VeraSol

Walk-in Cold Rooms for Horticultural and Agricultural Produce in Tropical Climates:

Field Performance Tests for Temperature, Cooling Capacity and Energy Consumption

AUTHORS

This test protocol has been prepared for the VeraSol program by independent consultants Jeremy Tait and Sonja Mettenleiter. We are grateful for the dedication and substantial technical input provided by a volunteer working group of independent experts and specialists on performance and testing of walk-in cold rooms and associated equipment. We would like to recognize and thank all members of the working group, contributors and peer reviewers[1]. We are grateful for the loan of a WICR insulated enclosure by MISA Cold Rooms (Italy) for pilot tests using the draft protocol, carried out by Wageningen University Research in their ATP facility. We also thank Kuza Freezer (Kenya) for providing their cold room installed on Rusinga Island (Kenya) for pilot field tests carried out in collaboration with Kijani Testing Ltd.

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1. Introduction

This test protocol has been prepared for the VeraSol program by a working group of independent experts and specialists on performance and testing of walk in cold rooms and related equipment. The working group included experts in the testing of refrigerated transport containers and reefers the UNECE ATP test protocol (ATP is the French acronym for the Agreement on the International Carriage of Perishable Foodstuffs and on the Special Equipment to be Used for Such Carriage2). The working group included experts in the testing of refrigerated transport containers and reefers under the ATP and was coordinated by Jeremy Tait and Sonja Mettenleiter from May 2024 to June 2026 under contract to CLASP, which manages the VeraSol program. Pilot field testing of a commercial WICR unit was carried out at the Kuza facility in Rusinga Island, Homa Bay, Kenya in May 2026 to provide practical checks of the approach and details of set up and testing.

2. Scope

This document specifies the standard conditions and the field test methods for determining the cooling capacity and efficiency ratings of walk in cold rooms (WICR) where they are set up designed for use in hot, temperate and moderate climate zones (respectively 43°C, 32°C and 27°C) for storage of chilled horticultural and agricultural produce. It is generally intended to cover WICR in the size range 10m^3 to 100m^3, equivalent to a storage capacity of 2 to 20 metric tonnes.

The methodology is designed assuming that a refrigerant vapour compression system is providing the cooling power. How other cooling technologies would fare under such tests, such as absorption or evaporative cooling, has not yet been evaluated. Power supply for testing is assumed to be a reliable electrical grid connection[3].

This document does not address:

- WICR for freezing of produce and frozen storage of produce
- WICR designed for healthcare uses and vaccine storage
- Dedicated pre-coolers (designed solely for rapidly reducing the temperature of produce in batches, prior to its storage).
- Food safety aspects of performance regarding hygiene and storage temperatures, which depend upon regulations in the country of use.
- Performance associated with use of solar photovoltaic or any power supply other than mains grid.

Whilst instructions are included to enable testing to be carried out if thermal energy storage (TES) devices are supplied as standard with the WICR, the protocol does not attempt to quantify nor verify the performance of TES devices.

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[2] ATP is an Agreement between States to ensure safe transport of perishable foodstuff in frozen and chilled states by road and rail when transported between states. Primarily, it sets out categorisation by functionality, performance, marking and certification requirements for the equipment used to transport perishable foodstuff. ATP is managed by the Sustainable Transport Division of the United Nations Economic Commission for Europe (UNECE). A copy of the test standard document is available here: https://unece.org/text-and-status-agreement.

[3] The next version of this document will include solar power supply.

2.1. Reasons for having a field test methodology

A simple and affordable-to-implement test method is needed, without use of a thermal chamber, to confirm if the system runs – to a reasonable estimation as it should/is designed to do – in the following circumstances:

i. After installation as part of the commissioning or acceptance process
ii. Following repairs or concerns about performance in the field
iii. As part of the product development process by manufacturers / suppliers to verify or inform design changes
iv. For the manufacturer to ensure the quality of installation done by third parties, informing warranties
v. As a spot-check of a registered or procurement-qualified model in the field as part of due diligence quality checks (if/when a WICR registration system is established by VeraSol or a funding body approves a model for procurement or subsidy)
vi. Any other circumstances in which a test chamber is inaccessible or too expensive to consider and an indicative performance check would be useful.

3. Terms and Definitions

3.1. Parameters and properties

3.1.1. Gross volume

Total internal volume of the cold room.

Note: The space occupied by evaporator(s), ducts, racking and any other equipment located inside the WICR is included in the gross volume.

3.1.2. Seven-eighths cooling time (SECT)

The time needed for a temperature to drop by seven-eighths of the difference between the initial temperature and the target temperature.

Note: This is typically used as a cold room benchmark for performance, given that attaining full target set point can take a long time for some systems and conditions.

3.1.3. Half cooling time (HCT)

The time needed for a temperature to drop by half of the difference between the initial temperature and the target temperature.

3.1.4. Storage capacity of produce

The amount of produce that can be accommodated in a WICR during normal operation as designated by the manufacturer, measured in kg.

Note 1: Stated storage capacity generally assumes that the stored load is already at target temperature when loaded.

Note 2: The document: Guidelines: Design Specifications, Performance Guidelines and Testing Procedure for Solar Cold Storage with Thermal Energy Storage Back Up, published by the Ministry of New and Renewable Energy (MNRE), India in February 2025 stipulates that ‘Internal volume of temperature-controlled cold room storage space shall be 150 cubic feet per MT irrespective of the product stored’ (see section 3.1 Cold Room). This equates to a conversion of 4.25m^3 per MT.

3.1.5. Chilled storage temperature

A storage temperature generally covering a range that falls between -5°C and 18°C. Specific sub-sets of this general range are used for applications (see 4.1).

3.1.6. Frozen storage temperature

A storage temperature generally below -18°C but may extend up to -5°C.

3.1.7. Storage temperature

Target storage temperature that is intended to be maintained within the operating walk-in cold room.

3.1.8. Precooling

The initial faster cooling of harvested produce to remove heat from the produce before it is kept for long term storage or transportation.

3.1.9. Operational climate zone temperatures

The climate zone(s) under which the storage temperature(s) can be achieved by the WICR, as declared by the manufacturer. Climate zones are set out in 4.1.

3.1.10. Autonomy

The time taken for the highest measured air temperature inside the WICR to reach a pre-determined threshold level after the power supply is stopped.

3.1.11. Thermal energy storage (TES) capacity

Thermal energy storage capacity is the maximum amount of heat or cold a material can store for release later when required. Measured in kWh or MJ.

3.1.12. Heat leakage rate

The rate of heat loss through the insulated enclosure of the WICR at the rated operating conditions[4] when at stable operating conditions. Measured in kW.

3.1.13. Off-grid power supply

Power system that is isolated or independent of a utility electrical grid which instead depends on self-contained power generation and may include electrical storage, used where grid access is not possible, unavailable or unreliable.

3.1.14. Unreliable grid supply

A public electrical grid supply system that cannot deliver power consistently or maintain required voltage and frequency sufficient to enable reliable operation, often without prior notice of problems.

[4] This means at the highest rated ambient temperature (Table 1) and the target storage temperature (Table 2).

3.1.15. Limited supply

Electrical supply of reasonable or good quality but delivering not more than 22 hours of reliable power per day[5], for example at a set number of hours per day on virtually every day and known in advance. Maximum demand current limits may be imposed by the power provider.

Note: Examples of limited supplies include solar arrays, dedicated generators, renewable sources such as wind, or a mini-grid operating for fixed hours per day and/or with current limits that may be constant or variable in timing.

