducts is based on the hygienic ventilation rate with all-water systems, while an all-air system is designed on the basis of the maximum heating or cooling power required which lead to higher air flow rates;
- When there is a very important requirement for cooling or heating, an all-air system cannot provide the cooling or heating demand alone.
- It might be almost impossible to install an all-air system in buildings where no space has been foreseen for large ducts.
- It is simpler to use passive cooling with an all-air system than with an all-water system.

In all cases, a particular attention should be paid to:

- **Specific fan power (SFP)**. It depends on the pressure drop, on the efficiency of the fan and on the design of the motor. The standard [EN13779, 2007] gives some typical reference values:

Application	Category of SFP for each fan	
	Typical range	Default value
Supply air fan		
- complex HVAC system	SFP 1 to SFP 5	SFP 3
- simple ventilation system	SFP 1 to SFP 4	SFP 2
Exhaust air fan		
- complex HVAC system	SFP 1 to SFP 4	SFP 3
- simple ventilation system	SFP 1 to SFP 3	SFP 2
- extract air system	SFP 1 to SFP 3	SFP 2

With
SFP 1 corresponding to: < 500 W.m^{-3}.s
SFP 2 corresponding to: 500-750 W.m^{-3}.s
SFP 3 corresponding to: 750-1250 W.m^{-3}.s
SFP 4 corresponding to: 1250-2000 W.m^{-3}.s
SFP 5 corresponding to: > 2000 W.m^{-3}.s

- **Air Handling Unit performance in terms of air leakage, thermal transmittance, thermal bridging factor, filter bypass leakage;** EUROVENT certifies AHU.
- **Air handling Unit in terms of acoustic insulation;** EUROVENT certifies AHU.
- **Heat recovery efficiency;** EUROVENT certifies air-to-air plate heat exchangers and air-to-air rotary exchangers.

2.1. Constant Air Volume (CAV)

In this system, the temperature of the supply air can vary whereas the airflow rate is constant.

Although a CAV system operates normally at constant air flow rate, the fans are sometimes powered by two-speed motors, running at lower speed in part load.

2.2. Variable Air Volume (VAV)

In this system, the airflow rate can be adjusted between the hygienic air flow rate and the maximum available air flow rate, whereas the supply air temperature is kept constant. However, the supply air temperature is changed during the year according to the outdoor temperature.

On one hand, the airflow in each room is controlled by dampers in VAV boxes close to the supply air duct outlets. On the other hand, the central supply and exhaust air fans are controlled by variable inlet vanes or by variable speed drive controlled motors, usually of the frequency-inverter type. The central control system normally maintains a constant static pressure in the supply air duct.

The VAV system with recycled air in multi-zone buildings with different internal gains, cannot always maintain hygienic conditions in all zones[2] [REC, 2001];

---

[2] For instance, if high heating demand is requested in a North zone, the return air flow rate would be at the highest. If the heating demand in a South zone in the same time is low, the supply airflow rate would be low and thus the minimum hygienic air flow rate can be unsatisfied since the return air percentage is high.

APPENDIX 2: Glossary

Heat pump unit: In the context of the annex 48, the term heat pump unit, or simply heat pump (HP), is a general term referring to a reversible or non-reversible thermodynamic machine. It is composed of one or more compressors, two or more heat exchanger, an expansion valve and a refrigerant circuit. A HP can work in heating mode, in cooling mode or in simultaneous cooling and heating mode, depending on the type. Water loops, heat source, heat sinks and the building distribution system are not part of a heat pump, but are separate components. A classification of heat pumps based on the transfer media is given in table 1. The units are denominated in such a way that the heat transfer medium for the outdoor heat exchanger is indicated first, followed by the heat transfer medium for the indoor heat exchanger, as defined in the norm EN 14511.

Table 1: Heat pump types according to exchanger media

Packaged units
Air-to-water
Water-to-water
Brine-to-water
Air-to-air
Water-to-air
Brine-to-air
Water/air-to-water
Direct expansion (DX) units
Split system
VRF
DX (Ground) -to-water

Reversible heat pump unit: Heat pump unit with a refrigerant change-over.

