EBC

Introduction to EBC

Paul Ruyssevelt, Vice-Chair EBC ExCo

Aim: To support the acceleration of the transformation of the built environment towards more energy efficient and sustainable buildings and communities

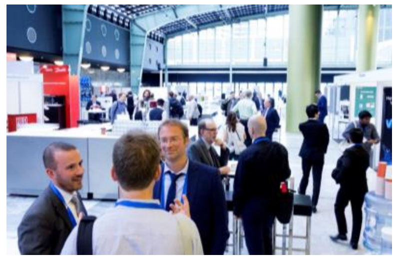
By: Energy research, innovation, development, demonstration and dissemination

- 26 member countries
- Established: 96 Annexes (projects) and 5 Working Groups
- Ongoing: 19 Annexes and 1 Working Group

Further information available at: www.iea-ebc.org

IEA Technology Collaboration Programme on Heat Pumping Technologies (HPT TCP)

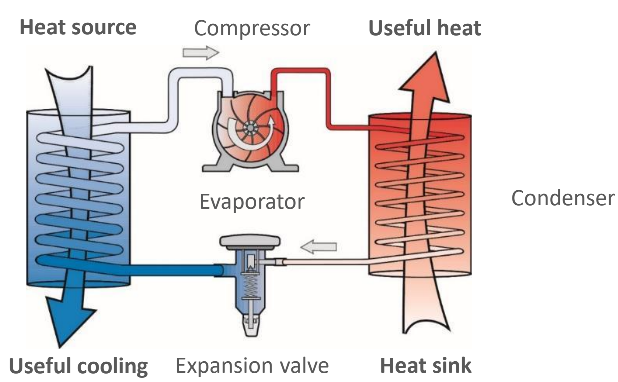
Dr Caroline Haglund Stignor, Heat Pump Centre



Research, Development, Demonstration, and Deployment of Heat Pumping Technologies

What are Heat Pumping Technologies?

The vapor compression cycle



…and other cycles

- Absorption heat pump
- Thermo-acoustic heat pump
- Electro-magnetic heat pump
- Mechanical vapor recompression

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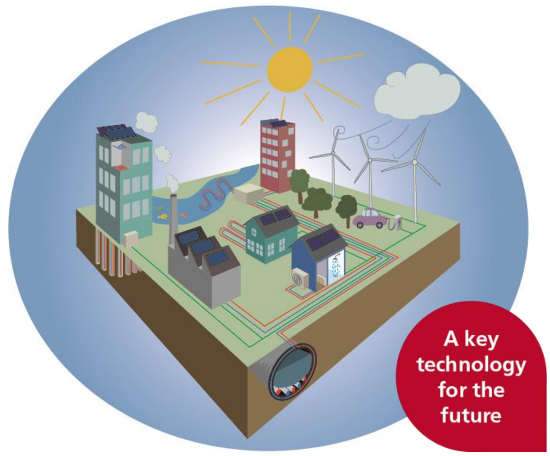
Heat Pumping Technologies

Includes:

- Heating and cooling
- Air conditioning
- Refrigeration

Covers applications in:

- Residential and commercial buildings
- Industries
- Thermal grids in cities and communities
- Other applications



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About Heat Pumping Technologies TCP

- A Technology Collaboration Programme (TCP) within **the IEA** since **1978**
- An international framework of **cooperation** and **networking** for different HPT actors
- A forum to exchange **knowledge** and **experience**
- A contributor to **technology improvements** by RDD&D projects

20 Member Countries

Austria
Belgium
Canada
China
Czech Republic
Denmark
Finland
France
Germany
Ireland
Italy
Japan
Netherlands
Norway
South Korea
Spain
Sweden
Switzerland
United Kingdom
United States

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HPT TCP Organization and Management

Executive Committee

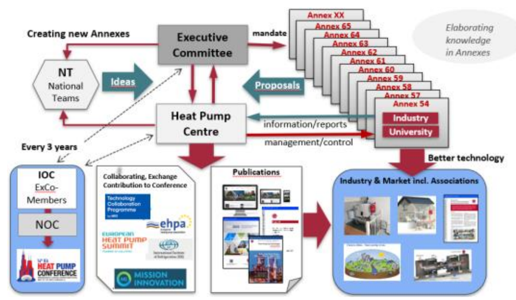
National teams

National experts meeting

Heat Pump Centre

Annexes

- **Executive Committee:** The board of HPT TCP - one vote per member country
- **National Teams:** Organizations representing national HPT activities. A forum for discussion networking and creation of new ideas. Meet at joint National Experts meetings.
- **The Heat Pump Centre:** The central program office and communication center of HPT TCP
- **Projects/Annexes:** Elaborating new knowledge through collaborative RDD&D work



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Communication and dialogues

Information dissemination and communication

- Publications (e.g. project reports)
- HPT Magazine and Newsletter (digital)
- Website: www.heatpumpingtechnologies.org
- Social media: LinkedIn, X (Twitter) (@heatpumpingtech) and WeChat

IEA Heat Pump Conference

- Organized every 3rd year
- Next one will be in May 2026 in Vienna, Austria

And

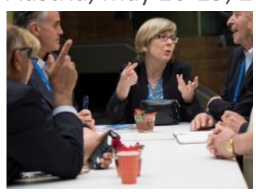
- National Experts meetings
- Workshops and webinars
- Support to IEA publications
- Outreach activities

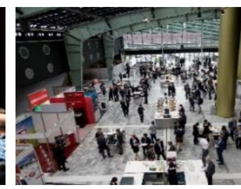
The IEA Heat Pump Conference

Every third year the IEA Heat Pump Conference is arranged. The purpose is to increase the awareness around heat pumping technologies but also to establish a meeting place for different actors working in the field of heat pumping technologies. It is also an opportunity to strengthen the collaboration with other TCPs.

The next conference will be in Vienna, Austria, May 26-29, 2026.







Call for abstracts will open on November 15, 2024

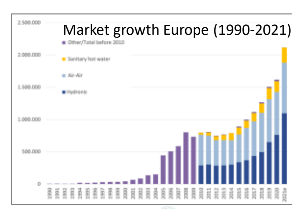
www.heatpumpingtechnologies.org

Status of Heat Pumping Technologies

Offers already a lot, but more efforts needed for further developments

This is a **proven efficient and clean technology, available** on the market

- upgrades renewable energy & reduces CO_2 emissions
- is an excellent flexibility provider to **balance the grid** to handle **intermittent production**
- contributes to improved **energy security and resilience**
- Heat pumping technology gets more attention from **policy and public**



…but there is still a **need for RDD&D** to

- sharpen the technologies and **widen the operating range**
- adopt solutions for **complex building** and **retrofit market**
- adopt solutions for **sector coupling** and **system integration** with other clean renewable energy technologies
- safe and efficient operation with **low GWP refrigerants**
- **alternative cycles**
- to **overcome non-technical barriers**

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RDD&D Priority Areas 2023-2028 – International collaboration projects (Annexes)

System integration	Robust, sustainable and affordable value chains	Extending operation range and applications	Refrigerants and New technologies
			
Sector coupling, energy efficiency, flexibility, resilience, storage, digitalization, positive energy districts	Improving affordability, securing value chains, circular economy, removing barriers for mass deployment	To fulfill demand from all climate zones, new markets, new applications and new demand. Refrigeration in emerging countries.	Non-traditional heat pumping technologies (for heating and cooling) Refrigerants (low GWP, safety etc.)
• Annex 57: Heat pumps in multi-vector energy systems **END SOON** • Annex 61: Heat Pumps in Positive Energy Districts • Comfort and Climate Box solutions for cooling and dehumidification • Flexibility from Large-Scale and Aggregated Heat Pump Systems • Digital Services for Heat Pumps • Heat pumps for hydrogen and carbon capture	• Annex 63 Placement Impact on Heat Pump Acoustics **NEW** • Annex 65 Heat Pumps in a Circular Economy **NEW** • Project 66 Optimal Heat Pump Design and Operation for Broader Acceptance **NEW** • New or alternative business models for heat pumps • Enhanced miniaturized components	• Annex 60: Retrofit Heat Pump in Larger Non-domestic Buildings • Annex 58: High Temperature Heat Pumps **END SOON** • Annex 59: Heat Pumps for Drying • Annex 62: Heat Pumps in residential multifamily buildings in cities **NEW** • Industrial High Temperature Heat Pumps • Heat Pumps in residential multifamily buildings in cities – follow-up	• Annex 53: Advanced cooling and refrigeration technology development • Annex 54: Heat Pump Systems with low GWP Refrigerants **END SOON** • Annex 64: Safety Measures on Flammable Refrigerants **NEW** • Monitoring of Advanced Vapor-Compression and non-Vapour-Compression Technologies for Heating, Cooling and refrigeration

