Walk in cold rooms for horticultural and agricultural produce in tropical climates: performance tests for temperature, cooling capacity and energy consumption

Version 3, 17 November 2024

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1 Introduction

This is the first full draft of a test methodology and includes aspects that require further development. Key advances that the document makes for quality assurance for this market include defining rating conditions for ambient temperatures, storage temperatures and characterising the cooling capabilities of equipment (section 4).

This document includes explanatory text and supporting notes and observations in blue text that would not appear in a final test method but assist understanding, explain reasons for suggested approaches and point out issues yet to be resolved.

2 Scope

This document sets out tests to assess the temperature, cooling capacity and energy performance of walk in cold rooms (WICR) designed for use in hot, moderate and temperate ambient temperature zones (respectively 43ºC, 32ºC and 27ºC) in Global South economies for chilled storage of horticultural and agricultural produce.

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 but this will be done in due course, and tests will be adapted if/as necessary to fairly assess other technology types.

This test method does not attempt to address food safety aspects of performance regarding hygiene and storage temperatures. These depend upon regulations in the country of use. Instead, assessments are guided by food quality objectives.

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).

Two set of tests are included, one set to be carried out in a thermal test chamber similar to chambers used for ATP (refrigerated container) testing, and a second set for testing in the field or other locations where a thermal chamber is not available. The field tests aim to emulate the most important tests made in a thermal chamber but at lower implementation cost. The field test approach aims to manage the main sources of uncertainty that field testing involves, when compared with lab testing.

Tests in a thermal chamber, described in section 8, are the following:

1. Empty pull-down test under declared ambient conditions (no heat load), 8.1
2. Pull-down test and temperature stability test with dummy produce load, 8.2
3. Verification of steady state effectiveness, energy consumption and cooling capacity with representative heat load, 8.3

4. Autonomy test, 8.4

Field tests in section 9 are:

1. Visual inspection of insulated enclosure and key components in the field (9.2.1)
2. Temperature pulldown field test without thermal load (9.2.2)
3. System effectiveness field test (9.2.3)
4. Autonomy field test (9.2.4)

Tests covering additional functionality are identified in section 12 but not yet fully developed:

1. Maximum ambient shade operating condition
2. Heat leakage rate
3. Air flow inside the WICR
4. Air tightness test
5. Assessment of thermal storage
6. Condensation and drainage assessment.

3 Terms and Definitions

3.1 Parameters and properties

3.1.1 Gross volume

Internal volume of the cold room, measured from floor to ceiling and from left to right (total height x total width x total length in cubic meters (m^3). When measuring in meters, the precision for measurements shall be of two decimals; tolerance shall be of ± 0,5 cm.

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 (produce, tonnes)

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

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

Note 2: review of capacities declared for WICR on the market suggests that estimated storage capacity in metric tonnes can be converted to a storage volume in cubic metres using the following formula: volume in m^3 = 4.73 x [metric tonnes] + 3.75.

3.1.5 Chilled storage

A storage temperature covering a range that falls between -5ºC and 18ºC. Commonly used chilled storage temperature zones are set out in 4.1.

3.1.6 Frozen storage

A storage temperature generally below -18ºC, but may extend up to -5ºC.

3.1.7 Precooling

Initial removal of excess heat from produce to prepare it for storage. Removal of heat that is absorbed from being out in the field and, for example, from any time spent in direct sunshine between harvest and storage.

Note: Precooling is important because cooling achieved in the first hour after harvest has the most benefit to reducing food loss and upholding quality.

3.1.8 Operational ambient temperature zone

The ambient temperature zone under which declared storage setpoints can be achieved by the WICR. Ambient temperature zones are set out in 4.1.

3.1.9 Autonomy

The time in hours taken for the highest measured air temperature inside the WICR to reach a pre-determined threshold level after the power supply is stopped. Autonomy may be extended by presence of thermal storage and/or electrical (battery) storage.

3.1.10 Thermal storage capacity

The amount of cooling effect stored in the form of pre-cooled fluids or solids, which may be boosted by latent heat storage when phase change materials (PCM) are used. Measured in kWh or MJ.

3.1.11 Total Heat Leakage (thermal loss)

The total rate of heat loss through the insulated enclosure of a WICR due to a temperature gradient across the thickness of the insulated enclosure. Measured in kW.

3.1.12 Off-grid

Means that no public or private electricity grid connection is available at the point of use and therefore a standalone electricity supply system is required.

3.1.13 Unreliable grid

Means that a connection to an electrical grid is available but power is subject to highly variable power quality and reliability, often without prior notice of problems.

3.1.14 Limited supply

Means electrical supply of reasonable or good quality but operating 22 hours or less per day[1], for example at a set number of hours per day on virtually every day and known in advance. Maximum current limits may also apply.

> 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.

3.1.15 Reliable grid

Means that power is generally available for 22 hours per day or more on a planned basis and meets the international quality benchmarks for public supply such as IEC TS 62749[2], EN 50160[3], or reasonably close to that level of power quality. Voltage stability would be adequate for normal operation of equipment with few power outages, most of which are pre-warned.

3.1.16 Total fan input power

Power (kW) absorbed by all fans in evaporator(s) or fan unit(s) inside the WICR when running at full speed. This can be estimated by adding up the rating plate power (kW) for each fan.