3.1.16. Reliable grid

Connection to an electrical network that is generally available for at least 22 hours per day on a planned basis and meets the international quality benchmarks for public supply reliability, voltage level and power quality such as IEC TS 62749[6] or EN 50160[7].

3.1.17. Total fan input power

Power (kW) absorbed by all fans in evaporator(s) (plus any permanently fitted air circulation fan unit(s)) inside the WICR when running at full speed.

3.1.18. Discharge airflow

Rate of flow of air from the evaporator or fan unit, measured in cubic metres per hour in unrestricted flow.

Note: See also ISO 5801 Fans — Performance testing using standardized airways.

3.1.19. Air turnover rate

The number of times per hour the volume of air in the empty cold room should theoretically pass through the heat exchanger due to operation of its fan(s). Equal to the air volume flow of the evaporator(s) in m^3/hour divided by the empty volume of the storage compartment in m^3.

3.1.20. Rated operating conditions

The combination of rated climate zone temperature and rated storage temperature that the manufacturer declares the unit can achieve for the declared performance parameters, see 4.1.

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[5] For comparison: to qualify for Tier 5 of the ESMAP multi-tier framework requires a minimum of 23 hours of power per day. For cooling systems, 23 hours per day is, to all intents and purposes, unlimited (most cooling systems would easily ride through 1 hour without power). 22 hours power out of 24 is a level at which system design steps may be needed to ensure comfortable ride-though.

[6] IEC TS 62749:2020 Assessment of power quality – Characteristics of electricity supplied by public networks. This standard sets out expected characteristics of electricity at the supply terminals of public networks for low, medium and high voltage at 50 Hz or 60 Hz.

[7] EN 50160:2011/A2:2019 Voltage characteristics of electricity supplied by public electricity networks. This standard describes the value ranges within which the voltage characteristics can be expected to remain at any supply terminal in public European electricity networks.

3.1.21. Stable operating conditions

A state of air temperature stability under which during a period of 12 hours, the average air temperature matches, within ±1.0°C, the corresponding points on the time-temperature curve. See 6.4.

Note: The temperature may vary over time due to compressor cycling and defrost cycles but stability relates to the comparability of the repeating cycles.

3.1.22. Representative cooling capacity

Measured cooling capacity of the WICR (W) when operating with the representative heat load at stable operating conditions and under thermostatic control (see 8.5).

3.1.23. Representative energy consumption

Measured energy consumption of the WICR (kWh/24 hours) when operating with the representative heat load at stable operating conditions and under thermostatic control (see 4.5). Indicative of typical energy consumption when WICR is operating for its intended purpose.

3.1.24. Representative heat load

Heat added inside the WICR of a level simulating a load incurred from stored produce so that WICR performance is tested to reflect its intended end-use. The level is calculated from the heat leakage rate and a factor selected according to the intended use classification. See 4.5.

3.2. Equipment types

3.2.1. Walk-in cold room (WICR)

A cooled and thermally insulated structure designed to maintain an artificially generated low temperature, sometimes with control of humidity; it can be free standing outdoors or located within another structure with at least one door that is large enough for a person to walk through but is not large enough for fully mechanised produce handling by forklift truck and similar.

Note: WICR are generally considered to have storage volume in the range $10m^3$ to $100m^3$, roughly equivalent to a storage capacity of 2 to 20 MT.

3.2.2. Prefabricated kit WICR

A WICR that is assembled on site from a kit that includes all components ready for assembly, without any rework of insulating panels, that can be set to use after a specified commissioning and adjustment process. Could be with floor or without floor.

3.2.3. Pre-assembled WICR

A factory-made fully functional WICR assembly that is transported to site ready for use with no on-site assembly required.

3.2.4. Customized WICR

A WICR assembled on site by staff of the supplier company using specified components and modular sub-systems and following a designated design and construction process with insulated panels cut to size and jointed on site. Such WICR are tailored to specific size and purpose with some design and sizing decisions made on site during construction.

3.2.5. Converted shipping container WICR

WICR made using an ISO shipping container (freight, 'dry' or intermodal container) through installing insulation, cooling system and power source.

Note: The most common size used for cold rooms is a 20ft container (6.09m long, nominal 33 m^3 volume) with internal dimensions 5.9 m long x 2.35 m wide x 2.39 m high.

3.2.6. Self-built WICR

WICR built from locally available materials and reconfigured components that are affordable and accessible at that time. These are, to all intents and purposes, unique constructions.

3.2.7. Compact refrigerating unit

A packaged single refrigerating unit assembled, filled and ready for use without the need for connecting any refrigerant containing parts. Also known as monoblock or integrated refrigerating unit.

3.2.8. Split system

A packaged refrigerating unit comprising one unit providing cooling to the cold room and one unit used for condensing the refrigerant, connected by pipework and assembled on site.

3.2.9. Intended purpose

Manufacturers may declare an intended purpose of the WICR as one of the following (see 4.2):

- Chilled storage only
- Chilled storage and limited pre-cooling

The following and other intended purposes are also possible but not in scope of this protocol:

- Dedicated pre-cooler
- Frozen storage only
- Frozen storage and limited freezing capacity.

3.2.10. Pre-cooler

A cooling device or approach specifically designed to remove the bulk of contained heat from produce as fast as possible before the produce is placed into cold storage or loaded for shipment to market. Could be either batch pre-cooler or continuous pre-cooler.

4. Standard rating of walk-in cold rooms

4.1. Rating conditions for climate zone and storage temperature class

Tests shall be carried out at the manufacturer's declared rated operating conditions for the WICR, within given tolerances. Manufacturers may declare performance at one or more climate zone and storage temperature class as set out in Table 1, Table 2 (preferred temperature classes for simplicity) and Table 3 (further sub-divided temperature classes). If more than one rated operating condition is declared, then the default climate zone for testing is the highest and the default storage class for testing is the lowest. Permutations of classes are shown in Table 7 with their associated nominal ΔT.

If stable operating conditions cannot be established at the rated operating conditions declared by the manufacturer then the unit cannot be considered compliant with those rated operating conditions. The unit may be tested at less demanding rated operating conditions.

Table 1. Climate zones and their temperature conditions (source: WHO).

Climate zone	Maximum rated ambient operational temperature of the WICR	Average air temperature in test chamber to be used during tests	Tolerance on the measured average value
Hot Zone	+43°C	+43°C	+/- 1°C
Temperate Zone	+32°C	+32°C	
Moderate Zone	+27°C	+27°C	

Table 2. Preferred chilled storage temperatures in three classes
(more comprehensive options for seven temperature classes are shown in Table 3).

Storage temperature class	Rated operational storage temperature range of the WICR	Average storage temperature during tests	Tolerance on the measured average value
Cold	0 to +2°C	+1°C	+/- 1°C
Cool	+7 to +10°C	+8°C	
Moderate	+13 to +18°C	+15°C	

Table 3. Chilled storage temperature in seven classes, according to USDA[8], and adopted by the government of India[9].
Note: Groups 1, 2 and 3 would be tested at the same temperature. (see preferred options for three temperature classes shown in Table 2).

Storage temperature class (USDA / Gov. of India)	Rated operational storage temperature range of the WICR	Storage temperature set point to be used during tests	Tolerance
Group 1: Fruits and vegetables	0 to 2°C with 90-95% relative humidity	+1°C	+/- 1°C
Group 2: Fruits and vegetables	0 to 2°C with 95-100% relative humidity		
Group 3: Fruits and vegetables	0 to 2°C with 65-75% relative humidity		
Group 4: Fruits and vegetables	4.5°C with 90-95% relative humidity	+4.5°C	
Group 5: Fruits and vegetables	10°C with 85-90% relative humidity	+10°C	
Group 6: Fruits and vegetables	13 to 15°C with 85-90% relative humidity	+14°C	
Group 7: Fruits and vegetables	18 to 21°C with 85-90% relative humidity	+19°C	

[8] See McGregor, B.M. 1989. Tropical Products Transport Handbook. USDA Office of Transportation, Agricultural Handbook 668). Available from: https://pdf.usaid.gov/pdf_docs/PNABA768.pdf.
[9] See Technical standard NHB-CS-Type 02-2010, Cold storage for fresh horticulture produce requiring pre-cooling before storage. Available from: https://nhb.gov.in/documents/cs2.pdf.