Recently finalized, Ongoing, Proposals under discussion

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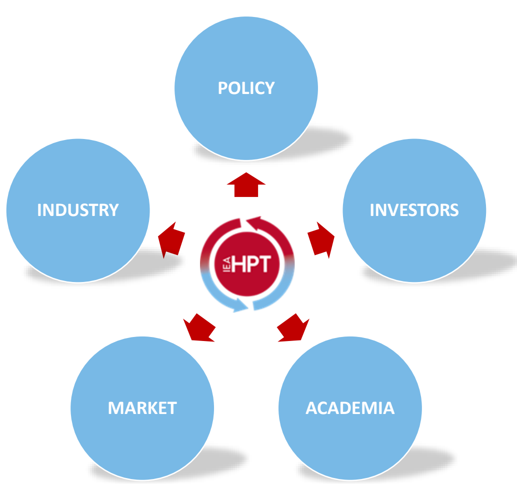

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Evaluation and Demonstration of Actual Energy Efficiency of Heat Pump Systems in Buildings (Annex 88)

The State of the Art (Subtask A Report)

Alberto Hernandez Neto
University of São Paulo, Brazil
10/24/2024

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ANNEX 88 EBC Energy in Buildings and Communities Programme

Chapter 1: Testing methodologies and performance rating standards for heat pump systems

Chapter 2: Monitoring methods and database for actual energy efficiency of heat pump systems

The State of Art Report

Chapter 3: Energy use calculation methods for heat pump systems

Chapter 4: Design guidelines for heat pump systems in buildings

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Chapter 1: Testing Methodologies and Performance Rating Standards for Heat Pump Systems

Category A & B Standards

- Category A: Steady-state testing, compressor speed fixed
- Category B: Load-based testing, accounts for real-world performance

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Chapter 2:Monitoring Methods for Heat Pumps

- Monitoring real-world heat pump performance in non-steady-state conditions
- Impact of partial load ratios and current testing standards
- Monitoring Methods for Air and Hydronic Systems
  - Air conditioners: Indoor/outdoor air enthalpy difference, refrigerant enthalpy
  - Hydronic systems: Water-side methods
  - Standards: T/CAS 305-208, ASHRAE 221-2020

Chapter 3: Energy Use Calculation Methods

Energy policies evolved since 1970s oil crisis

+

Need for reliable methods for calculating heat pump energy consumption

Challenges in Energy Calculation
- Accuracy and comprehensiveness
- Data input challenges
- Impact of operating conditions (e.g., part-load ratio, outdoor temperature)

Reviewed Energy Calculation Methods
- Review of 8 existing methods: EN 15316-4-2, NECB, EnergyPlus, etc
- Variability in heat pump calculation methodologies across countries

Chapter 4: Design Guidelines for Heat Pumps

1. Review of installation and design guidelines
2. Focus on hydronic and air-to-air systems

Standards and Tools for Designers
- EN 15450, ASHP Sizing Toolkit (Canada)
- ACCA Manuals (USA), NEEP guides
- ISO 13153 framework for design

The State of Art Report Team

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Evaluation and Demonstration of Actual Energy Efficiency of Heat Pump Systems in Buildings

- Chapter 1: testing methodologies and performance rating standards for heat pump systems -

Presenter: Niccolo` Giannetti

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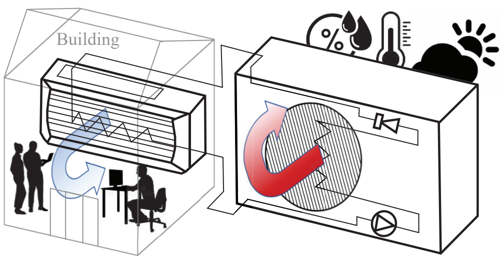
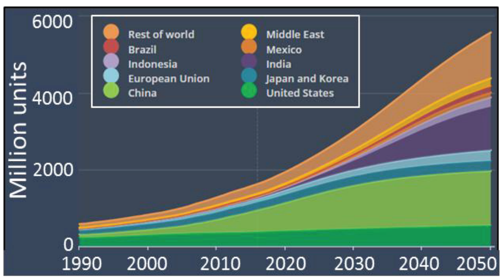
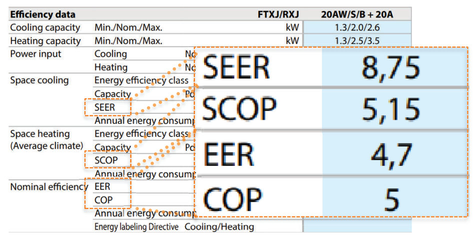
1. Background and Motivation





- ❖ Billions of heat pump installations interacting with building structures, occupants' lifestyles, and climates.
- ❖ Hardware performance
- ❖ Operation performance



- ❖ Operation performance and field performance of HP and AC installations remains largely unknown.

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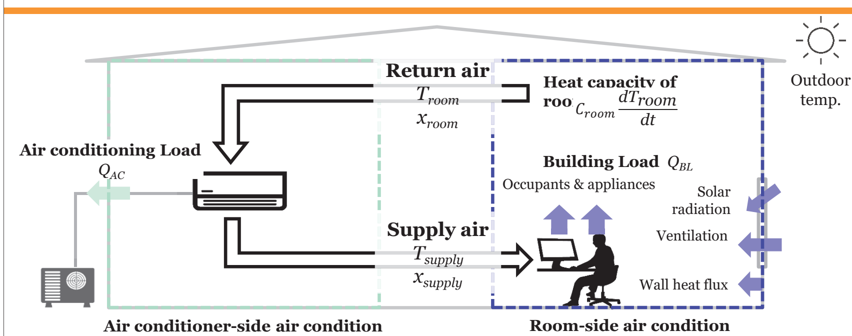
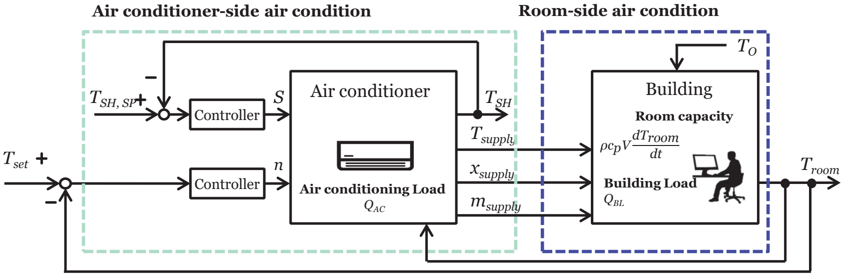
1. Background – Field System Operation



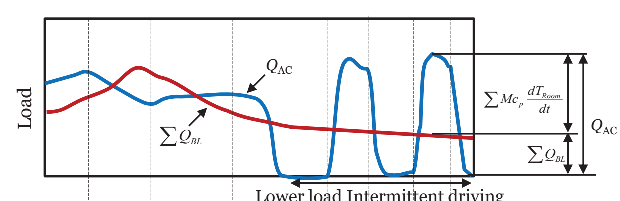


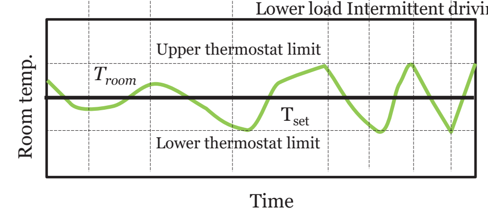
Block diagram of air conditioning control

- ❖ System operation

$$0 = \sum Q_{BL} - Q_{AC}$$

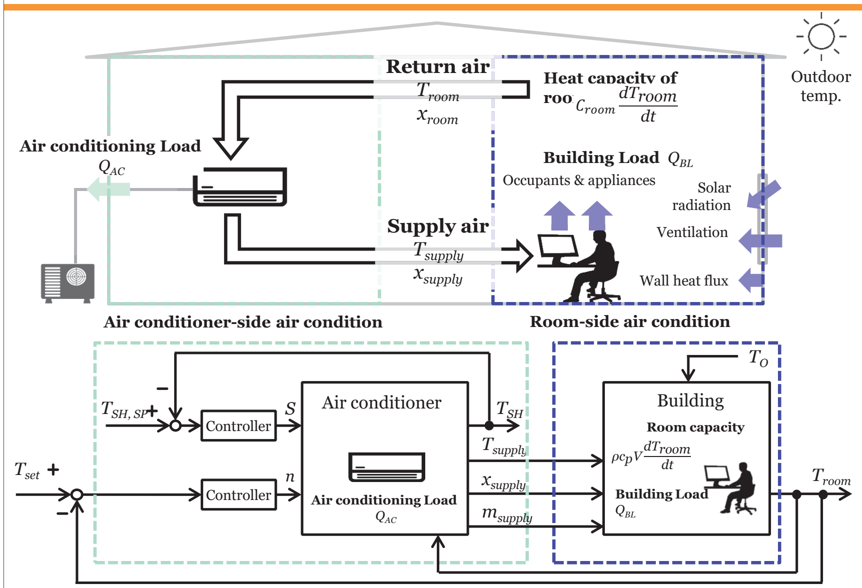
$$\sum Mc_p \frac{dT_{Room}}{dt} = \sum Q_{BL} - Q_{AC} \rightarrow \frac{dT_{room}}{dt} = \frac{\sum Q_{BL} - Q_{AC}}{\sum Mc_p}$$