3.1.17 Air flow (evaporator, fan unit)

A property of fan coil units and evaporators defining the air volume flow through its fan(s) in cubic metres per hour, measured in unrestricted flow.

3.1.18 Empty air changes per hour

The number of times per hour the volume of air in the cold room should theoretically pass through the heat exchanger as a result of its fan power. Number of empty air changes per hour is equal to the air volume flow of the evaporator(s) in m^3/hr. divided by the empty volume of the storage compartment in m^3.

3.2 Equipment types

3.2.1 Walk in Cold Room (WICR)

A cooled and 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

[1] 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.

[2] 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.

[3] 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.

to walk through but is not large enough for fully mechanised produce handling by forklift truck and similar.

3.2.2 Prefabricated kit WICR

A WICR that is assembled on site from a kit that includes all components necessary to assemble a working WICR and can be set to use after a specified commissioning and adjustment process. Insulation panels would generally be cut to size in the factory with manufactured joints pre-prepared for assembly on site with minimal tooling. 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, only needing a power supply and minimal set up to start working.

3.2.4 Customised 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 from an ISO shipping container (freight, ‘dry’ or intermodal container) through installing insulation, a cooling system and power source. The most common size used for cold rooms is a 20ft container (6.09m long, nominal 33m^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 Monobloc (compact refrigerating unit)

A packaged refrigerating unit assembled, filled and ready for use without the need for connecting any refrigerant containing parts.

3.2.8 Split system

A packaged refrigerating unit comprising one unit providing cooling to the cold room and one unit used for condensing that refrigerant (EN 17432).

3.2.9 Test chamber

A room in which the ambient air can be conditioned and kept in a steady state condition.

3.3 Other terms

3.3.1 ATP

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.

> Note: 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.

4 Standard rating of walk in cold rooms

4.1 Rated ambient temperatures and storage temperatures

To achieve comparability of test results between different WICR, tests shall be carried out at specific temperatures within given tolerances. Performance may be declared at one or more combinations of the rating conditions set out in Table 1, Table 2 and Table 3 according to the temperature compatibility declared by the manufacturer in its published data sheet or instruction manual.

If more than one ambient temperature category is declared, then the default ambient category for testing will be the highest. If more than one storage temperature category is declared, then the default storage category for testing will be the lowest.

Table 1. Ambient temperature rating conditions.

Ambient temperature class	Maximum rated ambient operational temperature of the WICR	Ambient temperature to be used during testing to this methodology
Hot Zone	+43ºC	+43ºC +/- 1ºC
Temperate Zone	+32ºC	+32ºC +/- 1ºC
Moderate Zone	+27ºC	+27ºC +/- 1ºC

Table 2. Chilled storage temperature rating conditions in three categories (see also alternative and more comprehensive options for five temperature categories shown in Table 3).

Storage temperature class	Rated operational storage temperature range of the WICR	Target storage temperature during tests
Cold	0 to +2ºC	+1ºC +/- 1ºC
Cool	+7 to +10ºC	+8ºC +/- 1ºC
Moderate	+13 to +18ºC	+15ºC +/- 1ºC

Note; The target storage temperatures are chosen so that the unit will operate at the lowest workable temperature without straying out of the temperature range of the category (according to required tolerances).

Table 3. Chilled storage temperature rating conditions in seven categories, according to USDA[4], and adopted by the Government of India[5]. Note: groups 1, 2 and 3 would be tested at the same temperature. (See also alternative simplified options for three temperature categories 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
Group 1: Fruits and vegetables	0 to 2ºC with 90-95% relative humidity	+1ºC +/- 1ºC
Group 2: Fruits and vegetables	0 to 2ºC with 95-100% relative humidity	
Group 3: Fruits and vegetables	0 to 2ºC with 65-75% relative humidity	
Group 4: Fruits and vegetables	4.5ºC with 90-95% relative humidity	+4.5ºC +/- 1ºC
Group 5: Fruits and vegetables	10ºC with 85-90% relative humidity	+10ºC +/- 1ºC
Group 6: Fruits and vegetables	13 to 15ºC with 85-90% relative humidity	+14ºC +/- 1ºC
Group 7: Fruits and vegetables	18 to 21ºC with 85-90% relative humidity	+19ºC +/- 1ºC

4.2 Definition of produce storage and cooling capability

To enable accurate characterisation of performance, this section proposes a way to rate the performance of WICR within scope into one of two categories, either for:

A. Storage of pre-cooled produce at the rated conditions, or
B. Storage at the rated conditions with produce cooling capability.

This rating determines the representative heat load to be used in tests, as described in 4.4 and Table 5.

A WICR may be declared as suitable ‘storage of pre-cooled produce at the rated conditions’ if:

1. The WICR can attain the required average storage temperature when tested according to 8.3 steps 1, 2 and 3 or an equivalent test at the rated combination(s) of ambient temperature and storage temperature as declared by the manufacturer.

If a WICR cannot attain the required average storage temperature according to 8.3 or an equivalent test at the rated combination of ambient and storage temperatures as declared by the manufacturer then it must be re-assessed to be rated at a less demanding combination.

[4] 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.
[5] 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.

