
VeraSol

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

## Performance Tests in a Test Chamber for Temperature, Cooling Capacity and Energy Consumption

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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 Programme by a working group of independent experts and specialists on performance and testing of walk in cold rooms and associated equipment. The ATP test protocol was used as the basis for many aspects of this 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 Carriage[2]). The working group included experts in the testing of refrigerated transport containers and reefers under the ATP.

# 2. Scope

This document specifies the performance requirements, the standard conditions and the test methods for determining the cooling capacity and efficiency ratings of walk in cold rooms (WICR) designed for use in hot, temperate and moderate climate zones (respectively 43ºC, 32ºC and 27ºC) 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.

This document is not applicable to:

- 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 that depend upon regulations in the country of use.
- Performance of equipment used exclusively with solar photovoltaic or any power supply other than mains grid.
- Field testing of WICR.

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.

[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. 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[3] 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.

### 3.1.15. Limited supply

Electrical supply of reasonable or good quality but delivering not more than 22 hours of reliable power per day[4], 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.

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[3] This means at the highest rated ambient temperature (

Table ***1***) and the target storage temperature (Table 2).

[4] 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.

### 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[5] or EN 50160[6].

### 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 **Error! Reference source not found.**.

### 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 6.7.

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

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[5] 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.

[6] 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.

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 **Error! Reference source not found.**). 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. Test chamber

A test facility in which the ambient air can be conditioned and kept in a steady state temperature with control of air movement and equipped to carry out testing as per this protocol. See 6.1.

#### 3.2.10. 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.

#### 3.2.11. 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.

#### 3.2.12. M-bottle

A bottle identical to bottles used to form the dummy load that is filled with water or a water-based gel with a temperature sensor supported to remain at the geometric centre of the bottle, for monitoring the temperature of the dummy load. See 6.3.5.

# 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 8 with their associated nominal $\Delta T$.

If stable operating conditions (see 6.7) 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[7], and adopted by the government of India[8].*
*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 | |

[7] 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.

[8] 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) or tested according to 8.7, $m^3$/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 7.2, 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 leakage 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 $\Delta T_1$ and $\Delta T_2$ is less than 4°C.*

Where:
$W_1$ and $\Delta T_1$ are the known heat leakage and temperature difference conditions
$\Delta T_2$ 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 8.4, 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 **Error! Reference source not found.**. 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 8.4 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, $m^2$
$\Delta T$ = intended temperature difference between mean air temperature inside the WICR and mean air temperature of test chamber, °C
$\lambda$ = 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%[9] 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 3.2.10) 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.

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

| Intended purpose of the WICR (see 4.2) | Representative heat load factor |
|---|---|
| Storage only | 50% |
| Storage and limited pre-cooling | 120% |

## 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.

[9] 7% is an estimate of the aging effect derived from ISO 1496-2 Annex I including Figure I.1.

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.

### 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. Test chamber

The test chamber should ideally have the following characteristics:

1. Internal dimensions that enable space for free air flow around the WICR under test.
2. Walls and ceiling sufficiently insulated that external climatic conditions do not affect the internal temperature (recommended minimum of 80mm thick rigid polyurethane foam or equivalent).
3. Floor flat and firm.

4. Heating and cooling system such that air in the chamber can be regulated to stable operating conditions between 7°C and 43°C ±1°C under steady state test conditions. A higher maximum temperature would be required if testing is wanted at 50°C ambient or higher (highest temperatures needed in the field for several geographical regions). Air temperature in the test chamber may stray outside of the setpoint during transient conditions lasting several minutes to a few tens of minutes during the process to reach thermal equilibrium inside the WICR (e.g., after the WICR under test is first switched on for pull-down test).
5. The necessary cooling capacity of the test chamber HVAC system should be determined based on estimating a maximum system heat load, combined with assessing the COP of the cooling system. The maximum system heat load would include:
6. The heat leakage rate of the test chamber walls when the highest anticipated external climate zone temperature and lowest anticipated internal test chamber temperatures are occurring (a steady state load).
7. The maximum additional heat load that will be required to be applied inside the largest WICR that will be tested (a steady state load).
8. A margin of spare transient capacity so that the test chamber can be brought down to a target temperature in a reasonable time, and so that temperature inside the test chamber will not stray above its set point for more than a few tens of minutes when the WICR refrigeration system is first switched on (this creates a sudden large heat load, approximately equal to the cooling capacity of the WICR refrigeration unit).
9. Provision to ensure constant mixing of air inside the chamber around all external sides and ceiling of the WICR, see 7.5.
10. Good quality, bright internal lighting from widely dispersed sources to enable safe and effective work around the chamber and around all sides and top of products under test.

An ATP authority approved[10] chamber for testing reefers and refrigerated containers would be appropriate, or similar.

## 6.2. General instrumentation requirements

- Sets of readings shall generally be recorded at intervals of not more than 15 min. Stricter time limits apply to some measurements in the test procedures.
- Instruments for measuring air temperature placed inside and outside the WICR shall be protected against heating by radiation. This is to be achieved by shielding the body of the temperature probe from direct thermal radiation whilst allowing free circulation of air around the probe
- Instrumentation calibrated for the following accuracy: temperature-measuring devices: ±0,5°C
  The electrical energy consumption shall be determined with an accuracy of ±2 %. The length of cables connecting the power supply and its measuring instrument to the heaters inside the WICR enclosure shall be minimised; surplus cable length should preferably be located inside the WICR rather than outside. The humidity inside the WICR shall be measured with a humidity sensor placed in the geometric centre of the chamber. Its calibration shall be at least ±5%.
- Suggested instrument for measuring air speed: hand-held hot-wire anemometer with accuracy ±0.03 m/s + 5% of measurement value, with range 0 to 20 m/s air speed.
- Suggested instrument for measurement of speed of rotation of evaporator fans: hand-held tachometer (rpm sensor) accuracy ±1% of measurement value.