* The estimation of moisture content and moisture transfer is also implied

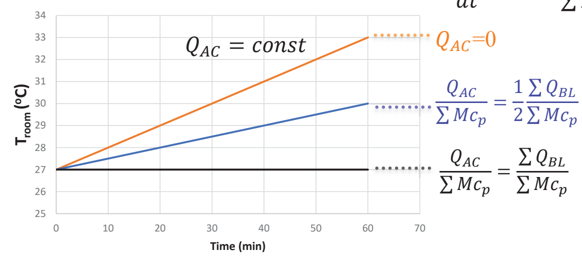
1. Background – Field System Operation



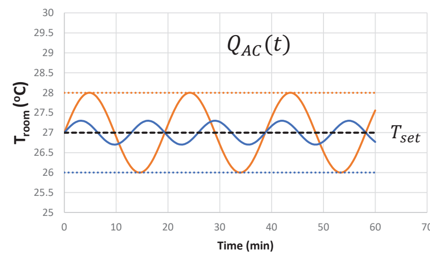
Block diagram of air conditioning control

❖ Deactivated-control operation

$$\frac{dT_{room}}{dt} = \frac{\sum Q_{BL} - Q_{AC}}{\sum Mc_p}$$



❖ Active-control operation



$$\sum Q_{BL} > \sum Q_{BL}$$

1. Background – Target Issue

❖ HPs performance depends on internal control, external parameters, and interactions with building features.

❖ Inconsistent viewpoints and technical approaches between HP designers, building owners and manufacturers .

Inappropriate design, control, sizing, and installation of heat pumps within buildings.

Gap between product and building performance

❖ Limited the potential of the heat pump technology as an integrated part of efficient buildings.

1. Background - Scope of the Project

Scope of the Project

❖ Provide shared viewpoints and transparent technological information transfer on heat pumps between technical experts, building owners and policymakers

- **Testing procedures**
- Energy calculation in buildings
- Design and commissioning guidelines
- Field performance monitoring

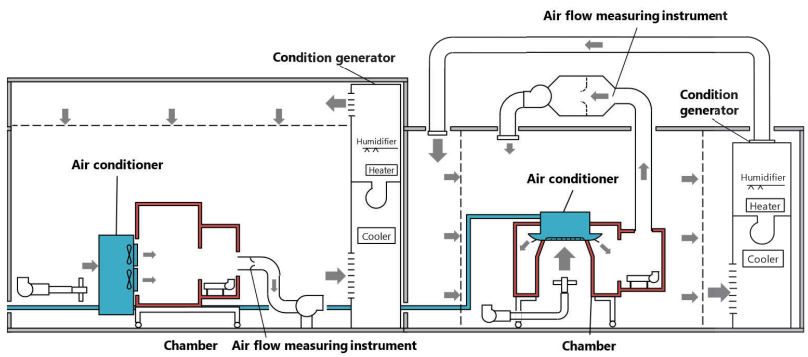
1. Review presently adopted testing methodologies and performance rating standards for air conditioners and heat pumps (Category A standards);
2. Review new testing procedures able to assess the performance of HPs and ACs when operated under the same control as operated in buildings (Category B standards);
3. Consider use of results to drive effective system design and control to maximize operational performance in buildings

2. Categories of Testing Standards

	Category A standards:	Category B standards:
Operation mode during tests	❖ Proprietary control to forcibly impose steady-state condition during tests. ❖ Provide reliable hardware performance but does not characterize operation performance.	❖ System operated under the same control as operated in the buildings. ❖ Provide reliable hardware and operation performance characterization of the tested unit.
	*obstinately considered indispensable to maintain a high accuracy and reproducibility.	*evidence of comparable accuracy and reproducibility have been provided.

3. Current Standards – Category A

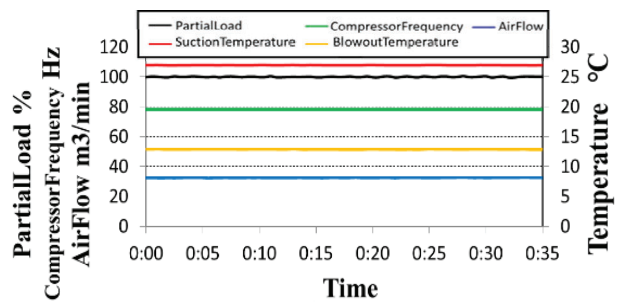
❖ Tests conducted while deactivating native control



$Q_{AC} = const$

*does not represent time-dependent response of the native-control.

Steady-state operation $0 = \sum Q_{BL} - Q_{AC}$



(a) Example of results of JIS test Cooling standard test

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3. Current Standards – Category A

No.	Title of standard	Year
1	ISO 5151. Non-ducted air conditioners and heat pumps – Testing and rating for performance	2017
2	ISO 13253. Ducted air-conditioners and air-to-air heat pumps – Testing and rating for performance	2017
3	ISO 15042. Multiple split-system air-conditioners and air-to-air heat pumps – Testing and rating for performance	2017
4	ISO 16358. Air-cooled air conditioners and air-to-air heat pumps – Testing and calculating methods for seasonal performance factors – Part 1: Cooling seasonal performance factor, Part 2: Heating seasonal performance factor, Part 3: Annual performance factor	2013
5	EN 14511-1, 2, 3. Air conditioners, liquid chilling packages and heat pumps for space heating and cooling and process chillers, with electrically driven compressors	2022
6	EN 14825. Air conditioners, liquid chilling packages and heat pumps, with electrically driven compressors, for space heating and cooling - Testing and rating at part load conditions and calculation of seasonal performance	2022
7	AHRI 210/240. Performance Rating of Unitary Air-conditioning & Air-source Heat Pump Equipment	2020
8	AHRI 340/360. Performance Rating of Commercial and Industrial Unitary Air-conditioning and Heat Pump Equipment	2022
9	AHRI 310/380. CSA-C744-17. Packaged Terminal Air-conditioners and Heat Pumps	2017
10	AHRI 550/590. Performance Rating of Water-chilling and Heat Pump Water-heating Packages Using the Vapor Compression Cycle	2023
11	AHRI 1230. Performance Rating of Variable Refrigerant Flow (VRF) Multi-Split Air-conditioning and Heat Pump Equipment	2023
12	ANSI/ASHRAE Standard 37-2009 (RA 2019). Methods of testing for rating electrically driven unitary air-conditioning and heat-pump equipment	2019
13	ANSI/ASHRAE 206-2013 (R2017). Method of Testing for Rating of Multipurpose Heat Pumps for Residential Space Conditioning and Water Heating	2017
14	JIS B 8616. Package Air Conditioners	2015
15	JIS B 8627. Gas Engine Driven Heat Pump Air Conditioners	2015

Current rating standards are reviewed in the following aspects:

- ❖ Targeted system,
- ❖ Test method,
- ❖ Test conditions,
- ❖ Unit control during tests,
- ❖ Performance indices and part-load test requirements
- ❖ Tolerance of measurement uncertainty.

Test condition	Dry-bulb (wet bulb) indoor temperature	Dry-bulb (wet bulb) outdoor temperature
Cooling	27 °C (19 °C)	35 °C (24 °C)
Heating	20 °C (14.5 °C)	7 °C (6 °C)
Heating*low T	20 °C (14.5 °C)	2 °C (1 °C)

Test condition	Cooling (heating) capacity (JATL)	Cooling (heating) capacity (Waseda)	Error
Cooling	7038 W	6926 W	-1.6%
Heating	(7845 W)	(7730 W)	-1.5%
Heating*low T	(8927 W)	(8715 W)	-2.4%

4. New Testing Methods and Rating Standards – Category B

- Unit set up as in a building installation.
- Automated test sequence within a test bin.
- Unit performance when operated under its native control and using its own thermostat.
- Capture the interaction of the system with building thermal features.
- Characterise efficiency losses of variable-speed units. (defrost, on/off cycles, etc.)
- COP: Prevent manufacturer from artificially inflating the efficiency.