A WICR may be declared as suitable for 'storage at the rated conditions with produce cooling capability' if:

1. The WICR can attain the required average storage temperature when tested according to 8.3 steps 1, 2 and 3 or an equivalent test at the rated combination(s) of ambient temperature and storage temperature as declared by the manufacturer, and
2. The WICR is capable of reducing the temperature of a dummy load as specified in 5.3 from the maximum rated ambient temperature to the minimum rated storage temperature within the time shown in Table 4, according to 8.2 steps 1 to 4 or an equivalent test. The dummy load is representing a batch of produce with weight equal to 10% of the maximum declared capacity of the WICR.

Some rearrangement of WICR setup may be carried out to achieve the produce cooling requirement, for example by use of tarpaulin, baffles or board(s) to direct air flow. Rearrangement shall not involve a cumbersome restructuring of the facility that is unlikely to be done in practice by users. A benchmark for this is proposed that rearrangements must be made with [two or less trained people] in a [time not exceeding 30 minutes]. In order for the WICR to not be defined as a dedicated pre-cooler (and so be out of scope of this test method) it shall be possible for other produce accounting for no less than [40%] of the rated storage capacity to be contained in the storage volume whilst the produce cooling process is being carried out. Any other produce in the store shall be already at the storage temperature.

> Note: The qualifying threshold in hours of Table 4 is set so that produce loaded at the start of a day can be cooled within one working day (single shift). This also ensures that cooling should be completed during a single period of good power availability if it is solar powered or uses a limited availability supply.

If there is no space for parallel storage of produce when carrying out pre-cooling, then the unit is, by definition, a dedicated precooler for that period. Dedicated pre-coolers are not included in scope of this test method and no performance requirements are indicated here.

Table 4. Required pull-down time to qualify as suitable for 'storage at the rated operational temperatures with produce cooling capability'. Pull-down times are for a dummy load according to 5.3 determined according to 8.2, from the maximum rated ambient temperature to 7/8 of the minimum rated operating temperature for the representative dummy load of a WICR.

Design purpose (cooling capacity rating)	**Pull-down time of mean temperature of a dummy load representing 10% of the rated load, from rated ambient temperature to 7/8 of rated operating temperature (hours)**
Storage of pre-cooled produce at the rated operational temperatures	n/a
Storage at the rated operational temperatures with produce cooling capability	6

4.3 Calculation of an assumed heat leakage rate (kW) for the WICR enclosure

[ATP testing includes a test to determine the heat leakage rate (K coefficient) of the insulated enclosure with a 25K temperature differential across the insulated enclosure walls. This is then used to determine a heat load that is applied to the inside of the container during certain tests, equal under ATP to 35% of the heat leakage rate. This testing step could be avoided (a suggestion – to be discussed) if a calculated value can be used instead, based on the dimensions and U-value of the insulation material. The validity and uncertainty implications of this must be evaluated. It will only be an estimate, but that could be adequate to establish some basic performance parameters of the WICR. Note that the 25K differential used for ATP is considered inadequately representative for tropical situation, where ambient temperatures are high (e.g., 35ºC and higher), WICR are stationary and so do not have such cooling effect of movement like trucks / reefers, and also the incident sunshine on the shell of cold rooms that are almost always isolated and rarely fully shaded causes a higher differential across the insulation thickness. ASHRAE data from the USA suggests that the temperature of a white surface in direct sunshine can peak at 20ºC higher than ambient air – solar intensity is higher in the tropics.]

An estimated heat leakage rate for the insulated enclosure of the WICR is an important performance parameter and is used to determine the representative heat loading under relevant tests (see 4.4). The heat leakage rate can be based on a test result (see 12.2 or similar) or calculated based on materials and construction as below. To account for uncertainty of a calculated approach, a penalty is applied in the form of the escalation factor as below.

If a heat leakage test result is available for the insulated enclosure as per 12.2, ATP or similar, then this may be used to calculate an assumed heat leakage rate by the following:

1. The assumed heat leakage rate shall be adjusted by calculation such that it is representative of heat leakage at a temperature differential across the insulation equal to the difference between the rated maximum ambient temperature and the rated minimum storage temperature.
2. The assumed rate shall also be adjusted such that it is representative of heat leakage for a structure aged by at least 4 years. In the absence of evidence about the specific materials used, the assumed heat leakage rate from a test on a new structure shall be raised by 7% to account for this.

   Note: Annex I of ISO 1492-2 provides a method to calculate the aging effect on polyurethane foam insulation (the most commonly used material) and concludes that U-values deteriorate by 2% after six months; 4% after 12 months; and 9% after 10 years. According to Figure I.1 of ISO 1496-2, 7% worsening of U-value corresponds to the empirically defined aging affect after 4 years.

If no heat leakage rate is available from testing then it shall be estimated by the following:

1. Determine the geometric mean surface area of the insulated enclosure m^2 (following the principles of ATP Annex 1 Appendix 2 section 1.2).
2. Look up the material and its thickness and the declared U-value of the insulating materials of walls, door, ceiling and floor (if/as applicable). Use the aged U-value of the materials (to take account of the degradation of effectiveness over time). If no aged value is available, then a U-value shall be used that is 7% worse than the value for the new material.