4.2. Purpose and use of walk-in cold rooms

The manufacturer's intended purpose of a WICR is closely associated with its cooling capacity and air flow plus other design factors. Intended purpose for WICR within the scope of this protocol may be rated as:

A. **Refrigerated storage only**
B. **Refrigerated storage and limited pre-cooling**

The intended purpose may be declared if the WICR meets the requirements for system effectiveness, cooling capacity and air flow as shown in Table 4.

This protocol does not specify the performance nor testing of equipment intended solely for pre-cooling.

Table 4. Cooling system requirements according to the declared 'intended purpose' of the WICR.

Intended purpose of WICR	System effectiveness requirement	Cooling capacity requirement	Internal air flow requirement
Refrigerated storage only	Attain the rated average storage temperature*	Empty pull-down time not exceeding 120 minutes**	Air turnover rate >40 /hour ***
Refrigerated storage and limited pre-cooling	Attain the rated average storage temperature*	Empty pull-down time not exceeding 60 minutes**	Air turnover rate >80 /hour ***

* When tested according to 8.5, steps 1, 2 and 3 for the highest rated climate zone. Note that the representative heat load is different for 'storage only' versus 'storage and limited pre-cooling', as shown in Table 5.
** When tested according to 8.2, steps 1 to 4 for the highest rated climate zone.
*** Calculated according to the formula below:
Air turnover rate, /hr = [Air flow rate] / [gross internal volume of the WICR]
Where:
Air flow rate = total air flow rate as declared in the technical specification for the evaporator(s), m^3/hr
Gross internal volume of the WICR is measured in m^3.

4.3. Thermal energy storage (TES)

The presence of thermal energy storage (TES) in a WICR system significantly affects its performance under testing and affects reproducibility and repeatability of results. This protocol does not attempt to quantify the performance of TES.

As specified in 3.1.11, TES devices supplied as standard with the WICR shall be left in place or installed according to manufacturer's instructions; if TES is an optional extra purchased separately then it shall not be installed for testing. The test report shall describe any TES included in the WICR.

4.4. Determination of the heat leackage rate of the WICR insulated enclosure

The relevant heat leakage rate as a declared property of the WICR is that for the temperature gradient (ΔT) at the rated operating conditions used during the test, i.e., the difference between the highest rated climate zone temperature (Table 1) and the target storage temperature (Table 2). If a k-value or heat leakage rate is known for a ΔT that does not align with the rated operating conditions, if the difference in ΔT values is less than 4°C then Equation 1 may be used to extrapolate to the required ΔT.

Note: The 4°C extrapolation limit reflects principles of temperature interpolation limits set out in IEC 62552 Part 3 Household refrigerating appliances - Characteristics and test methods - Part 3: Energy consumption and volume, Annex E.

$W_1 / \Delta T_1 = W_2 / \Delta T_2$

Equation 1. Proportional adjustment of a heat leakage value based on the ΔT.
Note: equation is valid only when the difference between ΔT_1 and ΔT_2 is less than 4°C.

Where:
W_1 and ΔT_1 are the known heat leakage and temperature difference conditions
ΔT_2 is the required temperature difference at operating conditions
W_2 is the required heat leakage estimate.

The heat leakage rate as a declared property of the WICR may be determined by following one of the methods described in 1 to 3 below:

1. By testing as section 8.5, in which case an initial estimate of the heat leakage rate is needed as a starting point for the iteration during the test that is set out in 8.5. The initial estimate of heat leakage can be determined using Equation 2. Estimate of heat leakage.
2. By adopting a heat leakage rate declared by the WICR manufacturer if supported by a test report from the manufacturer, or a fully explained calculation according to established principles, as provided by the manufacturer.
3. By calculation method according to a published national or international methodology. Details of the calculation steps and reference to the adopted calculation methodology shall be provided in the test report.

Note: Approaches to calculation of heat leakage rate include EN 16855-1 or -2.

Under option 1 above, to prepare for a k-value test according to 8.5 it is necessary to determine an initial estimate of the heat leakage rate to set a suitable heater input power that is then adjusted iteratively during the test. An initial estimate of the heat leakage rate can be determined using Equation 2. Estimate of heat leakage.

$W_{est} = S_i \times \Delta T \times \lambda / d$

Equation 2. Estimate of heat leakage

Where:
W_{est} = initial estimate of the heat leakage rate, Watts
S_i = internal surface area of the WICR insulated enclosure, m^2
ΔT = intended temperature difference between mean air temperature inside the WICR and mean air temperature of test chamber, °C
λ = U-value of the insulation material, W/m.°C (for example, a typical value for polyurethane is 0.025)
d = estimated average thickness of the insulation of the enclosure, m

If a calculated k-value or heat leakage rate is used as the basis of the declared heat rate for the WICR (i.e., under options 2 or 3 of the list above, and not based on a test result) then it shall be based on properties for a structure aged by at least 4 years as published by the material supplier. If a U-value for new material was used, or if it cannot be determined that a U-value for aged material was used by the manufacturer, then the declared k-value or heat leakage rate shall be increased by 7%[10] for the purposes of calculating heat leakage.

4.5. Calculation of the representative heat load

The representative heat load is applied inside the WICR during certain tests by means of a fan heater. This is applied in addition to the heat passing through the insulated enclosure during the test. The representative heat load ensures that the performance of the WICR reflects the intended end-use. It is calculated from the heat leakage rate using this formula:

Representative heat load = [Representative heat load factor] x [heat leakage rate]

Equation 3: Representative heat load

Where:

- The heat leakage rate is determined as described in 4.4, either from a test or calculated.
- The Representative heat load factor derives from the intended purpose (duty rating – see 3.2.9) of the WICR as in Table 5.

Following the factors of Table 5, for storage only the total heat load on the cooling system during test is effectively 1.5 times as much as the heat that enters via insulation at the rated climate zone and is intended to reflect operation with limited door openings and coping with stored produce respiration heat and external solar heat gain. For comparison: Added heat load for ATP testing is 35% of the total heat leakage rate (i.e., 1.35 times the heat leakage rate).

For storage and limited pre-cooling, the total heat load on the cooling system during test is effectively 2.2 times the heat that enters via insulation at rated climate zone – intended to reflect operation with regular (e.g., hourly) door openings, coping with stored produce respiration heat, daytime external solar heat gain and batch-wise cooling 10% of produce capacity loaded at climate zone (ambient) temperature.

[10] 7% is an estimate of the aging effect derived from ISO 1496-2 Annex I including Figure I.1.

Table 5. Table of representative heat load factors according to intended purpose of the WICR.

Intended purpose of the WICR	Representative heat load factor	Explanatory notes
Storage only	50%	Total heat load on the cooling system during test is effectively 1.5 times as much as the heat that enters via insulation at the rated climate zone and is intended to reflect operation with limited door openings and coping with stored produce respiration heat and external solar heat gain. For comparison: Added heat load for ATP testing is 35% of the total heat leakage rate (i.e., 1.35 times the heat leakage rate).
Storage and limited pre-cooling	120%	Total heat load on the cooling system during test is effectively 2.2 times the heat that enters via insulation at rated climate zone – intended to reflect operation with regular (e.g., hourly) door openings, coping with stored produce respiration heat, daytime external solar heat gain and batch-wise cooling 10% of produce capacity loaded at climate zone (ambient) temperature.