[10] The ATP agreement does not specify details of requirements for the testing station test chamber, simply that “the checks shall be made at a testing station designated or approved by the competent authority of the country in which the equipment is registered or recorded…” (ATP Agreement 2022, Annex 1, Appendix 1, clause 1).

- All measurement equipment and instruments used shall show evidence of calibration (preferably through an ISO 17025 compliant or ILAC-approved laboratory).

## 6.3. Specification of the dummy load

### 6.3.1. Purpose of the dummy load

A dummy load is used during a pull-down test (8.3) to simulate operation with produce in the cold room to provide more insight into the effectiveness of cooling than the empty pull-down test. Bottles are used instead of actual produce to ensure some degree of comparability of results.

### 6.3.2. Amount and material of the dummy load

The total dummy load used in the test shall be calculated as equivalent to 10% of the total produce loading capacity of the cold room in kg. The dummy load shall consist of typical cylindrical 500ml bottles made of PET plastic. The test report shall note the number and dimensions of bottles used. The bottles shall be filled with water (leaving a small air gap in case of freezing) and stabilised at the climate zone temperature for testing (±1°C) before use.

### 6.3.3. Type of crates to hold the dummy load

Crates shall be used to hold the bottles with perforated sides and base so that air can flow freely to the bottles. The mass, material and general type of crate used shall be described in the test report, including a photograph.

### 6.3.4. Stacking of the dummy load inside the crates

The bottles shall be stacked into the crate in a way that they are in the most contact possible standing vertically as shown below. If the bottles do not fill the crate space perfectly, then stack them in contact to each other and leave the space between the bottles and the crate wall(s). Ensure the spacing is maintained after placing the crates inside the WICR.

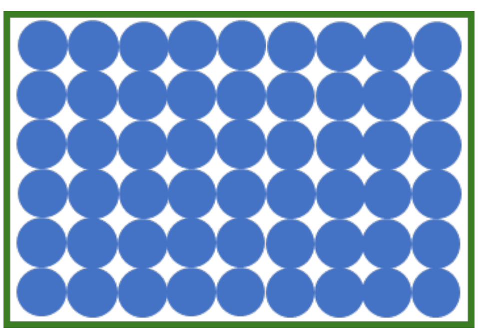


*Figure 1. Plan view sketch of bottles in a crate.*

### 6.3.5. Measuring the temperature of the dummy load

The average mean temperature of the dummy load inside the WICR shall be determined using bottles fitted with temperature sensors, called M-bottles. M-bottles shall be identical to bottles used in the dummy load and shall also be filled with water or a water-based gel with the sensor supported to remain at the geometric centre of the bottle. See Figure 2.

*Figure 2. Example M-bottle, with its temperature sensor that is mechanically held at the geometric centre of the bottle.*

M-bottles are to be located at the following points of the dummy load crates as in Figure 3, in which each rectangular cell represents one crate of bottles in an array – the array used in a test may vary in shape and size from this example:

a) The (near-)centre of the crates that are at the outmost corners of the dummy load lowest (or only) layer; and
b) The (near-)centre of the crate nearest the geometrical centre of the dummy load lowest (or only) layer

| | | | | |
|---|---|---|---|---|
| a) | | | | a) |
| | | | | |
| | | b) | | |
| | | | | |
| a) | | | | a) |

*Figure 3. Schematic plan view of an array of crates containing bottles as the dummy load, laid out on the floor of the WICR. Crates marked a) are at the outermost corners of the array; crate marked b) is at the geometric centre of the array (or close to centre, given the number of rows and columns).*

The same pattern of outermost corners and geometrical centre shall be followed for the crates that constitute any second layer of crates. The number of crates required for any second layer may not be sufficient to cover the entire first layer - its outer corners and near-centre shall be identified for the occupied shape.

Only one M-bottle shall be installed in any crate.

Wires from M-bottle temperature sensors shall be brought to the outside of the room in such a manner as to interfere as little as possible with air seal of the door or wall.

### 6.3.6. Stacking of dummy load crates in the WICR

Plan locations of M-bottles according to 6.3.5 before loading the WICR with dummy load.

If the WICR includes permanently fitted shelving or racking, then crates shall be placed on shelving such that crates are touching and distributed evenly across the shelves and at least 10cm away from any nearby wall to allow free air flow.

If no shelving is present in the WICR, then crates shall be laid out on pallets or similar structures that allow largely free air flow under the crates to a depth of around 10cm of air flow space. Stacking shall be symmetrical over the floor area. Crates shall be in double rows, at least 10cm away from any nearby wall to allow free air flow, and in contact with each other within double rows. An access gangway shall be allowed along the wall that contains the door and perpendicular to that between rows of crates. Example layout is shown in Figure 3. If more than one layer of crates is required to hold the calculated amount of dummy load, then a second layer of crates may be started.

Photos of the dummy load and its layout shall be included in the test report along with a diagram showing locations of M-bottles.