   Note: Annex I of ISO 1492-2 provides a method to calculate the aging effect and concludes that U-values deteriorate by 2% after six months; 4% after 12 months; and 9% after 10 years. According to Figure I.1 of ISO 1496-2, 7% worsening of U-value corresponds to the empirically defined aging affect after 4 years.
3. Use principles of ATP Annex 1 Appendix 2 section 1.2 or EN 16855-1 or -2 to estimate the total heat leakage rate (kW) or K coefficient of the enclosure at its rated ambient and storage temperature class combination (if several combinations of rated temperature are declared, the default representative value would be the highest from the declared combinations). The calculated heat leakage rate method must account for typical losses incurred by joints and other features.
4. Apply a heat leakage escalation factor of 15% to account for the uncertainty of the calculation method, and aiming to ensure that a calculated heat leakage value will not be more favourable for the performance of the WICR than a tested value of heat leakage.

4.4 Calculation of the representative heat load

The heat load that a WICR can cope with varies depending on its intended purpose. For example, a WICR used purely for long term storage needs lower cooling capacity than a WICR designed for regular access and to cool some produce that is loaded warm. Testing should be adjusted to provide a ‘stress test’ of cooling appropriate to the declared purpose of the WICR. Using a representative heat load also ensures that a measured energy consumption value reflects the intended end-use and so is useful information for the end user. The heat load is proposed to be calculated based on the heat leakage rate through the insulated enclosure, following the principle used in ATP testing. This approach means that the heat load used in testing takes account of the design decisions taken by the supplier regarding the shape and insulating effectiveness of the enclosure (a well-insulated enclosure with low surface to volume ratio will have a lower heat load for testing). A key issue for ATP testing is ensuring appropriate matching of capacity of the cooling unit with the effectiveness of the insulated enclosure and this is assumed to have influenced the approach taken (accepting that the real unit is in the chamber and so these design decisions are already reflected in the test and in the heat load experienced by the cooling unit). See also section 13 paragraph 1 for an alternative approach to determine the representative heat load.

The representative heat load for a given cooling capacity rating is calculated from this formula:

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

Where:

- The heat leakage rate is either determined from a test (see 12.2) or by calculation including the escalation factor as per 4.3.
- The Representative heat load factor used depends upon the intended purpose (duty rating) of the WICR as in Table 5.

Table 5. Table of representative heat load factors by cooling capacity rating category.

Cooling capacity rating, description (design purpose of the WICR)	**Representative heat load factor**	**Explanatory notes**
Storage of pre-cooled produce	50%	Loading raised by modest amount above the ATP test level of 35%. Total heat load on the cooling system during test is effectively 150% of the heat that enters via insulation at rated ambient – intended to reflect operation with limited door openings and coping with stored produce respiration heat and external solar heat gain.
Storage with produce cooling capability	[120%]	Total heat load on the cooling system during test is effectively 220%* of the heat that enters via insulation at rated ambient – 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 ambient temperature.
ATP value (for comparison)	*35%*	*35% is heat load level used for ATP effectiveness test. The Test Method Expert Group agreed that heat loads matching ATP requirements would be inadequate to ensure effective operation for WICR applications in tropical applications.*

*Note: The 220% figure is not backed up by calculations but suggest this should be done before pilot testing. The loads identified in this list could be quantified and modelled.

5 Instrumentation and equipment for tests

5.1 Test chamber

A test chamber designed for ATP tests on refrigerated containers, or similar. See also section 9.

5.2 General instrumentation requirements

- Sets of readings shall generally be recorded at intervals of not more than 15 min. Time limits shorter than 15 minutes apply to some measurements in the test procedures.
- Instruments placed inside and outside the thermal container for measuring air temperature 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 K
  The electrical energy consumption shall be determined with an accuracy of ±2 %. Due to electrical cable losses (heat lost to resistance heating), the length of cables connecting the power supply and its measuring instrument to the heaters inside the WICR enclosure shall be minimised; surplus cable lengths 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%.
- Pressure and air flow (for airtightness test): The flow-measuring device shall be accurate to [±3 %] of the measured flowrate. The manometer shall be accurate to [±5 %].
- All measurement equipment used shall show evidence of calibration (preferably through an ISO 17025 compliant or ilac approved laboratory).

5.3 Specification of the dummy load

5.3.1 Purpose of the dummy load

A dummy load is used in an adapted pull-down test to simulate operation with produce in the cold room. This provides substantial additional insight into cooling of a produce load, in the form of the dummy load, rather than the pull-down of air temperature as shown in the empty pull-down test. Therefore, the specifications of this dummy load mimic typical produce in a reasonably reproducible way in its thermal properties, shape, size and arrangement inside the cold room.

5.3.2 Amount and material of the dummy load

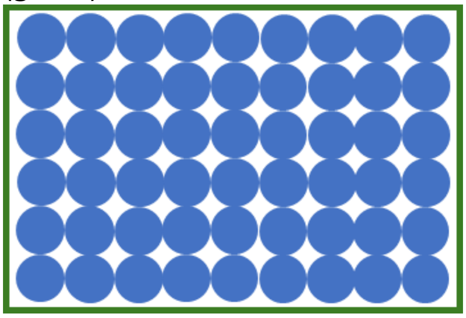
The total dummy load used in the test shall be calculated as equivalent to 10% of the total loading capacity of the cold room in kg of produce. The dummy load shall consist of standard PET cylindrical 500ml bottles. Preferred dimensions are 6.4cm ±0.3cm diameter and 20.3cm ±0.3cm height (the test report shall note dimensions of bottles used). The bottles shall be filled with 500g ±10g water and stabilised at the cold room's rated maximum ambient temperature (±1°C) before use.