5. Preparation of the list of key components and parameters for the WICR

5.1. Components and parameters to be noted

A list of key components and parameters for the WICR as it is configured during these tests shall be prepared. If the manufacturer has provided a product information sheet then this shall be noted in the test report and any differences from the observed configuration shall be noted in the test report.

The following key parameters and components of the system shall be identified by brand, model number, key parameters and number of each item that are included in the WICR. This shall be noted in the test report with a photo of each item and its rating plate, where available:

i. Measured gross volume according to 5.2.
ii. Thickness and material of insulating panels, ceiling and floor (if present) (with U-value if provided by the manufacturer, description of skin material and paint finish inside and out)
iii. Thickness and material of door and description of its seal and closure mechanism
iv. Description and images of typical joints between insulated panels both inside and outside the WICR. Note the number of joints per panel if known.
v. Compressor(s) (if accessible without disassembling the refrigeration unit)
vi. Condensing unit for split system and/or monobloc unit
vii. Refrigerant type and charge quantity (as declared on the rating plate or in technical documentation provided by the manufacturer)
viii. Evaporator(s) or fan unit(s), including number of fans and total rated electrical fan input power (kW)
ix. Number, size, type(s) and locations of any thermal storage devices, whether phase change material(s) are present and their phase change temperature(s), storage capacity (kWh or MJ). Note any hazardous material content.

x. Number, size, type(s) and locations of any electrical batteries with Voltage, storage capacity (kWh). Also any hazardous material content.
xi. Description of user interface panel and any switches.
xii. Presence of any input supply Voltage regulator(s) (units that stabilise the input voltage to mitigate impact if electrical supply is unreliable)
xiii. Interior lighting type (e.g., LED, fluorescent, incandescent), number of lamps and rated input power (W).
xiv. Any solar power generation equipment (e.g., solar array quoting Wp, Voc, Vmp, Isc, Imp).

Any test standard compliance or certification declared by the manufacturer for any of the components or systems listed above, or for the overall WICR, should be noted in the list of key components and documentation shall be provided by the manufacturer.

5.2. Determination of gross volume

The gross volume shall be calculated from measurements from floor to ceiling and from left to right (total height x total width x total length), in cubic meters (m^3). Measurements shall be rounded to nearest cm; tolerance ± 0.5 cm. Checks shall be made for parallelism of walls and absence of rhombus distortion of the room shape in vertical and horizontal planes by measuring diagonals and wall edges. Measurements showing more than 0.5% difference in lengths expected identical shall be noted in the test report. The space occupied by evaporator(s), ducts, racking and any other equipment located inside the WICR is included in the gross volume.

6. Instrumentation and equipment for tests

6.1. Ideal temperature measurement

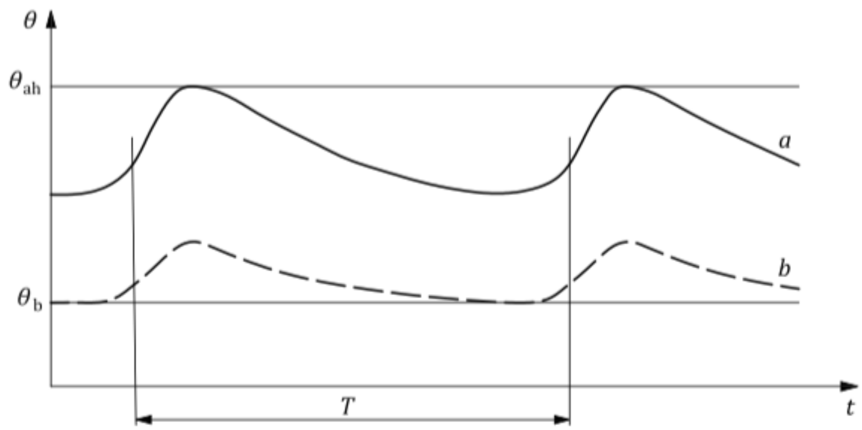
6.1.1. Air (storage) temperature measurement inside the WICR

The mean temperature of air inside the WICR (Ti) is the arithmetic mean of the temperatures measured **10 cm from the walls** at the following 12 points:

(a) The eight inside corners of the body; and

(b) The centres of the four inside faces the having the largest area (floor and ceiling are also inside faces).

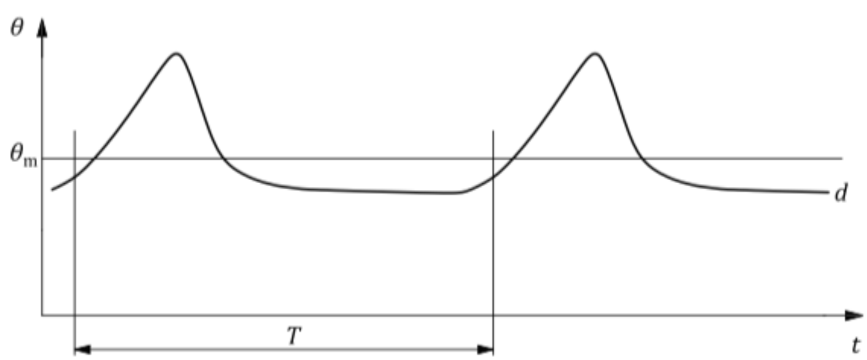
The temperature recorded by each probe is likely to vary through the cooling and defrost cycle as shown in Figure 1. The mean temperature of all air temperature probes will vary in the same cycle and this is used to determine the average mean temperature as shown in Figure 2. The average, minimum and maximum temperatures of sensors shall be recorded not less frequently than every 15 minutes.



Key

θ	temperature
θ_{ah}	highest temperature of warmest M-cans
θ_{b}	lowest temperature of coldest M-cans
t	time
T	test period
a	temperature curve a of warmest M-cans
b	temperature curve b of coldest M-cans

Figure 1. Illustrative chart of temperature readings from two temperature sensors (a and b), relevant for air temperatures, temperatures of M-bottles in the dummy load and temperature of thermal storage devices. Source: ISO 22044:2021 for beverage coolers (the source standard uses cans as test packs, rather than bottles).



Key

θ	temperature
θ_m	average mean temperature
t	time
T	test period
d	curve d of arithmetic mean temperature of all M-cans

Figure 2. Illustration of calculation of arithmetic mean temperature for each set of sensors (air temperature; thermal storage devices temperature; dummy load temperature). Source: ISO 22044:2021 for beverage coolers (the source standard uses cans as test packs, rather than bottles).

If not enough sensors are available, then the following shall be prioritised:

- At least two shall be used to record the temperature inside the WICR storage volume, at diagonally opposite upper and lower corners, 10cm from the walls
- At least two shall be used for external climate zone temperature located at a height level with the top of the insulated enclosure not more than 50cm from the surface at opposite ends of the enclosure
- At least one shall be used to measure the temperature of thermal storage devices
- Any additional temperature sensors shall be used to monitor the internal storage temperature in line with the previous paragraph.

  Note: Any sensors measuring the temperature of air flowing into and out of the evaporator are not included in calculation of Ti.

6.1.2. Measurement of the average air temperature entering and leaving the evaporator(s) and condensor(s)

At best four temperature sensors shall be uniformly distributed in the air stream at the inlet to the evaporator and at least four in the outlet from the evaporator. If enough sensors are available, at least one temperature sensor shall be place in the air stream at the inlet to the condenser and one in the outlet. The sensors and their mountings shall make minimum disturbance of the air flow through use of small cross-sectional areas presented to the air stream. The average, minimum and maximum temperatures of sensors shall be recorded not less frequently than every 15 minutes.