*Figure 4. Example stacking of crates of dummy load water bottles in a WICR. Top image: upturned crates on which the dummy load is subsequently placed to allow air flow under dummy load; bottom image: dummy load of crated water bottles in place.*

## 6.4. Temperature measurement

### 6.4.1. Air (storage) temperature measurement inside the WICR

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

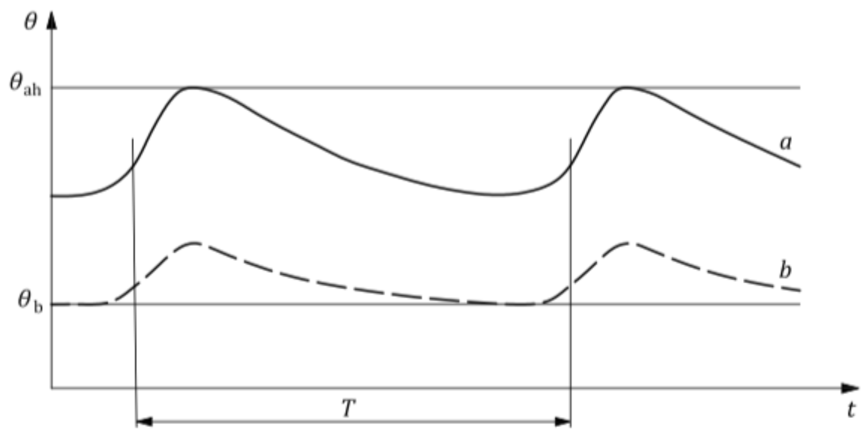
(a) The eight inside corners of the body; and

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

If a dummy load interferes with this probe location, then the probe shall be moved to be as close as possible to the intended location but not closer than 200mm to any dummy load crate.

The temperature recorded by each probe is likely to vary through the cooling and defrost cycle as shown in Figure 5. The temperature of all air temperature probes will vary in a similar cycle. The mean temperature of all 12 probes at each point of the cycle is first calculated, then the average of all means, to determine the average mean temperature as shown in Figure 6.

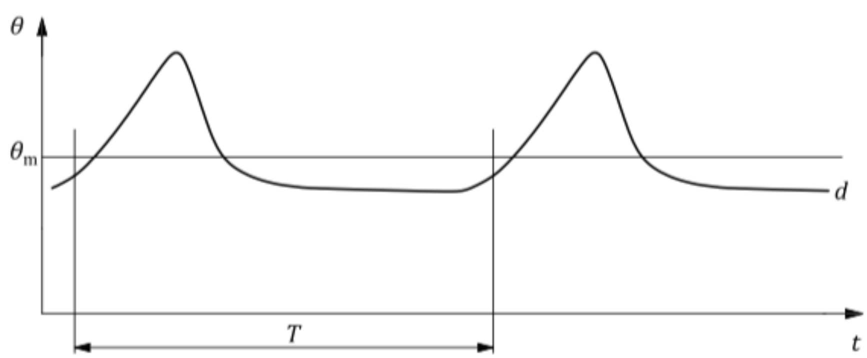
Note: Any sensors measuring the temperature of air flowing into and out of the evaporator are not included in calculation of $T_i$ in Figure 5.




**Key**

| | |
|---|---|
| $\theta$ | temperature |
| $\theta_{ah}$ | highest temperature of warmest M-cans |
| $\theta_{b}$ | 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 5. 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**

| | |
|---|---|
| $\theta$ | temperature |
| $\theta_m$ | average mean temperature |
| $t$ | time |
| $T$ | test period |
| $d$ | curve d of arithmetic mean temperature of all M-cans |

*Figure 6. 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).*

### 6.4.2. Test chamber temperature measurement

The temperature of the air circulating inside the test chamber outside of the WICR (Te), is the arithmetic mean of the temperatures measured 10 cm from the exterior surfaces of the WICR at the following 12 points:

(a) The eight outside corners of the WICR; and

(b) The centres of the four outside faces having the largest area of the six. If the WICR has a floor and it is not a face 'with largest area' then an additional temperature sensor shall be placed 10 cm below the centre of the WICR floor in the support structure on which the WICR rests, to monitor for any temperature difference due to inadequate air flow under the WICR. If the WICR is directly placed on the floor without an airgap, then this sensor shall be placed at the centre of the lower face of the floor layer, between the WICR floor and the floor of the test chamber. If the WICR does not have a floor then no temperature sensor is required at floor level.

### 6.4.3. Measurement of the average air temperature entering and leaving the evaporator(s) and condenser(s)

At least four temperature sensors shall be uniformly distributed in the air stream at the inlet to the evaporator and at least four in the outlet air stream from the evaporator. At least one temperature sensor shall be place in the air stream at the inlet to the condenser and one in the condenser outlet air stream. 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.

### 6.4.4. 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.

## 6.5. Humidity measurement

The air humidity shall be measured in the air in the test chamber (outside of the WICR) during the test and also 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.

## 6.6. Heaters used inside the WICR for the representative heat load test

For delivering the representative heat load inside the WICR, electrical fan heaters 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 12 points specified does not exceed 2°C 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.

### 6.7. Definition of stable operating conditions for measurements

A WICR without thermal energy storage (TES) is considered to operate under stable conditions if:

- During a period of 12 hours, the average air temperature inside the WICR agrees within ±1.0°C at the corresponding points on the time-temperature curve.

An illustrative curve is shown in Figure 6. Changes to the WICR temperature or air flow / fan control settings are not allowed during the stable conditions period, nor any other control changes that alter the temperature or energy consumption. Temperatures may drift outside of these limits during defrost events and the maximum deviation during defrost shall be noted in the test report.

If the WICR includes TES then an additional requirement is imposed based on measurements determined in line with **Error! Reference source not found.**:

- 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 and system setup for test in the test chamber

### 7.1. Assembly and mounting of WICR for testing

i. Set up for test should be carried out by the WICR manufacturer or supplier or according to the instruction manual.
ii. If the WICR is supplied with a floor then support it on a double layer of pallets or similar to allow 20cm or more for airflow between the underside of the floor of the WICR and the floor of the test chamber.
iii. If the WICR is not supplied with a floor then the WICR may be placed on the floor of the test chamber and an insulated floor shall be improvised within the walls using closely fitting PUR panels or similar of at least 80mm thickness laid directly on the test chamber floor. Record details and a photograph of the improvised floor in the test report.
iv. The WICR and its means of mounting shall be located in the test chamber to ensure as even air flow around its outside faces as possible. The gap between any WICR wall or door and any interior face of the test chamber shall not be less than 300mm.
v. Take photographs of the installed WICR from the inside and outside, including the floor and its cooling units, thermal storage components and temperature control system(s).

