IEA Energy in Buildings and Communities TCP
Annex 88 Evaluation and Demonstration of Actual Energy Efficiency of Heat Pump Systems in Buildings

ANNEX 88 EBC Energy in Buildings and Communities Programme

Monitoring methods and data on actual energy performance of heat pumps in buildings

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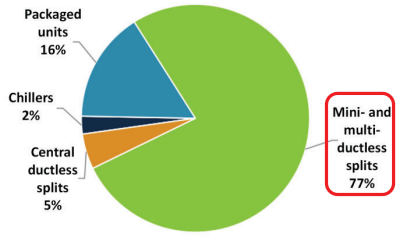
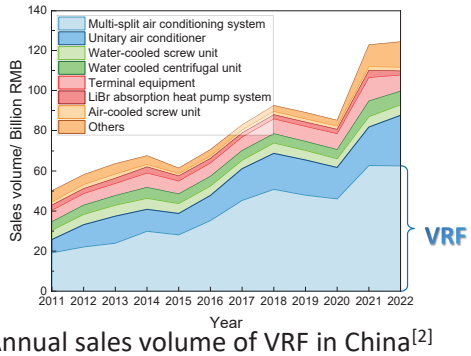
Technology Collaboration Programme by iea

1 Background

- **Heat pumps,** including RAC, VRF and so on, have been applied in various commercial buildings, residential buildings and industrial buildings worldwide.
- Field performance of could be much different due to complex field factors, such as indoor environmental demand, ambient parameters, installation, control strategies, occupants' behavior.
- Accurate measurement of the **cooling and heating capacity** becomes the focal point of field performance measurement.



Stock of ACs by type[1]



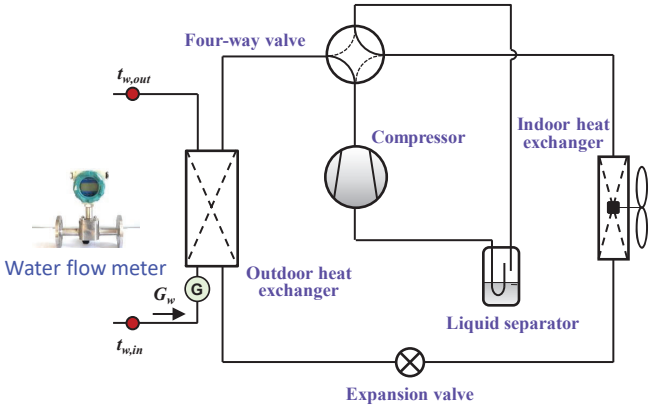
Annual sales volume of VRF in China[2]

[1] International Energy Agency. The future of cooling: Opportunities for energy- efficient air conditioning (2019).
[2] Central Air Conditioning Market, 2010-2022 China Central Air Conditioning Market Summary Report.

2 Current field monitoring methods

Air-water (hydronic) heat pump

Cooling/heating capacity can be obtained by measuring the **water temperature difference** and **water flow rate**.

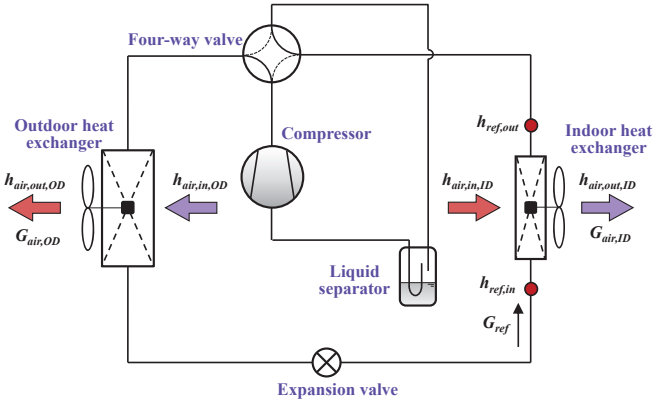


Heat transfer on outdoor unit: $Q_{out,w} = G_w c_{pw}\left(t_{w,in} - t_{w,out}\right)$

Cooling/heating capacity: $Q_{in,c} = Q_{out,w} - P_{com}$ $Q_{in,h} = Q_{out,w} + P_{com}$

Air-air heat pump

Two methodologies namely the **air-specific enthalpy difference (AE) method** and **refrigerant specific enthalpy difference (RE) method**.