Heat recovery: *(from EN 14511)* recovery of heat rejected by the unit(s), whose primary control is in the cooling mode, by means of either an additional heat exchanger (additional condenser or desuperheater), or by transferring the heat through the refrigeration system from units used in cooling mode to units used in heating mode.

Heat pump system : System composed of:

- one or several heat pump units;
- a building distribution system;
- one or several heat sources / sinks;
- if needed, some components or circuits to link the HP to the heat source/sink (water loops, cooling towers).

Heat pump systems can be of several types. A classification of heat pump system types with the nomenclature adopted is given in table 2.

Direct expansion exchanger (DX) : Exchanger in which the refrigerant is in direct contact with the final heat source/sink (ground-coupled heat pump systems) or with the terminal units (split / multisplit / VRF systems).

Nomenclature	***Heat pump unit type***	***Heat source / sink***	***Reversibility***	***Heat recovery***	***Change-over***	***Distribution to the heat source/sink***	***Distribution fluid to the building***
· *Reversible systems without heat recovery*							
Reversible air-to-water heat pump system	Reversible air-to-water	Outdoor air	Yes	No	Refrigerant	Direct	Water
Reversible ground coupled heat pump system	Reversible brine-to-water	Ground	Yes	No	Refrigerant	Brine	Water
Reversible groundwater(surfacewater) heat pump system	Reversible brine-to-water	Groundwater, surface water	Yes	No	Refrigerant	Open/closed water loop	Water
Exhaust air heat pump system	Reversible air-to-water	Extracted air	Yes	No	Water	Direct	Water
Air-to-air dual duct heat pump system	Air-to-air	Extracted air	Yes	No	Air or refrigerant	Direct	Air
Mono-split / Multi-split	Split type	Outdoor air	Yes	No	Refrigerant	Direct	Refrigerant
· *Non-reversible systems with heat recovery*							
Water-cooled chiller with heat recovery	Water-cooled chiller	Outdoor air (cooling tower)	No	Yes	-	Water loop	Water
Dual condenser chiller	Dual condenser chiller	Outdoor air or/and water	No	Yes	-	Direct	Water
Temperature Amplifier	Non reversible Water-to-water	water	No	Yes	-	Direct	Water
· *Reversible systems with heat recovery*							
Reversible water/air-to-water heat pump system	Reversible water/air-to-water	Outdoor air	Yes	Yes	Refrigerant	Direct	Water
Reversible (ground coupled, groundwater or surface water) heat pump system with heat recovery	Non reversible water-to-water (water-cooled chiller)	Ground, groundwater, surface water	Yes	Yes	Water	Two separate water loops	Water
VRF	VRF	Outdoor air	Yes	Yes (3-tubes)	Refrigerant	Direct	Refrigerant
Water-loop heat pump system	Decentralized reversible water-to-air	Boiler / Outdoor air (cooling tower)	Yes	Yes	Refrigerant	Water loop connecting the local heat pumps and the heat source / sink	
		Ground, groundwater, surface water					

Table 11: Classification of heat pump systems

Chiller: The term chiller refers generally to a central thermodynamic machine used for cooling only. Normally, a chiller is used to cool water, which is then distributed into the building or sent to the cooling coil of a AHU. The term “reversible chiller” is sometimes used in the annex instead of reversible heat pump, in the case of central air-to-water or water-to-water reversible heat pumps designed and sized on the base of the peak cooling load rather than of the peak heating load.

Free cooling: There is no generally accepted definition of what free cooling is. It can be interpreted as the ability to supply cooling without having to consume energy for it. Natural ventilation is an example of free cooling. In this case, no fan is required to supply fresh air in the building.

Passive cooling: The term passive cooling can be defined as the possibility to take directly advantage of a cold source without using a thermodynamic machine. Many cold sources can be used such as air, ground source, ground water or surface water. There are many way to take advantage of cold sources:

- **Mechanical over-ventilation:** Blowing of cool external air into the building by means of fans. The energy consumption is due to the fans;
- **By-passing of the heat pump:** When the heat source (air, ground source, ground or surface water) is at a temperature level which makes it possible to cool, a valve by-pass the heat pump and aliments directly the building distribution system. The energy consumption corresponds to that one of the pump. This type of passive cooling is often referred to as “free chilling”.