### 7.2. 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.

### 7.3. Electrical supply

During all tests other than that for operation under poor quality power supply, the electrical supply shall remain within the following variations:

a) ±2 percent of rated supply voltage; and

b) ±1 percent of supply frequency.

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

## 7.4. Setup and use of WICR controls during testing

WICR 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.

## 7.5. Air flow inside the test chamber during tests

During tests the air in the test chamber and outside the WICR under test shall be made to circulate continuously so that the speed of movement of the air when measured 10cm away from the exterior face of the walls of the WICR is maintained at between 1 and 2 metres/second. Air speed checks shall be made near to each air temperature sensor. Air movement is intended to ensure that the air temperature in the chamber outside of the WICR shall not generally vary by more than 5°C between any two points, other than within 10cm of any wall surface.

## 7.6. Overview of setup conditions and indicative durations of tests

The set-up conditions for each test are summarised in Table 6.

Table ***7*** shows indicative durations of time needed for set up and disassembly of each test plus the indicative duration of each test. Note that size of WICR and its design will influence these times.

‘Empty’ means that all accessories which are removable without the aid of a tool and not relevant to the test specified in this document shall be removed. No produce, crates, packaging etc shall be left in the WICR when under test. Test equipment and any dummy load and its support necessary for the test may be present.

*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 | Temperature of dummy load at start |
|---|---|---|---|---|---|
| **Error! Reference source not found. Error! Reference source not found.** | Empty | n/a | n/a | n/a | n/a |
| **Error! Reference source not found. Error! Reference source not found.** | Empty | Fully discharged (at climate zone temperature) | Equal to climate zone temperature | None | n/a |
| **Error! Reference source not found. Error! Reference source not found.** | Representative produce load | Fully charged | At target storage temperature | None | Equal to climate zone temperature |
| **Error! Reference source not found. Error! Reference source not found.** | Empty | Fully discharged (at climate zone temperature) | See Table 8 | None | n/a |
| **Error! Reference source not found. Error! Reference source not found.** | Empty, with heaters and fans as needed | Fully charged | At target storage temperature | Yes, as per **Error! Reference source not found.** | n/a |
| **Error! Reference source not found. Error! Reference source not found.** | Empty | Fully charged | At target storage temperature | None | n/a |
| **Error! Reference source not found. Error! Reference source not found.** | (Not important) | (Not important) | At target storage temperature | None | n/a |

*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 |
|---|---|---|---|
| **Error! Reference source not found. Error! Reference source not found.** | n/a | 0.5h | n/a |
| **Error! Reference source not found. Error! Reference source not found.** | 1d (without TES), min 2d (with TES) | 1-6h | n/a |
| **Error! Reference source not found. Error! Reference source not found.** | 2-4h | 4-12h | 2-4h |
| **Error! Reference source not found. Error! Reference source not found.** | n/a | 14h | n/a |
| **Error! Reference source not found. Error! Reference source not found.** | 4h | 14h | n/a |
| **Error! Reference source not found. Error! Reference source not found.** | 6h | 1-6h | n/a |
| **Error! Reference source not found. Error! Reference source not found.** | | | |

# 8. Performance tests in the thermal chamber

## 8.1. Visual inspection of insulated enclosure and key components

A visual inspection shall be carried out to:

1. Verify that all components are installed in place as-per the design specification or manufacturers instruction manual
2. Verify that installation has been completed satisfactorily (e.g., insulation panels have no gaps or damage, condition and thickness of insulation matches the design specification, doors close and seal correctly, displays and alarms work)
3. Verify that the refrigeration unit runs, cools, and fans circulate air
4. Verify reasonable airtightness by looking inside the WICR for any light getting in between panels and door edges, e.g., when shining a torch from outside
5. After cooling system has been running for a few hours, check for any areas of external insulation surface with condensation water that could indicate damage to the insulation or a thermal bridge. Note in the test report.

## 8.2.Empty pull-down test for rated climate zone (no heat load)

**Aim of test:**
To determine how long it takes to reduce the temperature inside the empty WICR from the climate zone to the target temperature. This test places attention on the cooling of thermal storage and its state of charge.

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

**Test conditions:**

- Temperature in test chamber shall not fall below the lower tolerance of the highest rated climate zone temperature declared by the manufacturer (see

- Table ***1***). Some transient periods outside the tolerance on this temperature (momentary overshoots) are acceptable but shall be noted in the report, for example after WICR cooling system is first switched on.
- No heating inside WICR.
- Temperature measuring instruments shall be placed inside and outside the WICR at the points specified in 6.4.1 and 6.4.2. The air -on and off temperatures to the condenser and evaporator shall be measured as per 6.4.3. Temperature of any thermal storage shall be measured as per 6.4.4.
- Thermal energy storage equipment shall be at the rated climate zone 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 (see also 4.3).

**Test procedure:**

**Step 1 – climate zone temperature stabilisation with WICR doors open:** The WICR shall be placed in an insulated chamber whose mean temperature shall be kept uniform, and constant to within ± 0.5 °C at the rated climate zone temperature during steady state operation. The air in the chamber shall be made to circulate as described in 7.5. The door(s) of the WICR shall be kept 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 +/-0.5°C of the average mean outside temperature of the WICR and within +/-0.5°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) and any other openings 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 0.5°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 its maximum capacity with a storage temperature set point so that maximum cooling is maintained as far as practicable (zero or minimal compressor cut-outs), and a timer started. If the temperature in the test chamber deviates outside of the target range during transient periods, such as after start-up of the WICR cooling system, this shall be noted in the report.