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4. New Testing Methods and Rating Standards – Category B

Institution	Test scope	Heating conditions	Cooling conditions	Building thermal inertia	3Rs analysis
Waseda University	Emulator-type load-based test for <u>air-to-air units</u>	2 tests defined consistently with JIS B 8515 for heating operation *partial-load at 25% of max capacity **(tentative)	3 tests defined consistently with JIS B 8515 for heating operation *partial-load at 25% of max capacity	Simulated thermal capacitance (sensible and latent) of building interior included in load calculation	Repeatability (completed) Reproducibility (completed) Representativeness (ongoing)
CSA	SPE-07:23 load-based and climate-specific test for <u>air-to-air units</u> (using emulator)	5 temperatures (-15 to 12.2C) plus one additional test for marine climate zone as well as optional test at lowest operating temp	4 temperatures (25 to 40C) plus one additional test for hot, dry climate zone	Simulated thermal capacitance (sensible and latent) of building interior included in load calculation	Repeatability (completed) Reproducibility (ongoing) Representativeness (completed)
BRI / Better Living	Load-based test for <u>VRF air-to-air units</u>	OC: 7C (DBT) 6C (WBT) IC: 20C (DBT) 15C (WBT)	OC: 35C (DBT) 24C (WBT) IC: 27C (DBT) 19C (WBT)	Artificial thermal capacitance (sensible and latent)	Repeatability (ongoing) Reproducibility (ongoing) Representativeness (ongoing)
BAM	Load-based test for <u>hydronic heat pumps</u>	5 or 6 outdoor temperatures in accordance with EN 14825:2022	Not applied yet (ongoing)	Defined within a simplified building model	Repeatability (completed) Reproducibility (ongoing) Representativeness (ongoing)
RWTH	Hardware in the Loop (HiL) for <u>building energy systems with hydronic heat pumps</u>	Outdoor conditions defined by weather data. Use reference days (~4 days) representing a whole year for a specific geographical location	See heating conditions. Depending on location, some days have cooling demand	Simulated by detailed Modelica model of a specific building and system to be studied	Repeatability (completed) Reproducibility (completed) Representativeness (ongoing)
CEPT and RMI	Load-based tests for <u>air-to-air units in humid climates</u>	*To be verified with the research group*	Investigating harmonization across jurisdictions and high humidity conditions	Artificial thermal capacitance (sensible and latent)	*To be verified with the research group*

4. New Testing Methods and Rating Standards – Category B - Waseda

Actual air conditioning operation

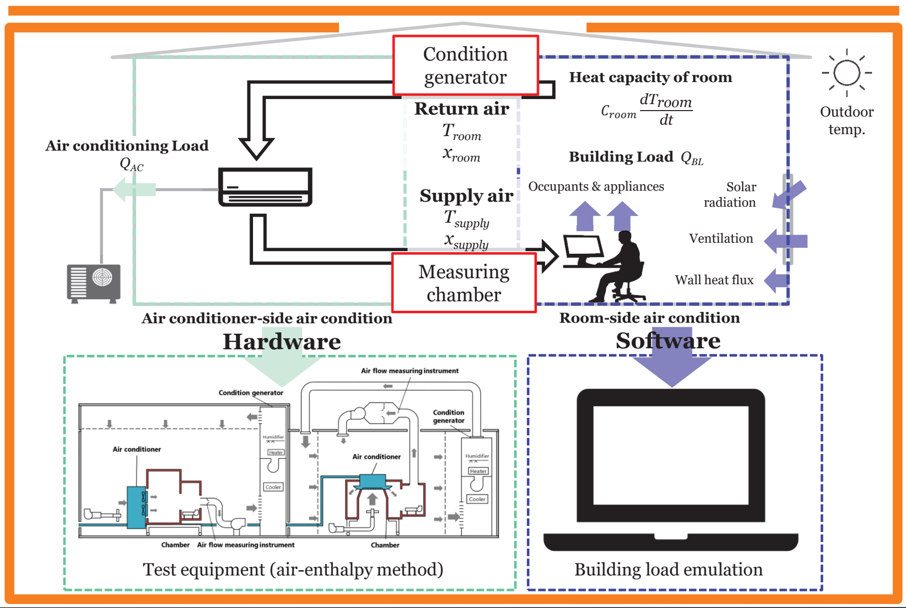
- ❖ Different control system response for different building and load features (challenges in reproducibility within different facilities).

Load-based test requirements:

- ❖ **Reproduce the room-side conditions.**
- ❖ **Measure the dynamic performance of the air conditioner.**

Emulator-type load-based tests

- ❖ Air-enthalpy testing equipment used for AC performance evaluation (Hardware).
- ❖ Building side conditions delegated to a numerical room emulator (Software).
- ❖ Interfaced by condition generator and measuring chamber (A/D converters).



*National project conducted between 2014-2016 for the development of a new testing method able to reproducibly capture the control response of variable speed drive units

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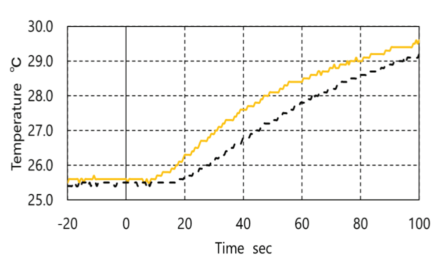
4. New Testing Methods and Rating Standards – Category B - Waseda

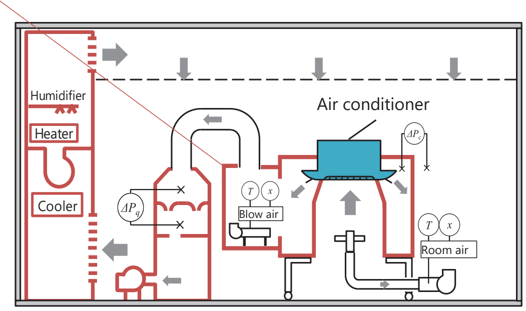
Assess factors that affect trackability and delay in measuring modulations of the supply and return air conditions, to verify suitability to perform dynamic tests.

- ❖ **calculation time delay of the emulator;** (< 1 s)
- ❖ **time delay of the signal from various sensors;**
- ❖ air flow rate and air condition tracking of the measuring chamber;
- ❖ temperature and humidity tracking at the condition generator;

②**Sensors delay**
Sensor response delay **15 sec**
Transportation delay **~15 sec**



(negligible delay compared to the system dynamics)



Reference room thermal time constant ~ 5000 s

4. New Testing Methods and Rating Standards – Category B - Waseda

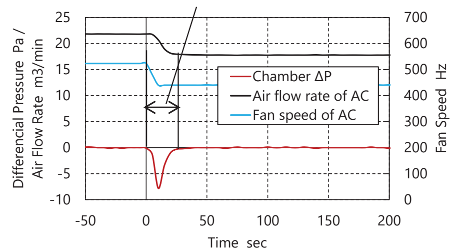
Assess factors that affect trackability and delay in measuring modulations of the supply and return air conditions, to verify suitability to perform dynamic tests.

- calculation time delay of the emulator;
- time delay of the signal from various sensors;
- **air flow rate and air condition tracking of the measuring chamber;**
- temperature and humidity tracking at the condition generator;

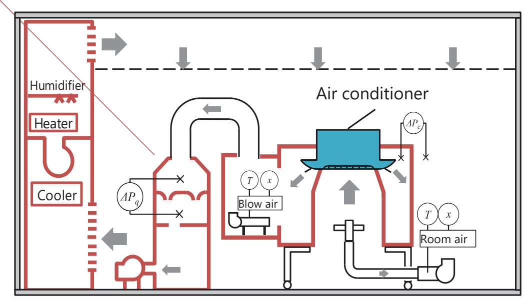
③Air flow measuring point

Differential pressure control delay
25 sec

25 sec



(negligible delay compared to the system dynamics)



Reference room thermal time constant ~ 5000 s

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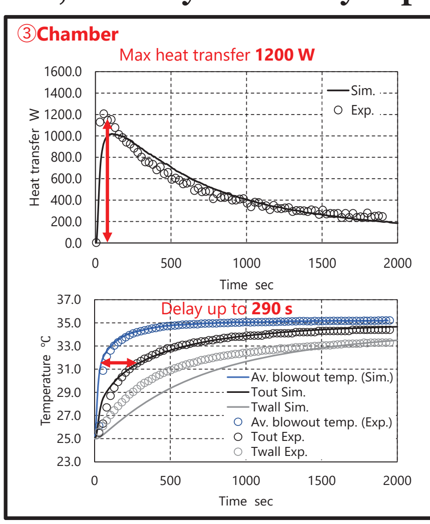
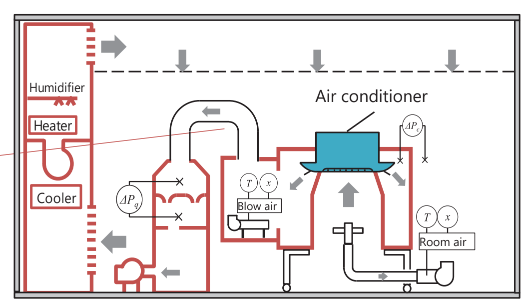
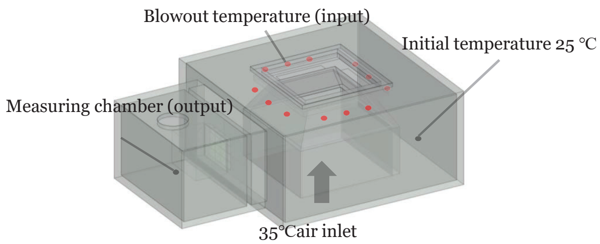




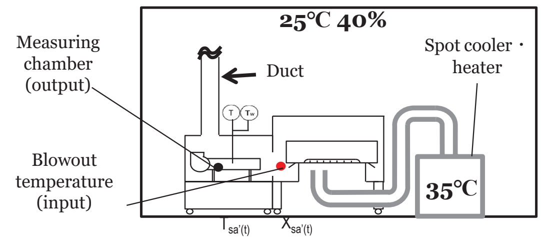
Reference room thermal time constant ~ 5000 s