$$Q_{cc} = m_{\text{air,ID}} \cdot \left(h_{\text{air,in,ID}} - h_{\text{air,out,ID}}\right) = m_{\text{air,OD}} \cdot \left(h_{\text{air,out,OD}} - h_{\text{air,in,OD}}\right) - P_{com} = m_{\text{ref}} \cdot \left(h_{\text{ref,out}} - h_{\text{ref,in}}\right)$$

$$Q_{hc} = m_{\text{air,ID}} \cdot \left(h_{\text{air,out,ID}} - h_{\text{air,out,ID}}\right) = m_{\text{air,OD}} \cdot \left(h_{\text{air,in,OD}} - h_{\text{air,out,OD}}\right) + P_{com} = m_{\text{ref}} \cdot \left(h_{\text{ref,in}} - h_{\text{ref,out}}\right)$$

2 Current field monitoring methods

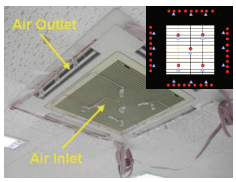
Indoor side AE method

(a) Air hood method

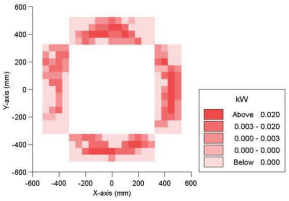
- Air hood introduces all the air outlets of the indoor unit into an **air duct**.
- **Not convenient** because it **disturbs the regular operation for both users and units**.

(b) Air sampling method

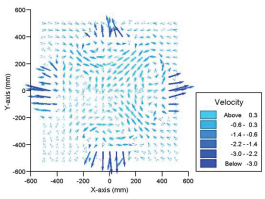
- The air inlet and outlet volumes are calculated by integrating distributed sensors and each measuring point's correction factor.
- The temperature and humidity sensors are arranged in each measuring point area.
- Thermal and vector velocity distribution in the indoor unit is **complex and exhibits evident non-uniformity**.



Measuring point



Thermal distribution



Vector velocity distribution

Outdoor side AE method

(a) Air hood method

- The air hood is connected to the air outlet of the outdoor unit.
- Installing an air hood **affects the air distribution of the air flow field**.

(b) Static multi-point air sampling method

- Air enthalpy difference is calculated by **multiple temperature and humidity sensors** at the inlet and outlet of the outdoor unit.

(c) Static/dynamic outlet air sampling method

- Using **outlet air sampling device** to obtain the temperature, humidity, and airflow parameters.
- **High cost** and **not convenient** to install the equipment.

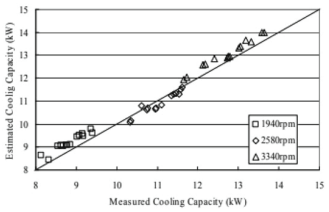

Dynamic outlet air sampling device

2 Current field monitoring methods

(Refrigerant side) RE method

(a) Compressor performance curve method

- Based on the provided information, this method calculates the refrigerant mass flow rate by **fitting a polynomial equation** to some directly measured parameters.
- This method **relies on the fundamental information supplied by the manufacturer**.
- Field performance will deviate from the initial performance due to wearing, showing **low accuracy in a long-term test**.



Compressor performance curve

(b) Compressor volumetric efficiency (CVE) method

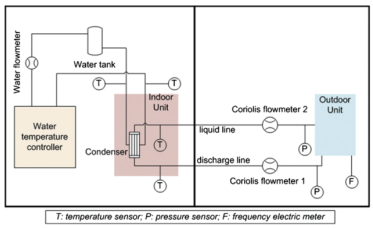
- The volumetric efficiency value is experimentally determined from the air conditioning capacity in a high-precision environmental test laboratory. The refrigerant mass flow rate (or cylinder volume) is calculated according to the equation.
- The accuracy of this method depends on the precision of volumetric efficiency, which may be **affected by the wear and deterioration of the compressor** during **a long-term operation**.

2 Current field monitoring methods

(Refrigerant side) RE method

(c) Refrigerant mass flow meters method

- By using the **Coriolis flow meter**, intrusive measurement on the refrigerant side can directly obtain the refrigerant mass flow.
- The Coriolis flow meter is **expensive**, and it is **inevitably intrusive**, which will **seriously affect the operation state of a heat pump**.



Refrigerant mass flow meters method

(d) Throttling model method

- According to the throttling characteristic equation for a compressible fluid, this method determines the mass flow rate of the refrigerant based on the compressible fluid throttling characteristic equation.