6.1.3. Temperature and status of thermal storage devices

The average temperature of the installed thermal storage device(s) shall be determined as far as is practicable. Design and formats of thermal storage vary and this means that the approach to temperature measurement cannot be standardised. Temperature sensors should be applied to at least one quarter of the number of TES packages, up to a maximum of 8 sensors, spread geometrically evenly throughout the set of packages. Temperature sensors shall be in good thermal contact with the storage medium and insulated from surrounding air. The average, minimum and maximum temperatures of sensors shall be recorded not less frequently than every 15 minutes.

6.2. General instrumentation requirements

The air humidity in % relative humidity shall be measured in the air outside of the WICR during the test as well as inside the WICR storage volume. The humidity sensors shall be placed at any point of free air flow, not closer than 20cm to any wall surface and not closer than 1 metre from any fan in the direction of air flow. Humidity need not be controlled during testing but its levels should be noted in the test report.

6.3. Heaters used inside the WICR for the representative heat load test

For delivering the representative heat load inside the WICR, electrical fan heater appliances shall be used. Fans may also be used, alongside fan heaters, to increase air flow so that the maximum difference between the temperatures of any 2 of the measurement points specified does not exceed 2ºC during the measurement period. The electrical energy consumption of fans shall be added to the calculated heater load. Baffle plates may be used to interrupt and randomise air flow and avoid air flow directly onto nearby temperature sensors.

6.4. Definition of stable operating conditions for measurements

The WICR undergoing field testing is considered to operate under stable conditions if, during a period of 4 hours, the average air temperature inside the WICR agrees within ±1ºC at the corresponding points on the time-temperature. Changes to the WICR controller settings are not allowed during the stable conditions period.

The difference between the heating power or cooling capacity measured over two periods of not less than 3 hours at the start and at the end of the stable operating condition period, shall be less than 10%.

The mean inside temperature at the beginning and the end of the calculation period of at least 4 hours shall not differ by more than 2ºC.

The mean outside temperature at the beginning and the end of the calculation period of at least 4 hours shall not differ by more than 5ºC.

If the WICR includes TES then an additional requirement is imposed based on measurements determined in line with 7.3. If the mean temperature of TES units shows a rising trend (i.e., ongoing depletion of stored energy during the test) then stable operating conditions are not considered as achieved because once the TES is depleted the unit would not be able to sustain the measured temperature.

7. Preparation for the test

7.1. Reference documents for field test planning

The following provide good practice advice for planning field evaluations. Direct relevance to testing of WICR varies but all have useful insights:

- ATP Appendix 1, paragraph 1(b) and 1(c)) (Verifying performance in service)
- Field Testing of Appliances Suitable for Off- and Weak-Grid Use, Generic guidance on appliance performance monitoring in the field, January 2022. Available from: https://efficiencyforaccess.org/publications/field-testing-of-appliances-suitable-for-off-and-weak-grid-use. [voltage, current and power sensors; data logging; set up on site etc]
- Designing and Implementing Field Testing for Off- and Weak-Grid Refrigerators, Guidance on refrigerator performance monitoring in the field, June 2022, Efficiency for Access. Available from: https://efficiencyforaccess.org/publications/designing-and-implementing-field-testing-for-off-and-weak-grid-refrigerators.
- Generic Guide for the field evaluation of new technologies for WHO PQS Prequalification, WHO/PQS/GENERIC/GUIDE.1.1, WHO, March 2016. Available from: https://extranet.who.int/prequal/sites/default/files/document_files/Generic%20Guide%20For%20Field%20evaluation_4.pdf.

7.2. Where to test and preparation of the test site

There are two distinct and different circumstances under which a field test may be carried out:

A. Protected from solar gain through being inside another building or with full shade, and so giving a degree of comparability with testing in a thermal chamber;

B. With solar gain so that WICR outer surfaces are exposed to direct sun, ideally without partial shade, and so emulating conditions experienced by many WICR in real use (noting that good practice would always be to protect the WICR from solar gain)

One or the other should be decided and clearly noted in the test report. Tests in which partial shade is present should be avoided.

A. For a field test to be carried out with shading:

If the WICR can be moved or assembled in such a location, then:

- The WICR should be placed in a warehouse or other large building or enclosure which provides shade from all direct sunshine and in which the ambient temperature can be held as stable as possible for the duration of the test.
- Air flow is allowed, for example through open doorways or windows of the building or enclosure, as needed if it assists maintaining stable temperatures around the WICR within or close to requirements.

If the WICR is already assembled on site and will not be moved, then the outside of the WICR and the entire condensing unit shall be shielded from direct sunshine with a free air flow gap of at least 300mm between sunshield and WICR outside walls.

B. For a field test to be carried out in the open with solar gain:

Sources of shade should be removed or reduced as far as practical with photographs and notes to describe the WICR orientation, weather, direct sun conditions. The degree and timing of any residual shading that occurs during any part of the test shall be noted.

For case A. and case B. of the above locations:

- There shall be free air flow into and out of the condenser fan unit. Debris and accumulated dust shall be removed from the fins of the condenser.
- The evaporator must be fully defrosted and substantially dry before the test begins.
- Inspect all door seals, insulation panels and seals between panels for damage. Repair any damage, or describe it in the test report, preferably with photos.
- Take photos of the WICR in situ from each direction when it is ready for test
- Tests should be carried out with the WICR substantially empty. If this is not practical then the amount and type of stored content must be described in the test report, with photos and it will not be possible to carry out all tests.
- Obtain weather forecasts and temperature profiles for the test days – choose timing of the test to coincide with the most stable period of temperature for the required [4] hours of the test.
- The ambient temperature throughout the test shall be equal to or higher than the rated climate zone temperature.

7.3. Use of thermal energy storage equipment

See 4.3 for general guidance on thermal energy storage under this protocol. Any thermal energy storage devices that are supplied as standard with the WICR, or are built into its structure, as specified in the technical documentation or instruction manual, shall be left in place or installed according to manufacturer's instructions.

If thermal storage is an optional extra purchased separately then it shall not be installed for testing.

7.4. Electrical supply

During all tests the electrical supply shall remain within the following variations:

a. ±2 percent of local standard voltage; and
b. ±1 percent of supply frequency.

Values of local standard voltage and frequency and the averages measured during the test are to be noted in the test report.

7.5. Setup and use of controls during testing

Controls that do not interfere with the set up and aims of the test may remain active for testing, e.g., thermostats, fan controllers.

If any control is suspected to undermine the intent of the test, for example by altering the set point(s) or suppressing energy consumption during the energy test in ways that are not typical of general operation, then those controls should be disabled without damage to the unit. If the control cannot be disabled then it shall be noted in the report with a description of how it might interfere with test conditions.

7.6. Instrumentation and equipment required for field tests

The following equipment is necessary as a minimum to perform an adequately robust field test:

A. Not less than five temperature sensors with cables adequate to reach anywhere inside the WICR storage volume and externally for climate zone temperature if the sensors are cable ones and not remote ones. The sensors shall have an accuracy of at least 0.5ºC, a measurement range of -20ºC up to +65ºC and record not less frequently than every 15 minutes.
B. One Humidity sensor with at least 5% accuracy and record not less frequently than every 15 minutes.
C. Data logger with average/max/min recording capability and number of channels to match the number of sensors and record data not less frequently than every 15 minutes.
D. Stopwatch
E. Adhesive tape to manage cable positions including through door seals
F. Two electrical power meter (kWh) with at least 2% accuracy and record data not less frequently than every 15 minutes.
G. Support rig(s) to hold sensors at suitable heights and locations
H. Handheld temperature sensor (preferably infra-red spot sensor) with at least 2ºC accuracy and record data not less frequently than every 15 minutes.
I. Multi-meter (for checks and troubleshooting during set up) with at least 3% accuracy
J. Flashlight (to inspect for gaps in insulation seals, debris/dust in fans/ducts and heat exchangers)
K. Camera to record test set up
L. Tape measure.
M. Adequately powered heater.
N. Extension cable.