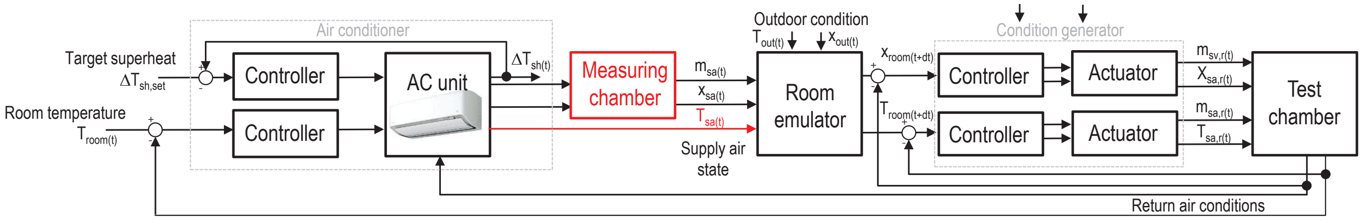
4. New Testing Methods and Rating Standards – Category B - Waseda

Thermal inertia of the measuring chamber is bypassed with a grid of 12 thermocouples



The grid of thermocouples is calibrated to steady-state measurements through the measuring chamber





bypassed thermal inertia of the measuring chamber without compromising sensors accuracy

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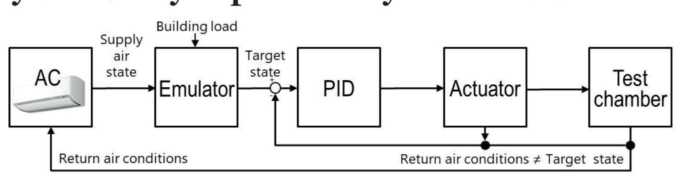

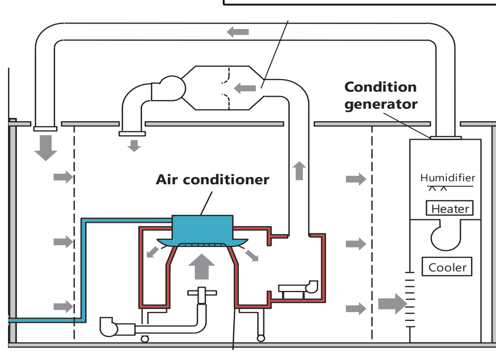

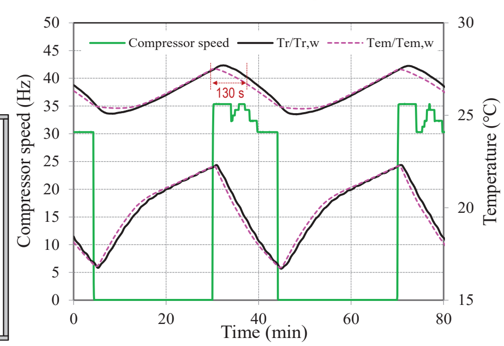

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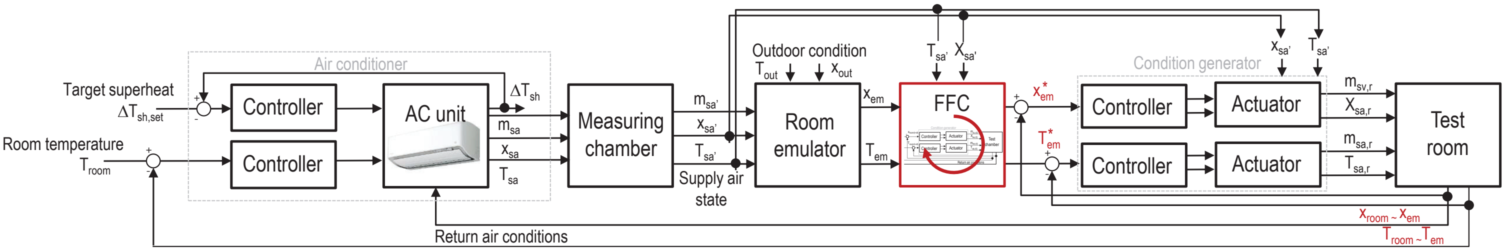
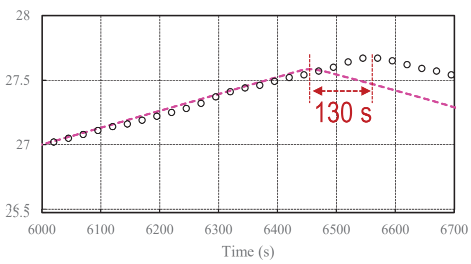
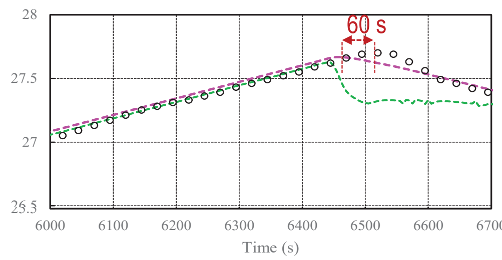
4. New Testing Methods and Rating Standards – Category B - Waseda



$$T^*_{em}(t+dt) = \frac{\frac{T_{em}(t+dt)-2T_{em}(t)+T_{em}(t-dt)}{25} + 0.0053\frac{T_{em}(t+dt)-T_{em}(t)}{5} + 0.00003407T_{em}(t+dt) + 0.028\frac{+2T^*_{em}(t)-T^*_{em}(t-dt)}{25} + 0.0058\frac{T^*_{em}(t)}{5}}{\frac{0.028}{25}+\frac{0.0058}{5}+0.000034082}$$



Feed-forward compensation to recalibrate the signal from the emulator and minimize error and delay



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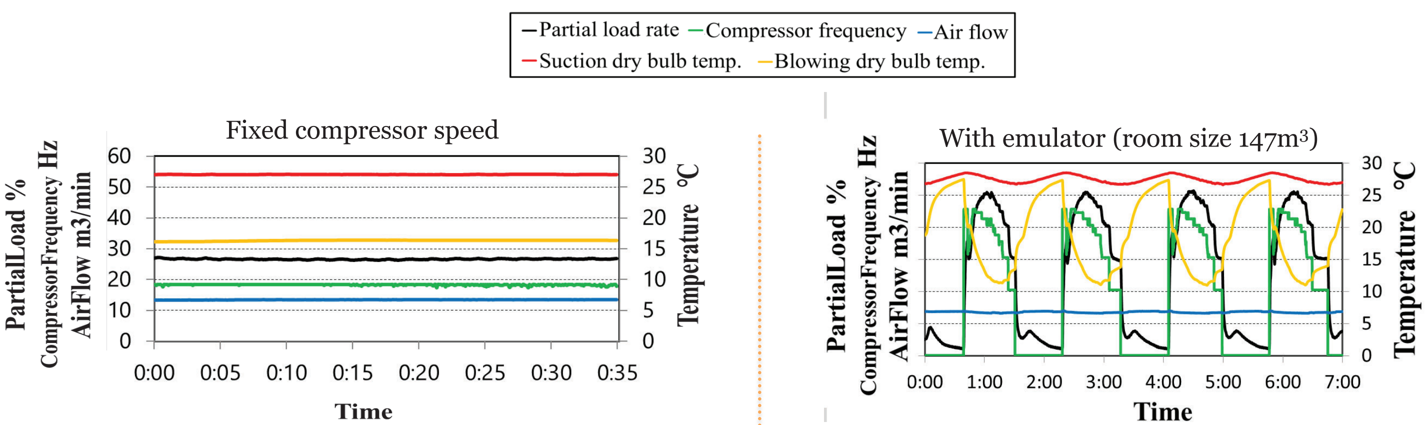
4. New Testing Methods and Rating Standards – Category B - Waseda

LOAD 25%, Indoor 27 °C, Outdoor air temp. 29°C

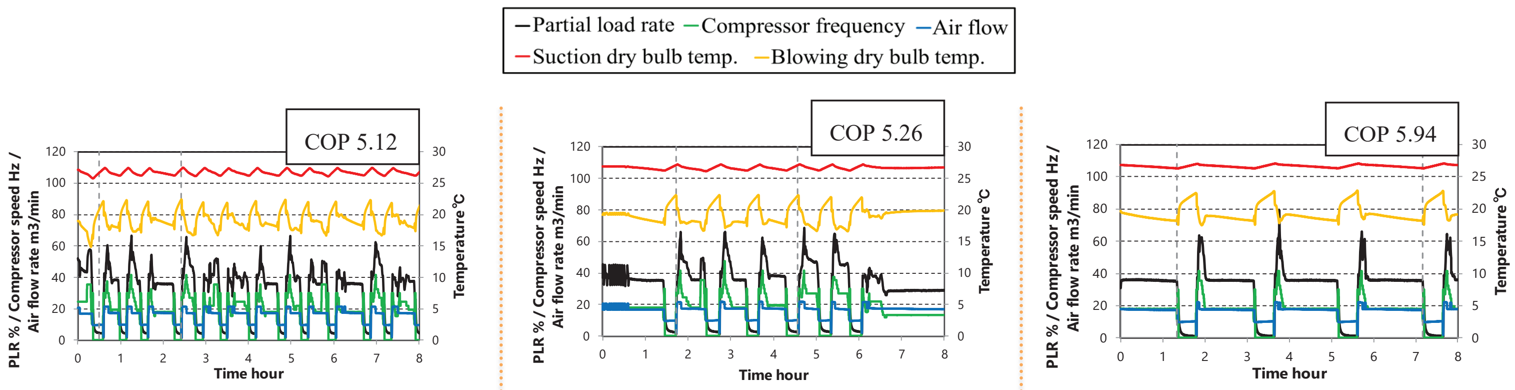


(COP 7.13)