**Step 4 - pull down time for mean air temperature:** The mean test chamber air temperature and the mean inside temperature of the WICR shall be recorded. Record the time taken in minutes from when the cooling is started until the mean air temperature of the 12 general sensors inside the WICR reaches 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 the instant when the average reaches the target and the average humidity inside and outside the WICR.

**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, showing 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 the 7/8 pull-down time could occur before completion of thermal storage phase change.

**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 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 of the test shall consider the stability indicators described in 6.4.4.

## 8.3. Dummy load pull-down test

**Aim of test:**

To determine how long it takes to reduce the temperature of a representative (dummy) produce load stored in the WICR, cooling from the rated climate zone to the target storage temperature. The time taken to reach temperature will be aided by any thermal storage equipment that is fitted as standard inside the WICR since this is to be fully charged at the start of the test. A second part of this test assesses temperature stability achieved by the WICR once at target temperature.

**Test conditions:**

- Temperature in test chamber shall not fall below the lower tolerance of the highest rated climate zone temperature declared by the manufacturer (see

- Table ***1***). Some transient periods above the tolerance on this temperature are acceptable but shall be noted in the report, for example after WICR cooling system is first switched on.
- Storage temperature steady at the corresponding lowest rated storage temperature class (see Table 2) before start of test both for air temperature and any thermal storage.
- No additional heat load.
- Dummy load prepared as per 6.3 with temperature measurement sensors placed as in 6.3.5.
- Dummy load, its crates and any spacers at the rated climate zone temperature is placed in the WICR according to 6.3.6.
- Temperature measuring instruments shall be placed inside and outside the WICR at the points specified in 6.4.1 and 6.4.2. The air -on and off temperatures to the condenser and evaporator shall be measured as per 6.4.3. Temperature of any thermal storage shall be measured as per 6.4.4.
- The average mean temperature of any thermal energy storage equipment shall be at the target storage temperature at the start of the test.

**Test procedure:**

**Step 1 – prepare the dummy load:** Prepare the calculated amount of dummy load including its temperature sensors as per **Error! Reference source not found.** and stabilise its temperature at the climate zone category target. Dummy produce load can be stored in the thermal chamber outside of the WICR until needed.

**Step 2 – stabilise WICR at target temperatures:** This step may be continued from the end of tests 8.1 or 8.6. Continue with 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 6.7 at the target temperature.

**Step 3 – install the dummy load:** When the air temperature inside the WICR and thermal storage temperatures are stable and within required tolerances of the target temperature, and temperature of the dummy load is stable at the climate zone temperature, wait for the next defrost cycle to complete, then open the WICR door(s) and install the dummy load as per 6.3. The content and layout of the dummy load shall be recorded in the test report with one or more photographs. The loading start and end time must be noted, and the air temperature and thermal store temperature at the end point of loading.

**Step 4 - pull down time for dummy load:** The mean outside temperature, the mean inside air temperature and the mean temperature of the dummy load shall each be monitored. Record the time taken in minutes from when the cooling is started until the mean temperature of the dummy load reaches 7/8 of the way to the rated storage temperature. Continue cooling and record the total time taken for the mean temperature of the dummy load to reach rated storage temperature. Note also the highest and lowest temperatures of the dummy load at that instant, the identification of the temperature sensors that had the highest and lowest temperatures and the mean temperature of any thermal storage.

**Step 5 - Delta-T and humidity:** Record the temperature difference between the mean storage temperature and the mean temperature of the air stream leaving the evaporator, and the humidity inside and outside of the WICR.

## 8.4. Determination of heat leackage rate and k-value of the insulated enclosure

**Aim of test:**

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

**Test conditions:**

- Temperature measuring instruments shall be placed inside and outside the WICR at the points specified in 6.4.1 and 6.4.2. Temperature of any thermal storage shall be measured as per 6.4.4.
- No dummy load.
- 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 or calculated. Select any electrical extension cables for the fan heaters and fans to be of minimum practical length; store any spare cable inside the WICR rather than outside, uncoiled.
- The test chamber is cooled. Suggested starting target temperatures for the test chamber and corresponding for the WICR are shown in Table 8.
- Test requires an iterative process of adjusting the heat input inside the WICR from an 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 8. Suggested target temperatures during the heat leakage rate test – iteration from these initial suggestions will be needed to achieve the required DT, depending upon the test equipment and set-up.*

| **Rated climate zone temperature, set point, °C** | **Rated target storage temperature, °C** (cold / cool / moderate) | **Target DT 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 ∆T from Table 8, 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 temperature inside the WICR is higher than the temperature in the test chamber.

**Step 2 - determine the initial estimate of heat leakage rate:** Use Equation 2 to determine the estimated heat leakage rate that 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 8. Start the heaters and fans inside the WICR such that total electrical energy input to fan-heaters and air circulation fans is close to West. 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, looking for when the temperature is starting to level out (rate of change reducing) and then estimating the likely stabilisation level compared with the target.

**Step 5 – adjust heat input level to achieve the target DT and stable conditions:** If the WICR air temperature appears to be stabilizing over [3°C] too low then increase the heat input if the heater equipment or its power supply enable this; 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 ∆T ±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. The achieved ∆T shall be noted in the test report.

**Step 6 – monitor heat and fan energy input to the WICR for 12 hours:** Monitor heater and fan input energy during stable conditions over a period of not less than 12 hours.

**Step 7 – calculate heat leakage rate and k-value coefficient:** Calculate the mean heat leakage rate, W, and the mean ∆T over the stable period. Use Equation 8 to calculate the k-value coefficient for the WICR insulated body (W/m2.°C).