The following equipment is desirable to further decrease uncertainty of results:

A. Hand-held hot-wire anemometer with 30 second average speed capability
B. Thermal imaging camera (for rapid inspection of insulation for thermal bridges and flaws)

7.7. Conditions for field tests

i. The WICR should be substantially empty for all field tests

ii. WICR storage temperature corresponding to the lowest rated storage temperature category (see Table 2).

iii. Temperature measuring instruments protected against radiation shall be placed inside and outside the WICR at the points specified in 6.1. If insufficient temperature sensors are available to meet 6.1, then the following shall be prioritised:

- At least two shall be used to record the temperature inside the WICR storage volume, at diagonally opposite upper and lower corners, 10cm from the walls
- At least two shall be used for external climate zone temperature located at a height level with the top of the insulated enclosure not more than 50cm from the surface at opposite ends of the enclosure
- At least one shall be used to measure the temperature of thermal storage devices
- Any additional temperature sensors shall be used to monitor the internal storage temperature in line with 6.1.

iv. The average ambient temperature around the WICR to be recorded not less frequently than every 10 minutes. If the climate zone temperature is measured as more than [10°C] from the target temperature for more than [30 minutes] during the test (i.e., at more than three consecutive or non-consecutive 10-minute readings) then the test shall be restarted or abandoned

v. Maximum, mean and minimum climate zone temperatures to be declared for the test period both as averages from measurement points and as individual values.

vi. The power supply must be within +/-10% of nominal voltage and +/-1% of nominal frequency for the duration of the test. Any current limit for the supply must be at least 10% above the maximum expected current draw. A stable grid connection or generator of adequate power shall be used in preference to solar or unstable grid connection.

7.8. Requirements of technicians carrying out field testing

Two test technicians are required to carry out the tests. At least one technician must have prior experience of use of each item of test equipment and of carrying out these tests.

8. Field test procedures

The following field tests are described:

Table 6. *Overview of setup conditions for each test*

Test	Contents of WICR storage volume	Charging status of thermal storage at start (if present)	WICR internal air (storage) temperature at start	Representative heat load
8.1 Visual inspection of insulated enclosure and key components in the field	Empty	n/a	n/a	n/a
8.2 Empty Pull-Down Field Test	Empty	Fully discharged (at climate zone temperature)	Equal to climate zone temperature	None
8.3 Autonomy test	Empty	Fully charged	At target storage temperature	None
8.4 Steady state effectiveness for air temperature, representative energy consumption, representative cooling capacity and maximum cooling capacity	Empty, with heaters and fans as needed	Fully charged	At target storage temperature	Yes, as per 4.5
8.5 Determination of heat leakage rate and k-value of the insulated enclosure	Empty	Fully discharged (at climate zone temperature)	See Table 8	None

Table 7. *Indicative set up and disassembly time ranges, with duration for each test. Disassembly is only for test equipment specifically needed for the test in question that will not be needed for the subsequent test (could be zero).*

Test	Indicative set-up duration range	Indicative duration of test	Indicative disassembly time
8.1 Visual inspection of insulated enclosure and key components	n/a	0.5h	n/a
8.2 Empty pull-down test	1d (without TES), min 2d (with TES)	1-6h	n/a
8.3 Autonomy test	6h	1-6h	n/a
8.4 Verification of steady state effectiveness for air temperature, representative energy consumption, representative cooling capacity and maximum cooling capacity	4h	14h	n/a
8.5 Determination of heat leakage rate and k-value of the insulated enclosure	n/a	14h	n/a

8.1. Visual inspection of insulated enclosure and key components in the field

A visual inspection shall be carried out to:

- Verify that components are installed in place as-per the design specification
- Verify that installation has been completed satisfactorily (e.g., insulation panels have no gaps or obvious breaches, condition and thickness of insulation matches the design specification, doors close and seal correctly, displays and alarms work)
- Verify that the refrigeration unit runs, cools, and fans circulate air
- Verify reasonable airtightness by looking inside the WICR for light ingress between panels and door edges when the unit is in a brightly lit space or shining a torch from outside
- Check for any areas of external insulation surface with condensation water.
- Observe the positioning of the WICR and record times of direct irradiation and other weather influences.

8.2. Empty pull-down field test (no heat load)

Aim of test:
To determine how long it takes to reduce the temperature inside the empty WICR from the ambient temperature to the target temperature.

Note: the time taken for the air to reach temperature will be extended by any thermal storage equipment that is fitted as standard inside the WICR as this begins the test at the ambient temperature and will therefore slow achievement of target temperature.

Test conditions:

- No heating inside WICR.
- Temperature measuring instruments shall be placed inside and outside the WICR at the points specified in 6.1 The air -on and off temperatures to the condenser and evaporator shall be measured as per 6.1.2 if sufficient thermocouples are available. Temperature of any thermal storage shall be measured as per 6.1.3.
- Thermal energy storage equipment shall be at the ambient temperature at the start of the test. The presence and type of thermal storage shall be known, and whether it includes phase change material(s), the phase change temperature(s), and whether a phase change is anticipated to occur during the test. This will affect both the procedure and the duration of test.

Test procedure:

Step 1 – temperature stabilisation WICR doors open: The door(s) of the WICR shall be fixed fully open and temperatures monitored. Average humidity shall be recorded inside and outside of the WICR. Continue until the average mean temperature of the air inside the WICR has been within +/-1°C of the average mean outside temperature of the WICR and within +/-1°C of the average mean temperature of any thermal storage devices for at least 6 hours.

Step 2 – close door; check for stability: the door(s) shall be closed and temperature inside the WICR monitored for 10 minutes without starting the WICR cooling system. If the average air temperature falls by more than 1°C during the 10 minutes, then the doors shall be reopened for stabilisation to continue and step 2 restarted later.

Step 3 – start cooling: The cooling unit shall be started up at maximum capacity with a storage temperature set point so that maximum cooling is sustained as far as practicable (zero or minimal compressor cut-outs). Start a timer.

Step 4 - pull down time for mean air temperature: The mean ambient air temperature and the mean inside temperature of the WICR shall each be recorded. Record the time taken in minutes from when the cooling is started until the mean air temperature of the room air temperature sensors inside the WICR reach the target storage temperature for the storage temperature category (the evaporator air in and air out sensors shall not be included in the mean temperature calculation). Note also the highest and lowest temperatures recorded at that instant and the average humidity inside and outside the WICR.

Optional steps if thermal energy storage is present in the WICR:

Step 5 - time to start and end of phase change (if relevant): if a phase change of the thermal storage is anticipated during the test then record the time(s) at which each thermal storage temperature sensor reaches the phase change temperature, noting their locations on a diagram. Record also the time(s) at which each thermal storage temperature sensor moves below the phase change temperature. Some or all of Step 4 could occur before completion of step 3.

Step 6 - 7/8 pull down time for thermal storage: Continue cooling and record the total time taken in minutes from when the cooling is started until the average measured temperature of thermal storage reaches a value marking seven-eighths of the progression from rated climate zone temperature to the target storage temperature for the storage temperature class.