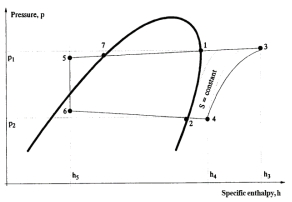
(e) Compressor energy conservation (CEC) method

- This method measures the refrigerant mass flowrate across the compressor based on the **energy conservation equation**.
- To cope with the two-phase suction situation and increase the method's accuracy, the CEC-CVE method is proposed to **improve the measurement accuracy in two-phase suction condition**.
- This method shows **long-term reliability, independence, and non-interference**.

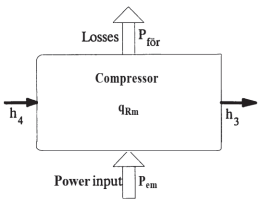
3 Existing standards and protocols for field monitoring

Europe's specification

- **Finnish standards NT VVS 115** and **NT VVS 116** specify the working conditions and measurement methods for on-site performance measurement of air-to-air units, including the measurement of the compressor suction and discharge temperature and pressure, condenser outlet temperature and compressor power. The performance data of heat pump are obtained by CEC method.



Designation of refrigerant states



Thermal balance of compressor

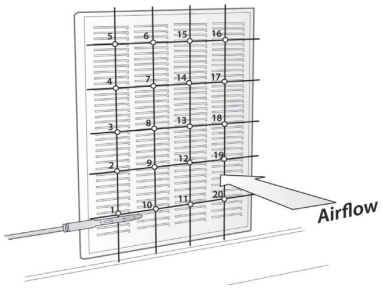
Canada's specifications

- In 2020-2022, **Natural Resources Canada** funded **field trials of air to air, variable capacity cold climate heat pumps in locations across Canada**. In order to provide guidance for these field tests, a technical guideline for field monitoring was developed.
- The Guideline covers 4 planning and undertaking field monitoring aspects, including site and equipment selection, monitoring parameters, short-term testing and long-term testing.
- By counting the temperature bin hours, seasonal performance factor is calculated. For example, seasonal coefficient of performance calculations in heating season ($SCOP_H$) could be calculated.

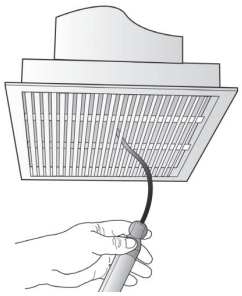
3 Existing standards and protocols for field monitoring

US's specification

- **ASHRAE Standard 221** provides a method to field measure and estimate the capacity and efficiency and score the performance of an installed HVAC system. It provides uniform methods of measurements and testing procedures for airflow, temperature, enthalpy, and power. Besides, test instruments, specifications, and calibration requirements for capacity and efficiency measurements are specified in this standard.
- The standard adopts **indoor side AE difference method** in field test.
- Test instruments includes air balancing (capture) hood assembly, digital anemometer, manometers, multisensory thermometer/psychrometer and electrical power meter.



Airflow measurement procedure


Air temperature or enthalpy measurement procedure

3 Existing standards and protocols for field monitoring

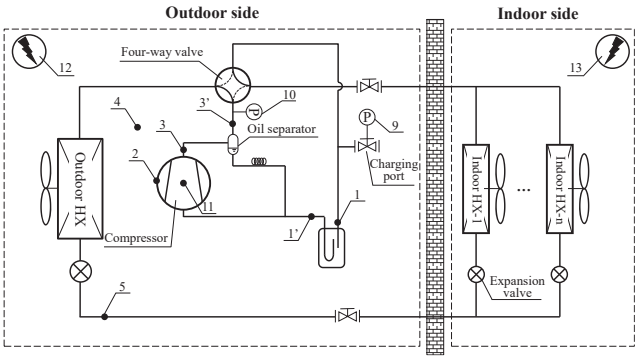
China's specifications and standards

- T/CAS 305-2018 "Specification for measurement of on-site performance parameters of air conditioner"
- T/CECS 846-2021 "Performance testing of heating and air-conditioning system in hot summer and cold winter zone"

Accuracy calibration conditions of measuring device in T/CAS 305-2018

Item		Calibration condition				Test item	Necessity
		Indoor side		Outdoor side			
		DBT	WBT	DBT	WBT		
Cooling	Nominal cooling	27	19	35	24	Nominal cooling	○
						Half cooling	○
						25% cooling	○/△
	Low temperature cooling	27	19	29	—	Low temperature	○
	Low humidity cooling	27	＜16	29	—	Low humidity	△
	Intermittent cooling	27	＜16	29	—	Intermittent cooling	△
	Maximum cooling	32	23	43	26	Maximum cooling	△
	Extreme high-temperature	32	23	48	—	Extreme high-temp.	△
Heating	Nominal heating	20	—	7	6	Nominal heating	○

Note: ○ represent the necessary item, and △ represent the selected item.