## 8.5. Verification of steady state effectiveness for air temperature, representative energy consumption, representative cooling capacity and maximum cooling capacity

**Aims 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 without a dummy load but with a steady calculated representative internal heat load. Refrigerating capacity and energy consumption are also determined during the test.

**Test conditions:**

- Temperature outside the WICR stable at the highest rated climate zone temperature (see

- Table ***1***).
- 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.
- No dummy load.
- Temperature measurement sensors shall be placed inside and outside the WICR at the points specified in 6.4.1 and 6.4.2. The air -on and off temperatures to the condenser and evaporator shall be measured as per 6.4.3. Temperature of any thermal storage shall be measured as per 6.4.4.
- Any thermal energy storage devices shall be fully charged at the start of the steady state effectiveness test.

**Test procedure:**

This test may follow on directly from the end of either the empty pull-down test (8.1) or the pull-down test with dummy load (8.3).

**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 6.7 at the target temperature and thermal storage is fully charged in line with 6.4.4. Record the climate zone humidity and humidity within the WICR.

**Step 2 – start representative heat load:** When the air temperature in the WICR and thermal storage temperature are stable and within required tolerances of the target temperature, turn on the heaters with a heating capacity equal or as close to the representative heat load calculated as per 4.5, as far as the available heating equipment and its power supply allow. The achieved heat input and its variation from the representative heat load shall be noted in the report.

**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 6.7.

> 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 so when curtailment of the test is otherwise reasonable. If an acceptable storage temperature is not achieved in a reasonable time period 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 energy consumption over a period of at least 12 hours of stable operating conditions (determined as per **Error! Reference source not found.**) 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 (see also 4.3 and 6.4.4). 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, ΔT and humidity**: Record the temperature stability which is equal to the temperature oscillation shown in Figure 7. Record the temperature difference between the average storage temperature and the temperature of the air stream leaving the evaporator (ΔT), the humidity inside and outside the WICR.

**Step 7 – calculate representative COP:** Representative COP is calculated from Equation 4.

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

*Equation 4. Representative COP.*

**Step 8 (optional) – maximum cooling capacity**: Adjust the thermostat of the WICR so that the refrigeration unit runs continuously. Gradually increase the heat load whilst monitoring the storage temperature until stable operating conditions are achieved as per 6.7. If the WICR temperature stabilizes higher than rated storage temperature, then lower the heat load slightly; if the temperature stabilizes lower than rated then raise the heat load slightly. The maximum cooling capacity can be calculated as equal to the heat gain through the insulation (evaluated in 4.5) plus the (electrical) energy input to the fan heaters and any fans installed for the purposes of air circulation during the test. The calculation shall be made over a steady state period of at least 12 hours.

Note: AHRI 1250 or EN 17432 could alternatively be used, with adjustment of declared temperatures as needed.

**Step 9 (optional) – repeat for alternative climate zone or storage temperature rating points:** Repeat Steps 1 to 3 plus 4, 5 and/or 6 under alternative climate zone temperature class / storage temperature class rating points to characterise how the unit performs.

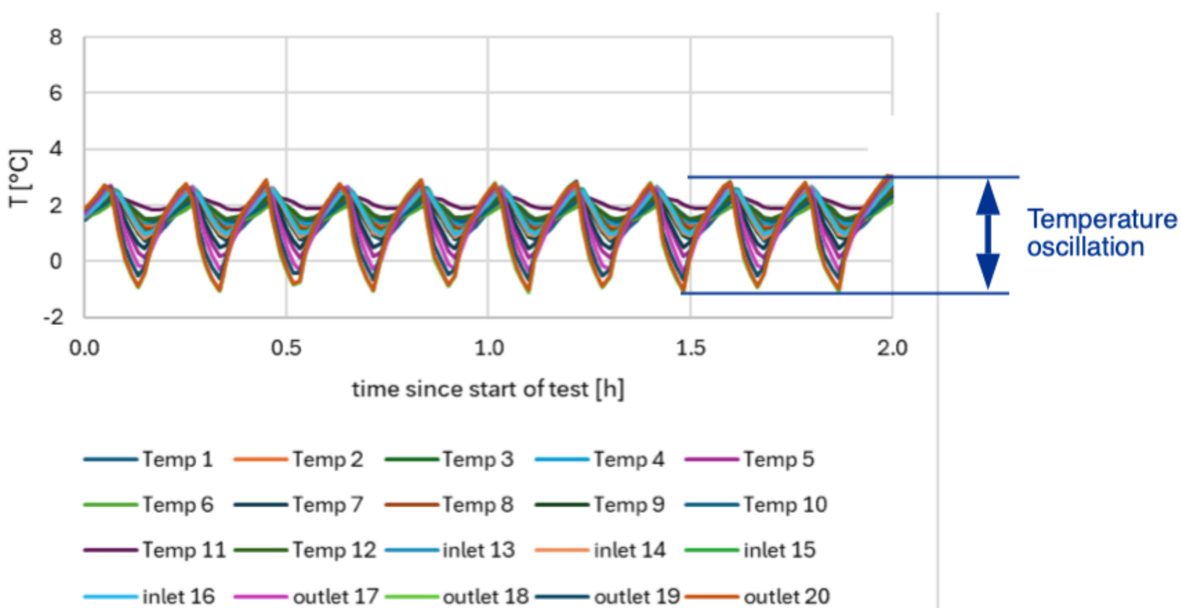



*Figure 7. Temperature sensor chart showing the temperature oscillation measured during the test, which is referred to as the Temperature stability, in °C.*

## 8.6. Autonomy test

**Aim of test:**

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

**Test conditions:**

- No additional heat load
- Thermal storage and batteries fully charged at start of test
- WICR substantially empty; no dummy load
- 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 6.7) 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 – Track 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.
- **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.