Step 7 - Delta-T: At the time for which 7/8 pull-down time for thermal storage is achieved, record the temperature difference between the average storage temperature and the temperature of the air stream leaving the evaporator.

Step 8 (optional) - time to fully charge thermal storage: Continue cooling and record the total time taken in minutes from when the cooling is started until the average measured temperature of thermal storage reaches the target storage temperature for the storage temperature category. Determination of the end point shall consider the stability indicators described in 6.4.

8.3. Autonomy test

Aim of test:

To establish how long the WICR can sustain air temperature within 5°C of its target after external power supply is cut off, making use of any electrical battery and thermal storage.

Test conditions:

- No additional heat load
- Thermal storage and batteries fully charged at start of test
- WICR substantially empty
- From start of test, no externally provided power is available to run compressors

Test procedure:

Step 1 - Stabilise at rated operating conditions: Allow WICR to reach stable operating conditions (see 6.4) at the rated operating conditions for at least 6 hours. Thermal storage and batteries should be fully charged.

Step 2 - Turn off power: Turn off external power source to the WICR systems at least one hour after the end of a defrost cycle and within one minute of the compressor turning off at the end of a cooling cycle. If the compressor is running continuously at stable operating conditions then power may be turned off at any point after confirming stable operating conditions and an hour after the end of a defrost cycle.

Step 3 – Record average air temperature: From the moment of turning off power, track the average air temperature inside the WICR against time until the average temperature has risen by at least 7°C. Track the ambient temperature and weather condition during the test time.

Step 4 – Calculate Autonomy period: Once a trace of the average internal air temperature has been obtained, determine the **start time** of the autonomy period - the temperature may initially drop as remaining refrigerant evaporates even after the fans stop and the start time is the instant at which the average temperature passes upwards through the mean average temperature during stable operating conditions. Determine the **end time** of the autonomy period as the time taken for the average internal air temperature inside the WICR to rise by 5°C above the start temperature. Record the autonomy time as the interval between start and end, in hours to 2 decimal places.

8.4. Steady state effectiveness field test under thermostat, energy consumption and refrigerating capacity (with heat load)

Aim of test:

To verify system effectiveness, meaning correct thermostatic regulation of air temperature with a specified internal heat load that is representative of the expected duty of the WICR. This is a steady state test with a steady calculated representative internal heat load. Refrigerating capacity and energy consumption are also determined during the test.

Test conditions:

- Storage temperature corresponding to the lowest rated storage temperature category (see Table 2).
- Cooling unit operating on normal thermostatic control.
- Heating inside WICR active at the representative heat load calculated as in 4.5.
- Temperature measuring instruments shall be placed inside and outside the WICR at the points specified in 6.1. The air -on and -off temperatures to the condenser and evaporator shall be measured as per 6.1.2. Temperature of any thermal storage shall be measured as per **Error! Reference source not found.**.
- Any thermal energy storage devices shall be fully charged at the start of the steady state effectiveness test.

Test procedure:

Step 1 – stabilise at target temperatures, no heat load: Continue with internal heaters off and cooling system operating on thermostatic control until the average internal air temperature and the average temperature of thermal storage devices are both stable within limits described in 6.4 at the target temperature and thermal storage is fully charged in line with 6.1.3. Record the ambient humidity and humidity within the WICR.

Step 2 – start representative heat load: When the air temperature and thermal storage temperatures are stable and within required tolerances of the target temperature, turn on the heaters with a heating capacity equal to the representative heat load calculated as per 4.5.

Step 3 – determine if temperature is attained with representative heat load: Record the air temperature and thermal storage temperature. Continue the test until stable operating conditions are achieved at the rated storage temperature for at least 12 hours, as per section 6.4.

> *Note: It may take several days for the TES to become fully charged and fully stable conditions to be attained, though an acceptable storage temperature may be achieved before this point (at which point the test may be curtailed if necessary, noting the conditions in the test report). Check with suppliers to determine how long full charging should take and when curtailment of the test is otherwise reasonable. If an acceptable storage temperature is not achieved in a reasonable time period (recommendation is after maximum 6 hours) then the WICR is deemed not capable of meeting the capacity requirements for that design purpose and/or at the rated operating conditions. The test may be repeated with less demanding cooling capacity and/or rated operating conditions (i.e., without a produce cooling capability and/or with a lower rated climate zone temperature and/or with a higher rated storage temperature).*

Step 4 – representative energy consumption: Measure the WICR's total energy consumption over a period of at least 12 hours of stable operating conditions (determined as per 6.4) and use this to calculate the representative energy consumption in kWh per 24 hours. The temperature of any thermal storage devices may vary cyclically during this time but may not show a rising or falling trend of temperature. If the temperature requirements are not met, then an energy consumption measurement is not valid for the failed rated operating conditions. The energy test must be repeated to give a valid result associated with a temperature rating that the WICR can meet.

Step 5 - Representative cooling capacity with heat load at stable operating conditions: When stable operating conditions are reached, the cooling capacity with representative heat load under thermostatic control can be calculated as equal to the heat gain through the insulation (evaluated in 4.5) plus the total (electrical) energy input to the fan heaters and any fans installed for the purposes of air circulation during the test (evaporator fan power is ignored). The calculation shall be made over a stable operating conditions period of at least 12 hours.

Step 6 – Temperature stability, ∆T and humidity: Record the temperature stability which is equal to the temperature oscillation shown in Figure 6. Record the temperature difference between the average storage temperature and the temperature of the air stream leaving the evaporator (∆T), the humidity inside and outside the WICR.

Step 7 – calculate representative Coefficient of Performance (COP): Representative COP is calculated from Equation 5.

Representative COP = ([representative cooling capacity, kW] x 24) / [representative energy consumption, kWh per 24h]

Equation 5. Representative COP.

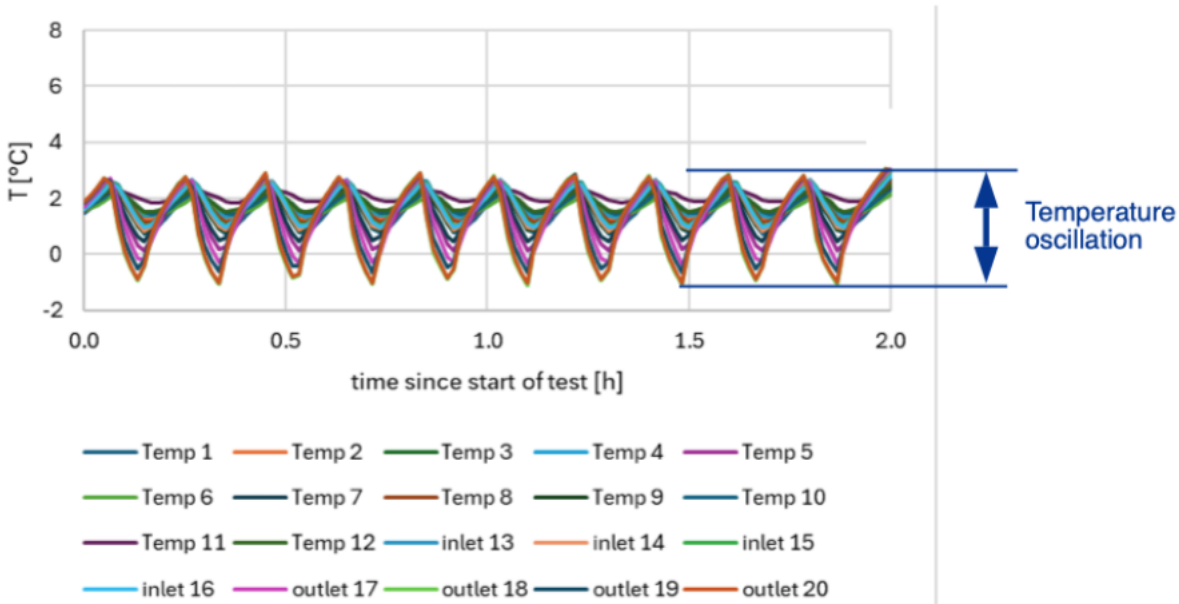


Figure 6. Temperature sensor chart showing the temperature oscillation measured during the test, which is referred to as the Temperature stability, in °C.