5.3.3 Type of crates to hold the dummy load

Standard perforated euro crates shall be used to hold the bottles, with base dimensions of 600 x 400 mm (DIN 55423-2:1985-10, Packaging; stacking containers; perforated plastic crates for use in mechanical handling and transportation).

5.3.4 Stacking of the dummy load inside the crates

The bottles are stacked into the crate in a way that they are in the most contact possible standing vertically. With the given dimensions of the crate, 54 bottles (blue) fit per crate (green) as shown below.



5.3.5 Stacking of dummy load crates in the WICR

Plan locations of M-bottles according to 5.3.6 before loading the WICR with dummy load. Crates shall be placed in a standard replicable manner inside the cold room representing the manufacturer's recommendation for produce placement. If the WICR includes permanently fitted shelving or racking, then loading shall make use of the shelving in a way that follows the principles set out below. 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 to a depth of 100 +-20mm beneath the crates. In the absence of recommendations or instructions from the WICR supplier, stacking shall start at a corner furthest from the door, working towards a single layer covering the floor area of the WICR. Crates shall be in double rows and 100 +-10mm from any nearby wall for 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 double rows of crates. See Figure 1. If more than one layer of crates is required to hold the calculated amount of dummy load, then a second layer of crates shall be started at a corner furthest from the door.

Loading inevitably results in variations between the different cold rooms as the recommended setup by the manufacturer differs, the exact shape of bottles might vary.

All of this affects air flow around the dummy load. Records and photos of the dummy load and its layout shall be included in the test report along with a diagram showing locations of M-bottles.
In general, with the given variation in stacking the dummy load, a significant loss of comparability of tests using the dummy load is given. This is acceptable as this test evaluates the performance of the WICR against the manufacturer's specification; rather than forming a neutral test.

Figure 1. Example stacking of crates of dummy load water bottles in a WICR. Note that a 100mm air gap should be allowed between any crate and a nearby wall.

5.3.6 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 but shall be filled with 500ml water mixed with 30g of gelatine powder and allowed to set before inserting the temperature probe located at the geometric centre of the bottle. M-bottles shall replace dummy load bottles in certain locations in certain crates. M-bottles are to be located at the following points of the dummy load crates:

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)

c) The same pattern of outermost corners and geometrical centre shall be followed for the crates that constitute the second layer of crates. The second layer may not cover the entire floor plan area of the WICR, and 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 seals.

5.4 Temperature measurement

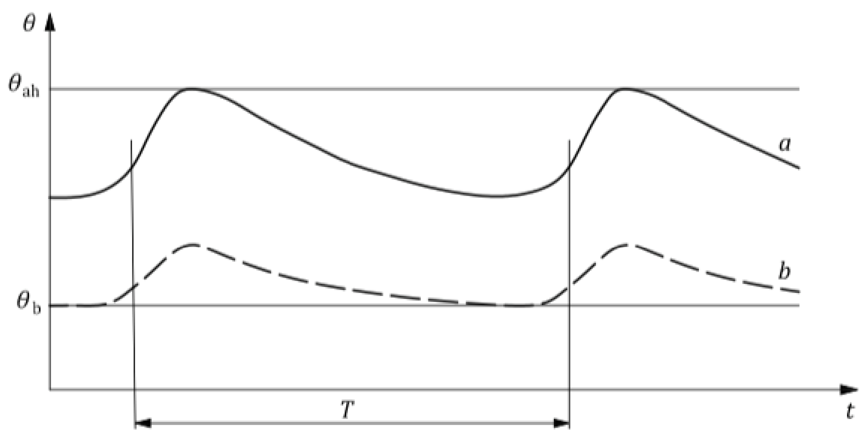
5.4.1 Air (storage) temperature measurement

The average mean inside temperature of the WICR (Ti) (see Figure 2 and Figure 3) 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.

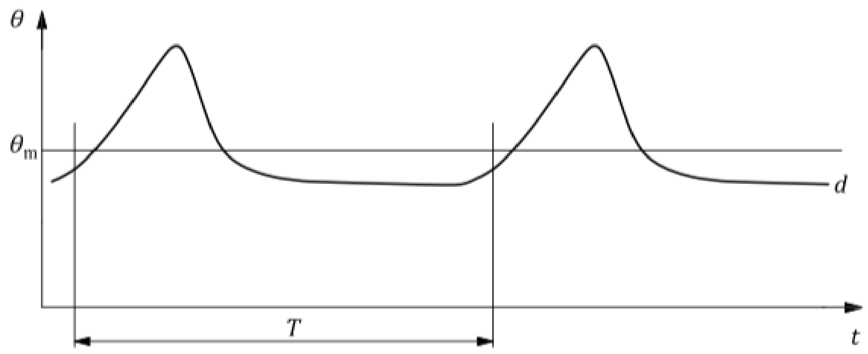
Connections from the temperature measuring elements shall be brought to the outside of the room in such a manner as to interfere as little as possible with air seals



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 2. Illustrative chart of temperature readings from temperature sensors, 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 3. 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).