## 8.7. Verification of evaporator fan effectiveness and air turnover rate

**Aim of test:**

To provide an indicative air speed and volume flow rate for the evaporator(s) and calculate an air change ratio for the WICR which is the number of times per hour that the air volume in the empty store is drawn through the evaporator(s).

> Note that this methodology is only indicative to confirm a broad level of performance and differences of up to around [20%] between measured values and values declared by the manufacturer should be ignored. Differences greater than 20% could indicate that performance does not meet what is declared.

**Test conditions:**

- Test to be carried out with WICR air temperature at operational storage temperature.
- WICR door closed.

- WICR loading status is unimportant.

**Step 1 – stabilise the WICR air temperature at its target storage temperature ±2°C and close the WICR door.** If more than one evaporator fan speed is available as a user option, then set it to its lowest value and wait 5 minutes for air flow to stabilise.

**Step 2 – measure the speed of the air stream for each fan:** Using a hand-held tachometer (if available, optional), measure the fan speed in RPM. Using a hand-held anemometer, measure the speed of the air flow from each evaporator fan at three locations on a horizontal plane through the axis of the fan no farther than 1cm from the face of the grille enclosing the fan, designated by radius Rm in Figure 8, where:

Ro is the outer radius of the air stream from the fan
Ri is the inner radius of the air stream from the fan
Rm is the radius at the point of measurement (centre of tip of the hand-held anemometer)

The three locations are:

Rm1 = Ri + (0.1 x (Ro – Ri))
Rm2 = Ri + (0.5 x (Ro – Ri))
Rm3 = Ri + (0.9 x (Ro – Ri))

*Equation 5. Radial locations of three speed measurements in the evaporator fan air stream*

**Step 3 – measure air speed at each fan speed level:** if the air speed is adjusted in discrete levels, switch to the next highest fan speed and wait 5 minutes for the air flow to stabilise; repeat air speed measurements. Repeat Step 3 for each available air speed level. If the air speed is continuously variable then select three levels, lowest, mid-point and highest.

**Step 4 – calculate estimated volume flow rate:** Calculate the estimated volume flow rate from the fans using these measurements, at each fan speed using Equation 6.

Air flow rate for all fans, $m^3/hr$ = $V_{air}$ x $CSA_{air}$ x 60 x 60 x 0.75 x N

*Equation 6. Estimation of fan air volume per hour.*

Where:

$V_{air}$ = average of the three air speed measurements on the fan, m/s
$CSA_{air}$ = cross-sectional area of the air stream, calculated from ((pi x $Ro^2$)-(pi x $Ri^2$))
60 x 60 = conversion from seconds to hours
0.75 is an experimentally determined scaling factor to account for boundary effects and averaging of air speed
N = number of fans in the evaporator(s)

Note: if fans of different sizes are present, air volume must be separately calculated and summed.

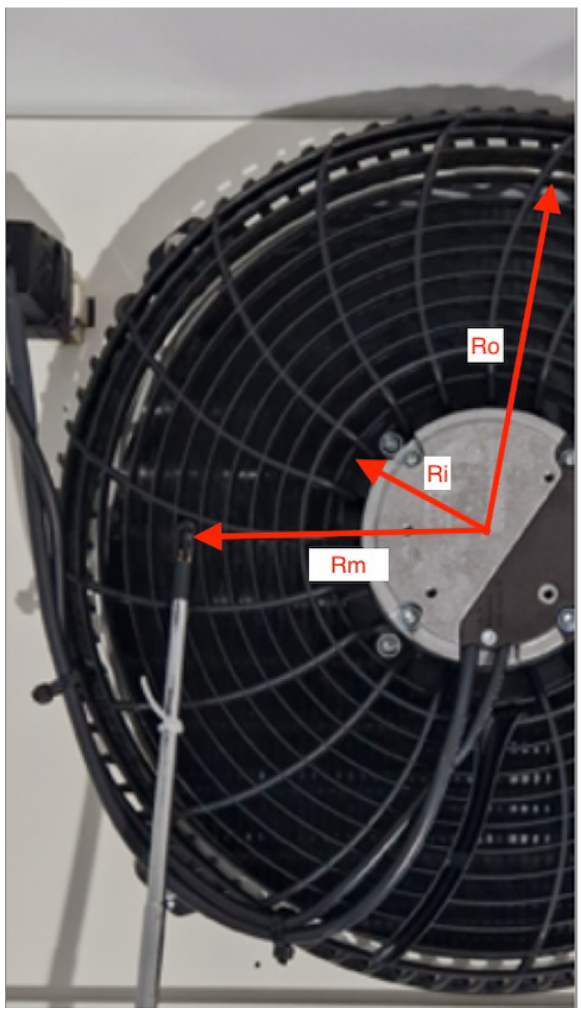



*Figure 8. Image of front face of evaporator fan showing measurements of the fan air stream (Ri to Ro) and position of the tip of the hand-held hot wire anemometer (Rm).*

**Step 5 – calculate air turnover rate for the WICR**:

Air turnover rate = [Air flow rate $m^3$/hr] / [gross internal volume of the WICR $m^3$]

*Equation 7. Calculation of air turnover rate.*

Where:
Air flow rate = total air flow rate for all fans and all evaporators calculated from Equation 6, $m^3$/hr
Gross internal volume of the WICR, measured in $m^3$

# 9. Test report

Test reports may be formulated to suit the quality system and procedures of the lab 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. Description of the type of WICR (prefabricated, preassembled, customised) and its manufacturer and address.
2. 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.
3. Results of visual inspection
    - As per section 8.1
4. List of key components assessment results
    - As per section 8.1 including any additional physical description of the WICR under test, with photographs.
5. Description of how the WICR was mounted and positioned for test
    - As per section 7.1, with photographs
6. Calculation of the indicative heat leakage rate
    - As per sections 4.4 and 4.5, including explanation of the determined heat leakage rate and representative heat load.
7. Determination and description of the dummy load (if used)
    - As per section 6.3, with photographs.