(COP 5.58)

Different performance at corresponding conditions between proprietary- and native- control (approx. 25%)

4. New Testing Methods and Rating Standards – Category B - Waseda



30% Partial load (75m³) | 30% Partial load (147m³) | 30% Partial load (300m³)

❖ **Freedom to test the system in built environments with different size and characteristics.**

❖ **Results demonstrate evidence for performance interaction with building features.**

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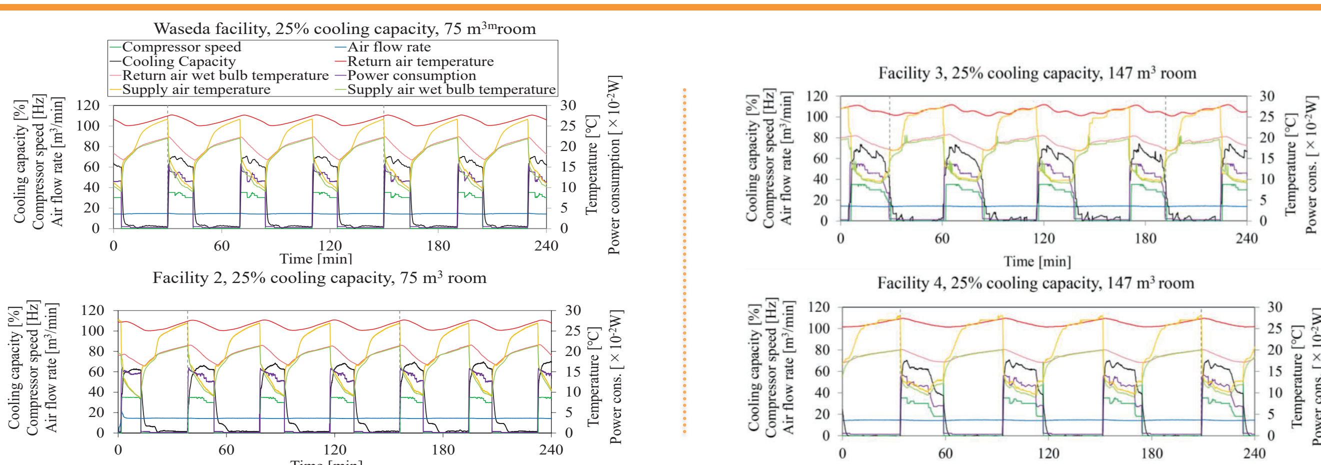
4. New Testing Methods and Rating Standards – Category B - Waseda

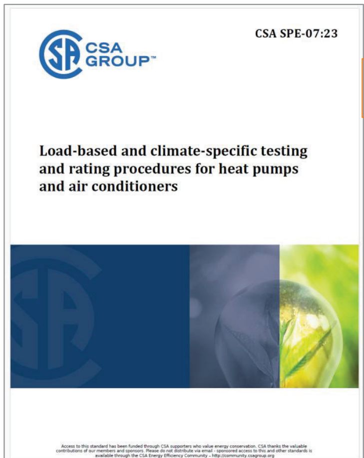


Conditions	COP Waseda	COP Facility 2	COP Facility 3	COP Facility 4	Deviation from average
Low load virtual room 1	5.34	5.57	5.39	5.33	**3.01 %**
Low load virtual room 2	5.37	5.22	5.23	5.30	**1.70 %**
Mid load virtual room 1	6.24	6.10	6.04	6.03	**2.25 %**

Evidence for similar reproducibility level between Category A and B standards.

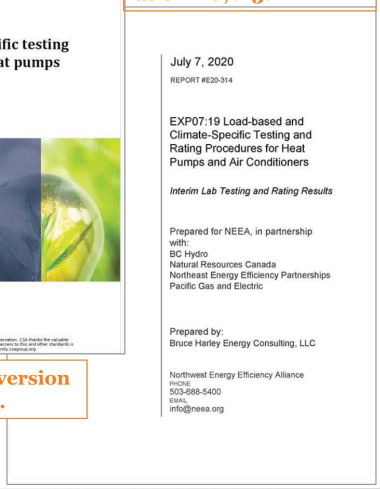
4. New Testing Methods and Rating Standards – Category B - CSA

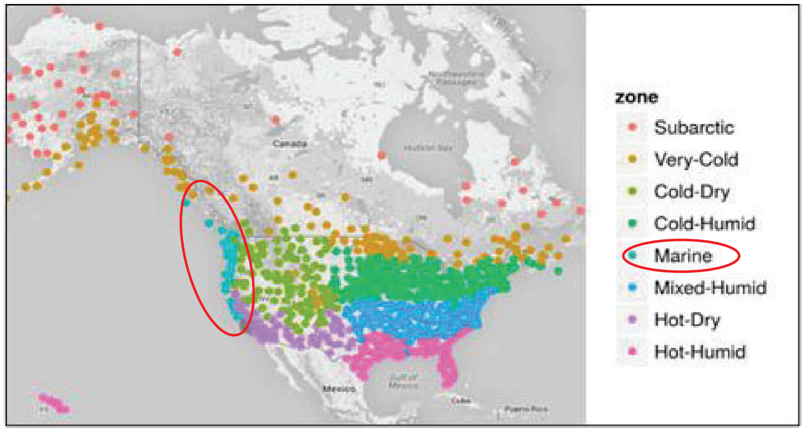
❖ **Published test method including both test procedures and performance rating calculations.**


CSA SPE-07:23
CSA GROUP
Load-based and climate-specific testing and rating procedures for heat pumps and air conditioners

Technical review version published in 2019.

Revised and published as SPE-07:23.


July 7, 2020
REPORT #E20-314
EXP07:19 Load-based and Climate-Specific Testing and Rating Procedures for Heat Pumps and Air Conditioners
Interim Lab Testing and Rating Results
Prepared for NEEA, in partnership with:
BC Hydro
Natural Resources Canada
Northeast Energy Efficiency Partnerships
Pacific Gas and Electric
Prepared by:
Bruce Harley Energy Consulting, LLC
Northwest Energy Efficiency Alliance
PHONE
503-688-5400
EMAIL
info@neea.org



SPE07 uses load-based tests for both heating and cooling operation in order to calculate a set of Seasonal Coefficient of Performance (SCOP) values, for seven different North American climates.

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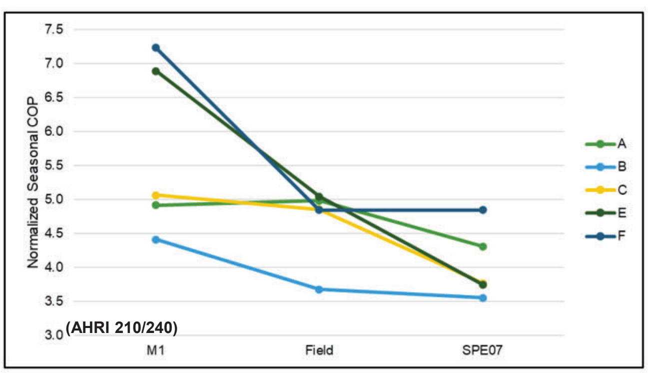
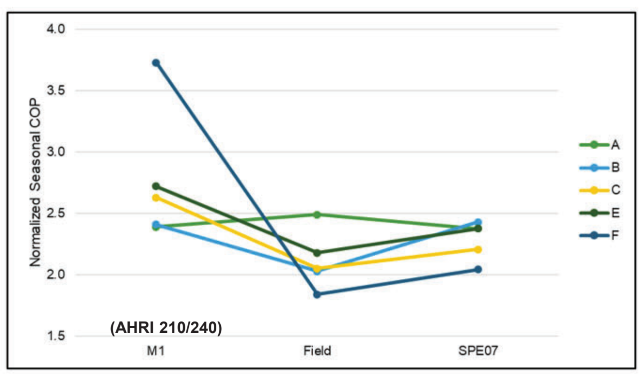
4. New Testing Methods and Rating Standards – Category B - CSA