5.4.2 Ambient temperature measurement

The average mean outside temperature the body (Te) is the arithmetic mean of the temperatures measured **10 cm from the walls** at the following 12 points:
(a) The eight outside corners of the body; and
(b) The centres of the four outside faces having the largest area.
If a dummy load interferes with this probe location, then the probe shall be moved to be as close as possible to the above intended location but not closer than 200mm to any dummy load crate.

5.4.3 Measurement of the average air temperature entering and leaving the evaporator(s) and condenser(s)

Temperature sensors shall be placed in the direct air stream both entering and emerging from the evaporator(s) and the condenser(s) to assess the average temperature of air entering and leaving. The sensors need not be protected from incident heat. 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.

5.4.4 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 significantly and this means that the approach to temperature measurement cannot be standardised. Temperature sensors should be applied to at least one quarter of any separate volumes of thermal store, up to a maximum of 8 sensors. The thermal storage devices selected to be fitted with temperature sensors shall be spread geometrically evenly throughout the set of devices. Temperature sensors shall be in good thermal contact with the storage medium and insulated or at least shielded from surrounding air. The average, minimum and maximum temperatures of sensors shall be recorded not less frequently than every 15 minutes.

If thermal storage installed in the WICR includes phase change material (PCM) that has a phase change temperature that is between the ambient temperature of test and the evaporating temperature of the chilling unit, then this affects how testing proceeds and how results are assessed. Before phase change occurs, the temperature of the thermal store will drop as heat is extracted from it by the cooling system. If a phase change occurs during the test, then suitably placed temperature sensors will show a period of heat extraction from the thermal store during which little or no change of temperature occurs[6]. This is when extraction of latent heat occurs and is referred to as the 'latent heat temperature plateau'. Depending upon system design the plateau could last many hours or days before all the thermal storage medium has changed phase (i.e., frozen) and temperature sensors show a further drop in average temperature as heat is extracted. It is difficult to determine when charging of the thermal store is complete due to little or no change of temperature during the latent heat plateau. The latent heat plateau could be mistaken for stable conditions during a test which means misleading results because energy movement is not properly accounted for during the test.

Determination of when thermal storage with PCM is completed and whether stable operating conditions have been reached should take into account:

a) How the readings from all thermal storage temperature sensors compare with the freezing temperature of the PCM and with the temperature of the cooling medium that is cooling the thermal store
b) The stability of the air temperature in the store
c) The stability of the thermal storage average temperature
d) The stability of energy consumption, and
   Regularity of compressor cycling periods.

5.5 Humidity measurement

The air humidity shall be measured in the ambient air surrounding the WICR during the test and also as an average inside the WICR storage volume.

5.6 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 with fans having a delivery rate sufficient to obtain 40 to 70 air changes per hour related to the empty volume of the WICR. Air distribution shall be sufficient to ensure that the maximum difference between the temperatures of any 2 of the 12 points specified does not exceed 2 °C when continuous operation has been established.

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[6] PCM is attractive to use as it enables a higher density of energy storage through transfer of latent heat as well as sensible heat.

Heaters inside the WICR may have to be placed alongside a dummy product load if the dummy load is already loaded ready for subsequent tests. The set up shall ensure that warm air from the fan-heaters does not blow directly onto temperature sensors, dummy product load packages nor walls of the WICR if closer than 2 metres. Positioning shall ensure that air from the heaters disperses and mixes with air inside the WICR. If necessary, this may be achieved by using a small number of baffle plates to interrupt and randomise the air flow.

5.7 Definition of stable operating conditions for measurements

If the WICR does not include thermal storage then the WICR is considered to operate under stable conditions if, during a period of 12 hours, the average ambient air temperature inside the WICR agrees within ±2°C at the corresponding points on the time-temperature curve (example curve is shown in Figure 3) and these temperatures shall not vary by more than ± 3.0 °C during the preceding 6 hours. Changes to the WICR controller settings are not allowed during the stable conditions period. Temperatures may drift outside of these limits during defrost events and the maximum deviation during defrost shall be noted in the test report.
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, and separated by at least 6 hours, shall be less than 5%.
The mean inside and outside temperatures at the beginning and the end of the calculation period of at least 6 hours shall not differ by more than 1°C.

If the WICR includes thermal storage then additional requirements are imposed on determination of stable operating conditions, as per 5.4.4.

> (Thermal storage provides buffer cooling and so can distort test results in many ways and the temperature trend of thermal storage must be taken into account when establishing stable operating conditions. If the thermal storage is being depleted during a test, then conditions cannot be considered stable, even if the there is sufficient reserve to get the unit through a timed test such as 8.2 Step 3. In real use over a longer time period this would result in failure to maintain temperature under those heat load conditions, once the thermal store is depleted).

6 Preparation and system set up for test in thermal chamber

6.1 Assembly and mounting of WICR for testing

i. Set up for test should ideally be carried out by the WICR manufacturer or supplier, or if not then at least according to their guidance.
ii. Check the WICR and its systems for any visual and technical defects or damages.
iii. For ease of access and removal from the thermal chamber, the WICR shall be mounted on a flat rigid wooden base plate secured to a wheeled trailer. The area of the rigid wooden base plate shall match or exceed the base area of the WICR.