8.5. Determination of heat leakage rate and k-value of the WICR

Aims of test:

To estimate the heat leakage rate and k-value coefficient of the overall insulated enclosure (walls, floor, ceiling, door) under mostly steady state conditions with a measured temperature differential across the thickness of the insulating envelope.

Test conditions:

- The test shall be conducted at the most stable conditions possible: at night to avoid solar gain through the walls and with the most stable temperature and wind still to limit the surface cooling effects.

  Note: K-value changes according to the mid wall temperature which changes with the outside and inside temperature and can change up to 5% when Delta-T changes by 10°C. This is because the lambda property of insulation varies a little with temperature.
- Electrical fan-heaters are run inside WICR with the option to also run air circulation fans if required to achieve uniform air temperature inside the WICR. An initial estimate of the heat input needed can be made using Equation 3. Electrical energy input to the fan heaters and air circulation fans is measured. Select electrical cables for the fan heaters and fans to be of minimum practical length; store any spare cable inside the WICR rather than outside, uncoiled.
- Test requires an iterative process of adjusting the heat input inside the WICR from the initial estimate followed by stabilising as necessary to establish a suitable stable temperature difference between the test chamber and inside the WICR.
- Any thermal energy storage devices shall be fully discharged at the start of the heat leakage rate test.
- The refrigeration unit of the WICR is not run during this test.

Table 7. Suggested target temperatures during the heat leakage rate test – iteration from these initial suggestions will be needed to achieve the required ΔT, depending upon the test equipment and set-up.

Rated climate zone temperature, set point, °C	**Rated target storage temperature, °C** (cold / cool / moderate)	**Target ΔT for the heat leak test, °C**	**Suggested initial set point of the test chamber, °C**	**Associated target temperature inside the WICR, °C**
43 (hot zone)	1	42	2	44
	8	35	2	37
	15	28	2	30
32 (temperate zone)	1	31	2	33
	8	26	5	31
	15	17	7	24
27 (moderate zone)	1	26	5	31
	8	19	5	24
	15	12	7	19

Test procedure:

Step 1 - determine the required temperature difference: Select the target ΔT from Table 7, selecting the highest rated climate zone temperature category (see Table 1) and the storage temperature corresponding to the lowest rated storage temperature category (see Table 2). Note that during this test the DT is inverted: temperature inside the WICR is aimed to be higher than the ambient temperature.

Step 2 - determine the initial estimate of heat leakage rate: Use Equation 3 to determine W_{est}, the estimated heat leakage rate which will be the initial value of electrical input of fan heaters and air circulation fans.

Step 3 - start internal heaters and cooling of thermal chamber: Begin cooling of air inside the test chamber with an initial set point as shown in Table 7. Start the heaters and fans inside the WICR such that total electrical energy input to fan-heaters and air circulation fans is close to W_{est}. Monitor the average air temperatures inside the WICR and inside the test chamber.

Step 4 – allow temperatures to stabilise: Monitor temperatures inside the WICR and inside the test chamber, projecting the WICR air temperature forwards to estimate the likely stabilisation level.

Step 5 – adjust heat input level to achieve the target DT and stable conditions: If the WICR air temperature appears to be stabilizing more than [3°C] too low then increase the heat input; if the WICR air temperature appears to be stabilizing more than [3°C] too high, decrease the heat input. Repeat Step 4 and iterate as needed aiming to stabilize with target ΔT ±3°C. Stable conditions are defined as when the mean air temperature inside the WICR and in the test chamber shall not vary by more than ±1°C over a period of not less than 12 hours.

Step 6 – calculate heat leakage rate and k-value coefficient: Calculate the mean heat leakage rate, W, and the mean ΔT over the measured period. Use Equation 1 to calculate the k-value coefficient for the WICR insulated body ($W/m^2.°C$).

9. Test report

Test reports may be formulated to suit the quality system and procedures of the testing entity carrying out the test, but reports shall include the following as a minimum, using a presentational format as close as practicable to the suggestions included here for ease of comparability.

9.1. Required sub-sections in the test report

The test report shall include the following sub-sections as appropriate for the tests carried out, amongst other sub-sections deemed necessary by the lab:

1. Standard rated operating conditions of the WICR under test
   As per section 4, including rated climate zone conditions, storage temperature class(es) and intended purpose as declared by the supplier. If no declaration is made by the supplier then this shall be noted and the parameters assumed by the lab as the basis for test shall be described.
2. Results of visual inspection
   As per section 8.1
3. Bill of Materials assessment results
   As per section 5.1, including any additional physical description of the WICR under test, with photographs.
4. Details of field tests
   - Weather conditions during each test (temperature profile during test (highs, lows, average); wind speed and direction if possible;
   - Time of each test start and finish
   - Orientation and weather protection of the WICR (shading from the sun; in the open/enclosed); other details of positioning as per 9.
5. Calculation of the indicative heat leakage rate and k value
   As per sections 4.5, including explanation of the determined heat leakage rate and representative heat load.

9.2. Required results tables

If/as appropriate for the tests carried out, the test report shall contain results summary tables as close as practicable to those described below.

9.2.1. Empty pull-down test

Parameter	Result value (measured or calculated, one decimal)	Unit
Max ambient temperature recorded and time of recording		°C hh:mm
Min ambient temperature recorded and time of recording		°C hh:mm
Mean ambient temperature		°C
Time taken to reach target temperature		Minutes
Time taken for TES to reach 7/8 of rated storage temperature (SECT)		Minutes
Temperature difference between the average WICR air temperature and the temperature of the air stream leaving the evaporator at time of SECT for thermal storage		°C
Time taken to fully charge TES		Hours

A plot of the temperature over time for the average ambient and WICR air temperature during test shall be included in an Annex.

9.2.2. Autonomy test

Parameter	Result measured value (one decimal place)	Unit
Autonomy		Minutes

9.2.3. Steady state effectiveness test

Parameter	Result value (measured or calculated, one decimal)	Unit
Average mean air temperature inside the WICR		°C
Average mean ambient air temperature		°C
The maximum deviation of temperatures during defrost events		°C
Representative heat load used in test		W
Conclusion on temperature attainment at rated operating conditions		(pass / fail)
Temperature stability achieved (equal to the temperature oscillation at steady state)		°C
Representative energy consumption		kWh per 24 hours
Cooling capacity with representative heat load		kW
Maximum cooling capacity		kW
Representative COP (Equation 5)		W/W
Average humidity inside the WICR		%RH
Average humidity outside the WICR		%RH

9.2.4. Determination of the heat leakage and k-value test

Parameter	Result value (measured or calculated, one decimal)	Unit
Target temperature difference (inside to outside)		°C
Actual average temperature difference during test (inside to outside)		°C
Estimated heat leakage rate		W
Heat leakage rate determined during test		W
Calculated k-value coefficient (two decimals)		$W/m^2.°C$

9.2.5. Annexes to the test report

The following annexes shall be included:

1. Temperature traces for tests as designated in 8.2
2. Other temperature traces for tests as deemed appropriate.