## 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. The numbers in the sub-headings refer to the relevant section of this test protocol.

### 9.2.1. Empty pull-down test (Error! Reference source not found.)

| Parameter | Number (decimal places) | Unit |
|---|---|---|
| Mean test chamber temperature | X.X | °C |
| Time taken to reach target temperature | X.X | Minutes |
| Time taken for TES to reach 7/8 of rated storage temperature (SECT) | X.X | 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 | X.X | °C |
| Time taken to fully charge TES | X.X | Hours |

A temperature trace for the average WICR air temperature during test shall be included in an Annex.

### 9.2.2. Dummy load pull-down test (Error! Reference source not found.)

A sketch of locations of M-bottles shall be included.

| Parameter | Number (decimal places) | Unit |
|---|---|---|
| Time taken to reach SECT for the dummy load | X.X | Minutes |
| M-bottle warmest temperature at end of test ($\theta_{ah}$) | X.X | °C |
| M-bottle lowest temperature at end of test ($\theta_{ah}$) | X.X | °C |
| Highest mean temperature of all M-bottles during the test period | X.X | °C |
| Lowest mean temperature of all M-bottles during the test period, | X.X | °C |
| Average humidity inside the WICR | X | %RH |
| Average humidity outside the WICR | X | %RH |

The following temperature-time traces shall be included in an Annex:

- The warmest and lowest M-bottle temperatures for the entire test period (as per Figure 5).
- Arithmetic mean temperature of all M-bottles (curve *d* of Figure 6).
- The average mean temperature of all M-bottles ($\theta_m$ of Figure 6), °C
- Temperature difference between the average WICR air temperature and the average temperature of the air stream leaving the evaporator, °C

### 9.2.3. **Heat leakage test (**Error! Reference source not found.**)**

| Parameter | Number (decimal places) | Unit |
|---|---|---|
| Target temperature difference (inside to outside) | X.X | °C |
| Actual average temperature difference during test (inside to outside) | X.X | °C |
| Estimated heat leakage rate | X.X | W |
| Heat leakage rate determined during test | X.X | W |
| Calculated k-value coefficient | X.XX | $W/m^2.°C$ |

### 9.2.4. **Steady state effectiveness test (**Error! Reference source not found.**)**

| Parameter | Result or number (decimal places) | Unit |
|---|---|---|
| Average mean air temperature inside the WICR and inside the test chamber | X.X | °C |
| The maximum deviation of temperatures during defrost events | X.X | °C |
| Representative heat load used in test | X.X | W |
| Conclusion on temperature attainment at rated operating conditions | (pass / fail) | - |
| Temperature stability achieved (equal to the temperature oscillation at steady state) | X.X | °C |
| Representative energy consumption | X.X | kWh per 24 hours |
| Cooling capacity with representative heat load | X.X | kW |
| Maximum cooling capacity | X.X | kW |
| Representative COP (Equation 4) | X.X | W/W |
| Average humidity inside the WICR | X | %RH |
| Average humidity outside the WICR | X | %RH |

### 9.2.5. **Autonomy (**Error! Reference source not found.**)**

| Parameter | Result or number (decimal places) | Unit |
|---|---|---|
| Autonomy | X.X | Hours |

### 9.2.6. Fan air flow (Error! Reference source not found.)

| Parameter | | Result or number (decimal places) | Unit |
|---|---|---|---|
| Fan 1 at Fan speed setting 1 | Air speed at position Rm1 | X.X | m/s |
| | Air speed at position Rm2 | X.X | m/s |
| | Air speed at position Rm3 | X.X | m/s |
| | Average air speed, $V_{air}$ (Rm1, Rm2, Rm3) | X.X | m/s |
| | Air flow rate (Equation 6) | X.XX | $m^3$/hour |
| Fan 2 at Fan speed setting 1 | (as above) | | |
| (Repeat for all fans at Fan speed setting 1) | (as above) | | |
| Total air flow at Fan speed setting 1 (sum for all fans) | | X.X | $m^3$/hour |
| Air turnover rate at Fan speed setting 1 (total air flow rate divided by storage volume) | | X | /hour |

Repeat table for each fan speed setting as required.

## 9.3. Annexes to the test report

The following annexes shall be included:

1. Temperature traces for tests as designated in 9.2
2. Other temperature traces for tests as deemed appropriate.

# 10. ANNEX 1: General principles of k-value and heat leakage rate of an enclosure

The general principles of k-value and heat leakage rate are set out in Equation 8[11] :

$$K = \frac{W}{S \, . \, \Delta T}$$

*Equation 8: K-value*

Where:
K = overall heat transfer coefficient of the insulated enclosure (k-value), in W/m$^2$.°C.
W = heat leakage rate (equivalent to the heating power or cooling capacity required to maintain the constant absolute temperature difference ΔT), in Watts.
S = geometric mean surface area, in m$^2$
ΔT = a constant absolute temperature difference between the mean inside temperature and the mean outside temperature, °C.

The geometric mean surface area (S) of the insulated enclosure is determined from Equation 9:

$$S = \sqrt{S_i \cdot S_e}$$

*Equation 9: mean surface area*

Where $S_i$ is the inside surface area of the insulated enclosure and $S_e$ is the exterior surface area[12].

[11] From ATP Annex 1 Appendix 2 section 1.2.
[12] From ATP Annex 1 Appendix 2 section 1.2.