Representativeness Study



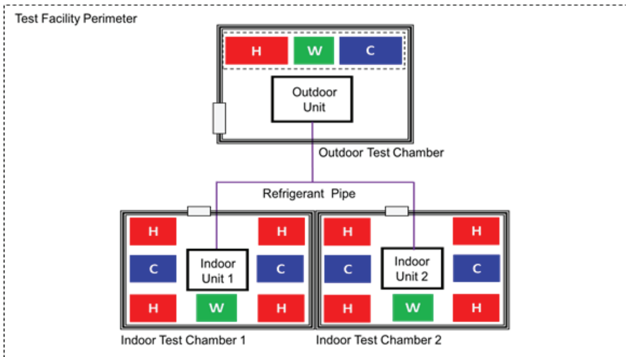


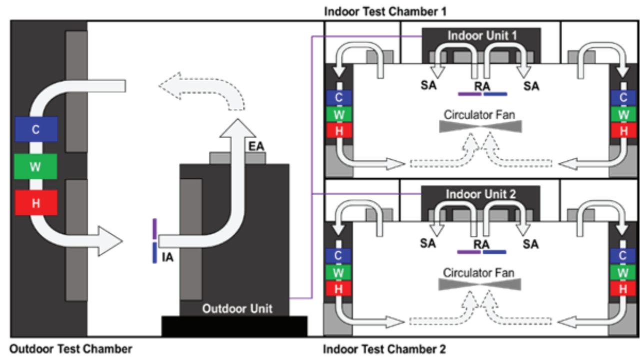
	Cooling RMSE		Heating RMSE		Cooling MAPE		Heating MAPE	
	SPE07	M1	SPE07	M1	SPE07	M1	SPE07	M1
Ducted	0.74	0.45	0.26	0.40	13%	9%	11%	17%
Ductless	0.92	2.14	0.20	1.39	13%	43%	10%	64%
Combined	0.82	1.40	0.24	0.93	13%	22%	10%	36%

SPE07 results shows smaller errors and better representativeness of field operation.

4. New Testing Methods and Rating Standards – Category B - Better Living

❖ **The purpose of this proposed test protocol is to improve the testing and evaluation of variable refrigerant flow (VRF) systems, covering especially low partial-load ratio.**





	Heating mode	
	Heating capacity, kW	Power consumption, kW
Catalogue value (rated)	25.00	6.43
Measured value (real)	23.88	6.48

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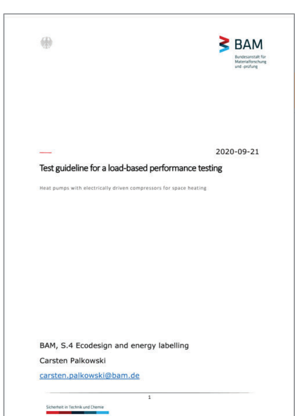
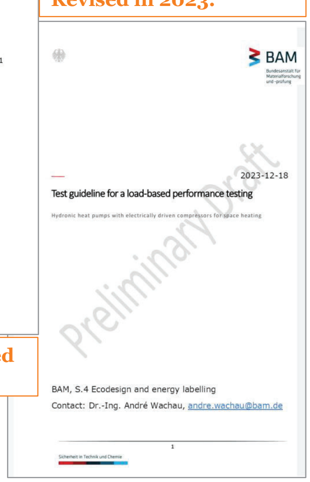
4. New Testing Methods and Rating Standards – Category B - BAM

❖ **The Federal Institute for Materials Research and Testing (BAM) assessed the current standards (EN 14511 and EN 14825).**

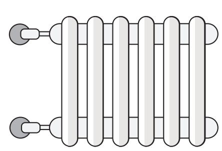


Technical draft published in 2020.

Revised in 2023.

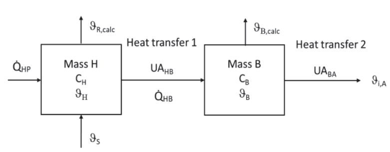


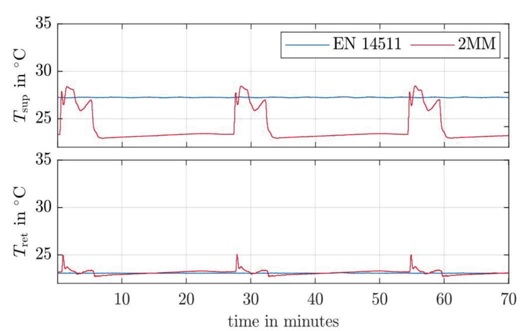
❖ **For hydronic heat pumps**



❖ load-based test with active control to overcome issues of current tests.

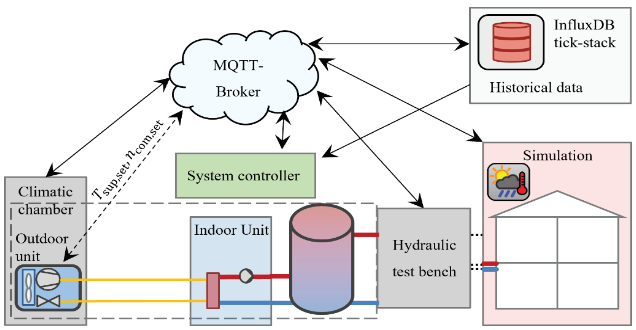
❖ Method refined with a simplified building model (emulator) for reproducible response in different facilities and enhanced representativeness.

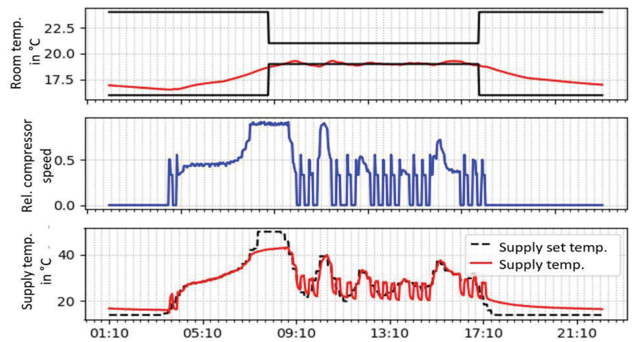




4. New Testing Methods and Rating Standards – Category B - RWTH

- **The Hardware-in-the-Loop approach couples hardware and software in real-time.**
- RWTH Aachen University developed a method for testing the holistic building energy system, including the hydraulic transfer system, PV-systems or thermal energy storages.
- The building performance simulation is a multi-zone Modelica model.





5. Concluding Remarks and Prospects

- **Testing methodologies provide fundamental measurements for:**
  - Development of effective MEPS
  - Define the basis for performance rating
  - Capturing and verifying design and operation characteristics
  - Stimulate technology developments, evidence-based policies, and guide consumers to beneficial choices.

*The performance of heating and cooling technologies cannot be separated from the building envelope and vice versa.

- **Opportunities from new test methods where systems are operated under the same control as in buildings:**
  - Load based tests rely on the same equipment and instrumentation required by current standards.
  - It can be arguably stated that load-based tests might require more time for test convergence than current standards, but this may be related to the necessary learning curve needed for new procedures
  - Testing heat pumps under the same control as operating in field installations provides opportunities for automating tests
  - Results provide additional value in terms of representativeness of field operation and transparency.

*The review explores potential convergence between product-level performance ratings and building-level energy calculations, simulations, equipment sizing, and policies.

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

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

Baolong Wang
Tsinghua University
October 2024

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CONTENTS

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1 Background

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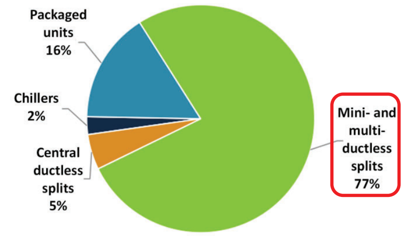
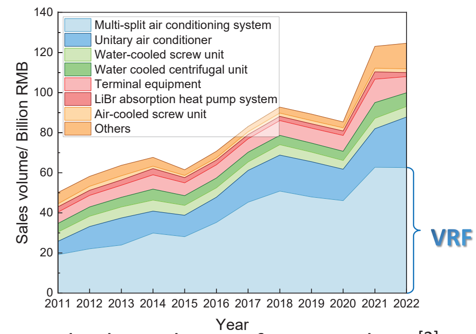
- **Heat pumps,** including RAC, VRF and so on, have been applied in various commercial buildings, residential buildings and industrial buildings worldwide.
- Field performance of could be much different due to complex field factors, such as indoor environmental demand, ambient parameters, installation, 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]

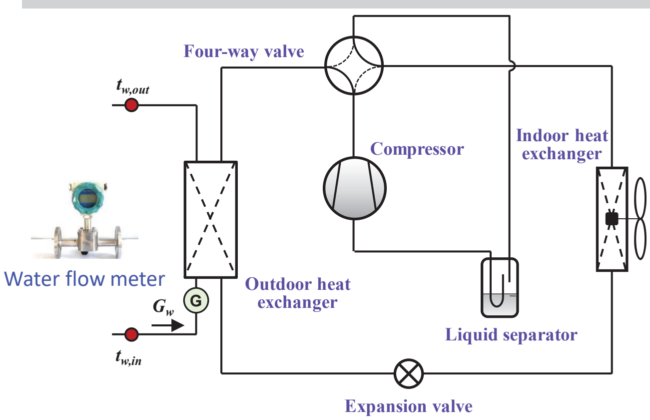
[1] International Energy Agency. The future of cooling: Opportunities for energy- efficient air conditioning (2019).
[2] Central Air Conditioning Market, 2010-2022 China Central Air Conditioning Market Summary Report.