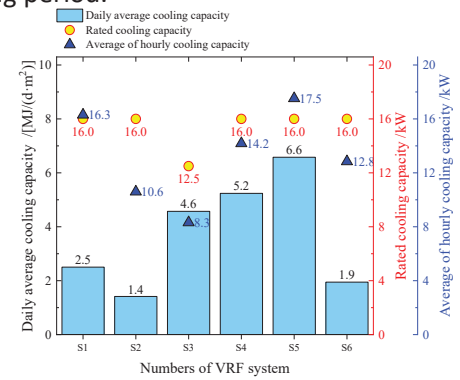


Schematic of sensors installation by CEC method on VRF system

4 Existing data on monitored heat pump systems

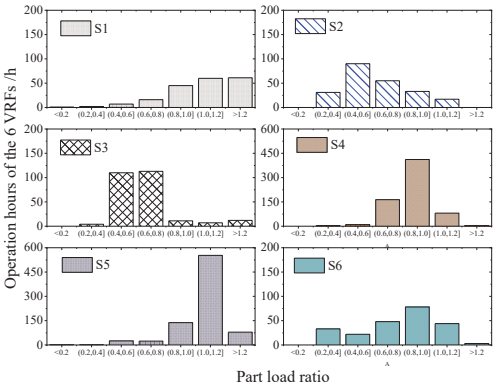
Case 1 (VRF)

- **Location**: Hefei, China
- **Testing period**: 90 days
- **Season**: Cooling season
- S5 VRF shows the largest daily average cooling capacity because it operated for 702 h during testing period.



Cooling capacities of 6 VRF system

- **Part load rate**: Vary in a large range.
- **EERs of the 6 VRFs during testing**: 3.41 ~ 4.08 kWh/kWh
- **Conclusion**: Actual operation conditions and performance of VRFs could be quite different. More attention should be paid to system design and sizing to ensure that the system operates in an appropriate and efficient part load rate area.

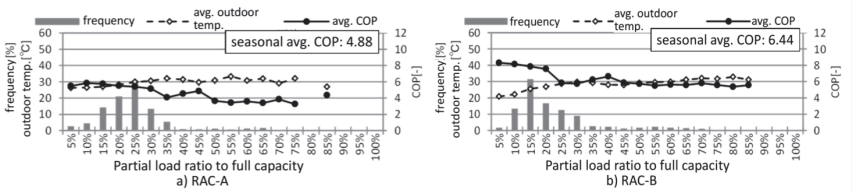


Part load rate and operation hours of the 6 VRFs

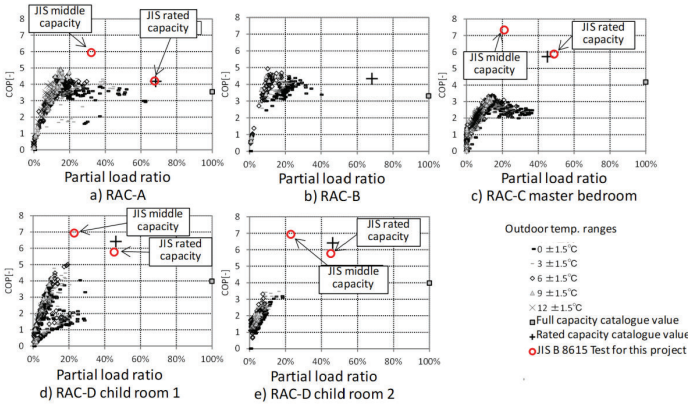
4 Existing data on monitored heat pump systems

Case 3 (RAC)

- **Location**: Japan
- **Season**: Cooling/Heating season
- **Operation schedule**: RACs were installed side by side in the living room and were operated alternately.
- **Cooling COP**: The average COP under a part load ratio below 25% was as high as or even higher than one under a part load ratio above 50%, presumably due to lower outdoor temperature.
- **Comparison between field and rated performance**: Actual COP in field test is much lower than JIS middle capacity and rated capacity testing result from laboratory.



Frequencies of appearance of part load rate and COP (Cooling season)



Relationship between part load rate and COP (Heating season)

5 Perspectives

- Developing highly accurate and easy-to-use monitoring technology of field capacity is essential.
- International regulations or standards for field performance testing should be developed.
- Large-scale field performance monitoring can provide important information for the development of new generation HP.
- Optimal control, such as demand response management, relies on field performance monitoring and modelling.

Thanks