Change-over : System to switch from a mode to another. It can be of three types: refrigerant change-over (in the refrigerant circuit of the heat pump), water change-over (in the water circuit) and, rarely, air change-over.

EER: Energy Efficiency Ratio, efficiency of a heat pump unit in cooling mode. It is defined as the ratio of the instantaneous cooling power at evaporator side and the effective power input of the unit in steady-state conditions.

The effective power input is the sum of:

- the power input of the compressor;
- the power input for all controls and safety devices of the unit;
- for units with an air condenser, the power input of the outdoor condenser fans;
- for mono-split units, the power input of the indoor evaporator fan;

For modular multi-split and VRF systems, where the number of indoor units is variable, catalogue data usually report the EER of the outdoor unit only (condenser fans + compressor) and separately the indoor unit power consumption.

Rating conditions: Evaporator-side and condenser-side temperatures at which the EER and the COP of a heat pump are evaluated. Standard rating conditions are defined by EUROVENT and they are reported in table 3.

Table 3: Standard rating conditions defined by EUROVENT

Application	**Temperature**			
	Cooling (EER)		**Heating (COP)**	
	Evaporator	Condenser	Evaporator	Condenser
Standard air-conditioning	12 / 7 °C	35 °C	40 / 45 °C	7 °C
Cooling/heating floor	23 / 18 °C	35 °C	30 / 35 °C	7 °C

COP: Coefficient of Performance, efficiency of a heat pump in heating mode. It is defined as the ratio of the instantaneous heating power at condenser side and the effective power input of the unit in steady-state conditions.

The effective power input is the sum of:

- the power input of the compressor;
- the power input for defrosting;
- the power input for all controls and safety devices of the unit;
- for units with an air condenser, the power input of the outdoor coil fans;
- for mono-split units, the power input of the indoor condenser fans;

For modular multi-split and VRF systems, where the number of indoor units is variable, catalogue data usually report the COP of the outdoor unit only (condenser fans + compressor) and separately the indoor unit power consumption.

SEER: Seasonal Energy Efficiency Ratio is the seasonal efficiency of a heat pump in cooling mode, defined as the ratio of the total cooling energy at evaporator side delivered to the building (including distribution heat losses) and the electrical consumption of the heat pump in cooling mode. It depends on the building cooling load profile and on the heating sink temperature over the year.

ESEER: For air-cooled and water-cooled chillers EUROVENT has proposed a seasonal cooling index, the ESEER (European Seasonal Energy Efficiency Ratio), aiming to give a measure of the part load performances in cooling mode. Additionally, the index takes into account the variation of outdoor temperature in European climates. The ESEER is calculated, based on four working points, as follows:

$$ESEER = A \cdot EER_{100\%} + B \cdot EER_{75\%} + C \cdot EER_{50\%} + D \cdot EER_{25\%}$$

Table 4 shows the test conditions of the four working points and the weighting factors defined for the air-cooled units.

Table 4: Test conditions for ESEER definition

Part load ratio	Air temperature (°C)	Water outlet temperature (°C)	Weight coefficient:
100%	35	7	A = 0,03
75%	30	7	B = 0,33
50%	25	7	C = 0,41
25%	20	7	D = 0,23

SCOP: Seasonal Coefficient Of Performance, is the seasonal efficiency of a heat pump in heating mode, defined as the ratio of the total heating energy at condenser side delivered to the building (including distribution heat losses) and the electrical consumption of the heating pump in heating mode. It depends on the building heating load profile and on the heating source temperature over the year.

EUROVENT: It is a consortium that certifies the performance ratings of air-conditioning and refrigeration products according to European and international standards. The objective is to build up customer confidence by levelling the competitive playing field for all manufacturers and by increasing the integrity and accuracy of the industrial performance ratings.

Water loop: *(from EN 14511)* closed circuit of water maintained within a given temperature range and, on which are connected several water-to-air heat pumps used in heating or cooling modes.