The base may extend beyond the perimeter of the WICR and trailer, subject to safe movement of the trailer.

iv. The calculated average k-value of the wooden base plus trailer on which it is mounted shall be maximised and not less than [TBD] W/mK.

v. If the WICR is supplied with a load-bearing floor (i.e., designed for placing on pillars or beams with an air gap underneath) then support it as specified by the manufacturer and such that there is an air gap of at least 20 cm underneath to allow for airflow underneath the insulated floor of the WICR.

vi. If the WICR is supplied with insulated floor panels that are designed to be placed directly on the ground (i.e., not a load-bearing floor) then place the WICR insulated floor directly onto the wooden base plate.

vii. Air movement under the WICR shall be, as close as reasonably possible to 1 to 2 m/s at 10 cm below the floor, the same as for side walls and ceiling of the WICR.

viii. Leave in place (or install into place) any thermal storage devices that are supplied as standard with the WICR, as specified in the technical documentation or instruction manual. If thermal storage is an optional extra purchased separately then it shall not be installed for testing.

ix. The WICR and its means of mounting shall be located in the thermal 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 thermal chamber shall not be less than [300mm].

x. 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).

6.2 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 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.

6.3 Use of controls during testing

6.3.1 Principles of approach

Controls may not work as advertised in each usage situation and/or may interfere with test conditions or settings and so may distort results. The aim of tests is characterising basic operation of the hardware, and it cannot be assumed that controls will be optimised or even correctly used in the field. This approach to testing aims to take this into account by minimising the influence of controls on the testing process other than where they aim to achieve correct and stable temperatures and efficient operation under typical, steady usage conditions.

Examples of controls that should be disabled when this is possible without damage to the WICR are:

- Energy saving devices that reduce compressor run time or adjust storage temperature settings during times of low usage e.g., when no door openings.
- Controls that are designed to achieve a changing pattern of temperature over time to precool or condition certain types of produce.
- Any systems and controls that adjust or detect humidity or gas levels inside the store.

6.3.2 Set up of controls for testing

i. Controls that support achievement of test set up requirements and do not interfere with the aims of the test may remain active for testing, e.g., thermostats, fan controllers. If these controls can be set in such a way that the required test conditions are sustained, then the test may be carried out with those controls active.

ii. If any control undermines the intent of the test (or there is reasonable risk of that) for example by altering the set point(s) or suppressing energy consumption during the energy test or otherwise achieving a more favourable result in ways that are not typical of general operation, then those controls shall be disabled by a mechanical or software switch or setting without damage to the unit, including with use of generally available tools. If the control cannot be disabled by these means, then the presence of the control must be flagged in the report along with a description of how that control is suspected to interfere with attaining the required test conditions and aim of the test. The measured (or estimated) deviation from test conditions must be quantified and reported in the test report.

6.4 Air flow inside the test chamber during tests

During tests the air in the thermal chamber and outside the WICR under test shall be made to circulate continuously so that the speed of movement of the air when measured 10 cm from the outside of the walls of the WICR (including under the base and above the ceiling) is maintained at between 1 and 2 metres/second.

6.5 Overview of set up conditions for tests

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

Table 6. Overview of set up conditions for each test.

Test	Contents of storage volume	Status of thermal storage at start (if present)	Internal air (storage) temperature at start	Representative heat load	Temperature of representative (dummy) produce load at start
8.1 Empty pull-down test under declared ambient conditions (no heat load)	Substantially empty	Fully discharged (at ambient temperature)	Equal to ambient temperature	None	n/a
8.2 Pull-down test and temperature stability test for a representative produce load	Representative produce load	Fully charged	At target storage temperature	None	Equal to ambient temperature
8.3 Verification of steady state effectiveness for air temperature, energy consumption, rated cooling capacity and maximum cooling capacity	Substantially empty or with representative produce load	Fully charged	At target storage temperature	Yes, as per 4.4	At target storage temperature
8.4 Autonomy test	Substantially empty	Fully charged	At target storage temperature	None	n/a

7 Preparation of the bill of materials for the WICR

A Bill of Materials (list of key components) for the WICR configuration as tested shall be prepared. This is to correlate the test result to the WICR configuration used in that specific test. In this way, validity and relevance of the test result can be objectively assessed following design changes in the future.
The following key parameters and components of the system shall be identified by brand, model number, key electrical parameters and number of each item that are included in the operational WICR. This shall be noted in the test report with a photo of each item and its electrical rating plate, where available:

i. Measured gross volume according to 3.1.1.
ii. Thickness and material of insulating panels, ceiling and floor (with U-value if available, including description of skin material and paint finish inside and out)
iii. Thickness and material of door and description of its mounting and closure mechanism
iv. Description and images of typical joints between insulated panels both inside and outside the WICR
v. Compressor(s) (if accessible without disassembling the refrigeration unit)
vi. Condensing unit and/or monobloc unit
vii. Refrigerant type and charge quantity (as declared on the rating plate or in paperwork 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)
x. Description of thermostatic temperature control apparatus
xi. Description of user interface panel and switches
xii. Presence of Voltage regulator(s)
xiii. Interior lighting type (e.g., LED, fluorescent, incandescent), number of lamps and rated input power (W).

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 bill of materials.