2 Current field monitoring methods

ANNEX 88 EBC

- **Air-water (hydronic) heat pump**

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

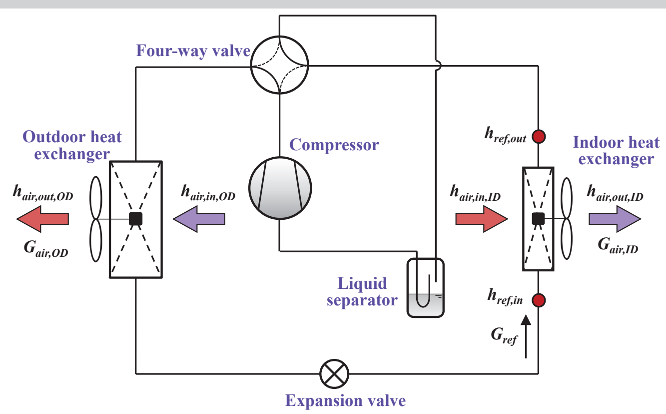


Heat transfer on outdoor unit: $Q_{out,w} = G_w c_{pw}\left(t_{w,in} - t_{w,out}\right)$

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**.



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

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

2 Current field monitoring methods

ANNEX 88 EBC

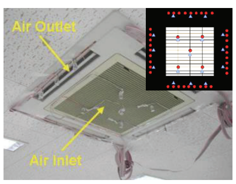
Indoor side AE method

(a) Air hood method

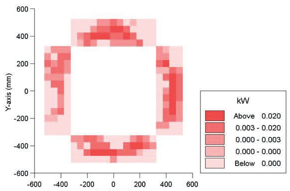
- Air hood introduces all the air outlets of the indoor unit into an **air duct**.
- **Not convenient** because it **disturbs the regular operation for both users and units**.

(b) Air sampling method

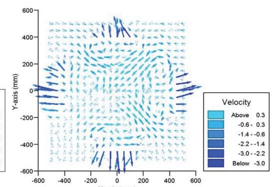
- The air inlet and outlet volumes are calculated by integrating distributed sensors and each measuring point's correction factor.
- The temperature and humidity sensors are arranged in each measuring point area.
- Thermal and vector velocity distribution in the indoor unit is **complex and exhibits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

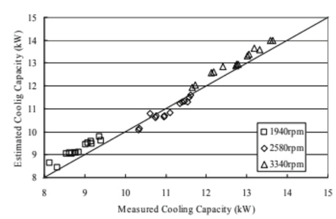
2 Current field monitoring methods

ANNEX 88 EBC

(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**.

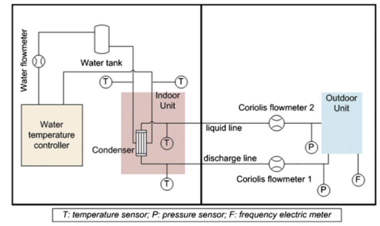
2 Current field monitoring methods

ANNEX 88 EBC

- **(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.

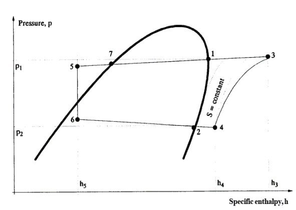
(e) Compressor energy conservation (CEC) method

- 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**.

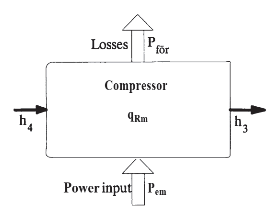
3 Existing standards and protocols for field monitoring

ANNEX 88 EBC

- **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.

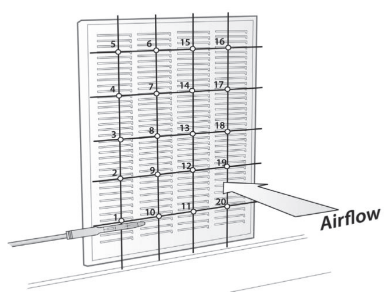
3 Existing standards and protocols for field monitoring

US's specification

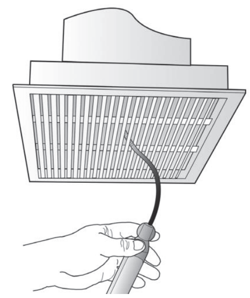
- **ASHRAE Standard 221** provides a method to field measure and estimate the capacity and efficiency and score the performance of an installed HVAC system. It provides uniform methods of measurements and testing procedures for airflow, temperature, enthalpy, and power. Besides, test instruments, specifications, 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

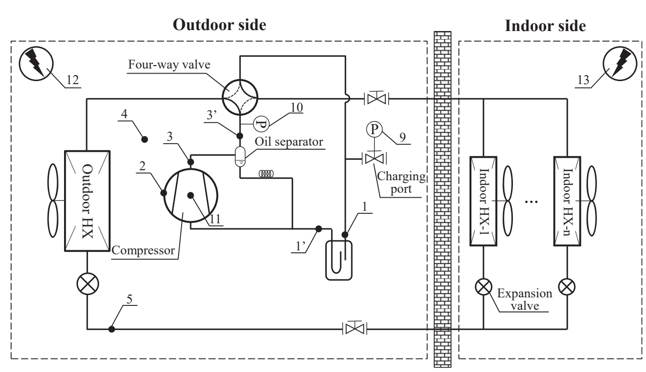
China's specifications and standards

- 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: Indoor side DBT	Indoor side WBT	Outdoor side DBT	Outdoor side WBT	Test item	Necessity
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.

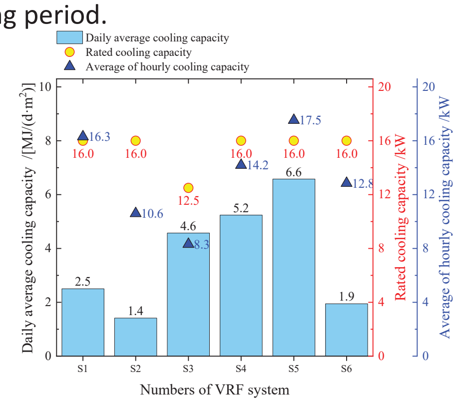


Schematic of sensors installation by CEC method on VRF system

ANNEX 88 EBC

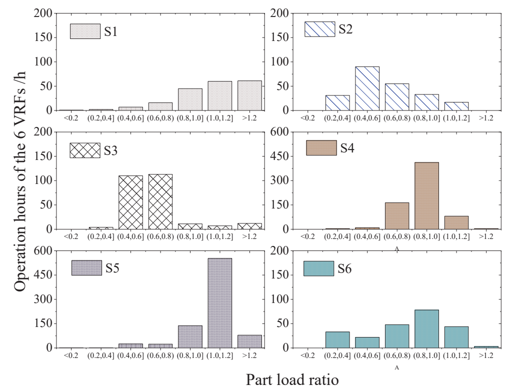
● Case 1 (VRF)

- **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.



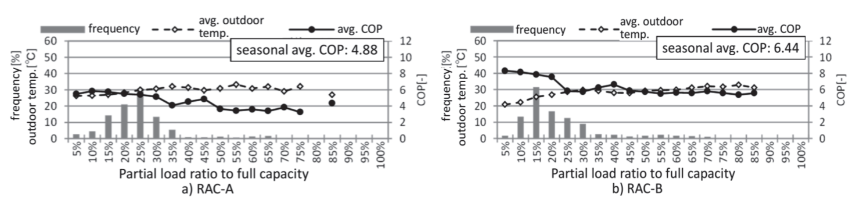
Part load rate and operation hours of the 6 VRFs

4 Existing data on monitored heat pump systems

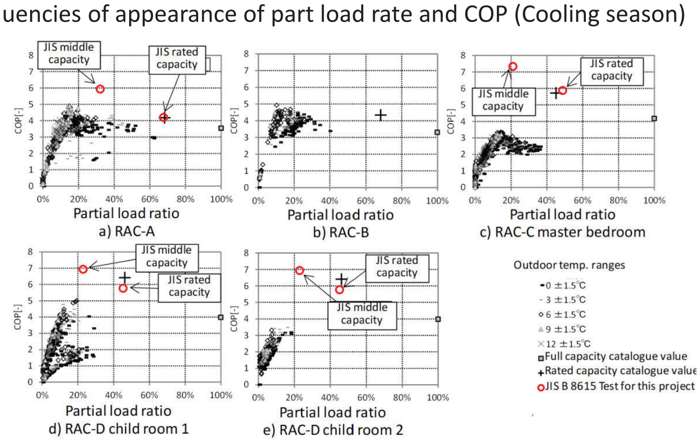
ANNEX 88 EBC

● 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.

ANNEX 88 EBC

Thanks

Technology Collaboration Programme
by iea