8 Performance tests in the thermal chamber

8.1 Empty pull-down test under declared ambient conditions (no heat load)

Aim of test:
To determine how long it takes to reduce the temperature inside the empty WICR from the rated ambient to the target temperature. This test places attention on the cooling of

thermal storage and its state of charge, also with regards to any phase change occurring of the storage medium.
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 ambient temperature and will therefore slow achievement of target temperature.

Test conditions:

- Ambient temperature corresponding to the highest rated ambient temperature category (see Table 1).
- Storage temperature corresponding to the lowest rated storage temperature category (see Table 2).
- Heating inside WICR not activated.
- If the WICR can be operated on different energy sources, repeat the test with each one of them.
- Cooling unit operating on normal thermostatic control but with set point at its lowest setting, so that the thermostat should not operate during the test (maximum cooling sustained).
- Temperature measuring instruments that are protected against heat radiation shall be placed inside and outside the WICR at the points specified in 5.4.1 and 5.4.2. The air -on temperature to the condenser shall be measured as per 5.4.2. Temperature of the air stream from the evaporator (air-off) and any thermal storage shall be measured as per 5.4.3 and 5.4.4 respectively.
- Thermal energy storage equipment shall be at the rated 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 (see 5.4.4).

Test procedure:

Step 1 – ambient temperature stabilisation 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 ambient category target temperature. The air in the chamber shall be made to circulate as described in 6.4. 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 is within +/-0.5ºC of the average mean outside temperature of the WICR and within +/-0.5ºC of the average mean temperature of any thermal storage devices.

Step 2 – close up and start cooling: the door(s) and any other openings shall be closed; and the cooling unit shall be started up at maximum capacity with a storage temperature set point at its lowest setting; start a timer.

Step 3- pull down time for mean air temperature: The mean outside temperature and the mean inside temperature of the WICR shall each be recorded not less frequently than every 15 minutes. Record the time taken in minutes from when the cooling is started until the mean air temperature inside reaches the target storage temperature for the storage temperature category. Note also the highest and lowest temperatures recorded at that instant and the average humidity inside and outside the WICR.

Step 4- 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, Note that some or all of Step 4 could occur before completion of step 3.

Step 5- 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 ambient to the target storage temperature for the storage temperature category.

Step 6- 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 7 (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 take into account the stability indicators described in 5.4.4.

8.2 Pull-down test and temperature stability test for a representative produce load

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 ambient 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:

- Ambient temperature outside the WICR corresponding to the highest rated ambient temperature category (see Table 1). [Note: ATP requires this test at 30ºC, but more flexibility is suggested for this market]
- Storage temperature steady at the corresponding lowest rated storage temperature category (see Table 2) before start of test both for air temperature and any thermal storage.
- No additional heat load (fan heaters, if present, are not running).
- Dummy load specified as per 5.3, to begin the test at the rated ambient temperature.

- The dummy load is placed in the WICR according to 5.3.5. Crates and other containers and spacers shall start the test at the same ambient temperature as the air in the WICR.
- Cooling unit operating on normal thermostatic control but with set point at minimum setting so that the thermostat should not operate during the test (maximum cooling sustained).
- Temperature measuring instruments protected against radiation shall be placed inside and outside the WICR at the points specified in 5.4.1 and 5.4.2. The air -on temperature to the condenser shall be measured as per 5.4.2. Temperature of the air stream from the evaporator (air-off) and any thermal storage shall be measured as per 5.4.3 and 5.4.4 respectively.
- Temperature measuring instruments shall be placed on the dummy load (if present) as in 5.3.6.
- 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 5.3 and stabilise its temperature at the ambient 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 8.4. 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 5.7 at the target temperature.

Step 3 – install the dummy produce load: When the air temperature and thermal storage temperatures are stable and within required tolerances of the target temperature, and temperature of the dummy load is stable at the ambient temperature, open the WICR door(s) and install the dummy load as per 5.3. The setup must be thoroughly documented. The loading of the dummy load must be executed by a maximum of two people. The loading start and end time must be captured, and the air temperature and thermal store temperature at the end point of loading.

Step 4: pull down time for dummy produce load: The mean outside temperature, the mean inside air temperature and the dummy produce load temperatures shall each be recorded not less frequently than every 15 minutes. Record the time taken in minutes from when the cooling is started until the average dummy produce load temperature reaches 7/8 of the target storage temperature for the storage temperature category. Continue cooling, and record the total time taken for the average dummy produce load temperature to reach target storage temperature. Note also the highest and lowest temperatures recorded at that instant and the average temperature of any thermal storage.

Step 5: temperature stability test for the dummy produce load: continue the test until stable operating conditions are reached as per 5.7, however, stability of temperature of thermal storage need not be established for this test. Determine which M-bottle records the warmest temperature (θ_{ah}) and which M-bottle records the lowest temperature (θ_b). Plot both of those M-bottle temperature-time curves on the same axes for the entire test period as per Figure 2. Record θ_{ah} and θ_b in the test report. Plot the temperature time curve for the arithmetic mean temperature of all M-bottles (curve *d* of Figure 3) and include this in the test report. Determine the highest mean temperature (*d*) and lowest mean temperature (*d*) of all M-bottles during the test period. Determine the average mean temperature of all M-bottles (θ_m of Figure 3) during the test period.

Step 6- Delta-T and humidity: Record the temperature difference between the average storage temperature and the temperature of the air stream leaving the evaporator, and the humidity inside and outside of the WICR.

8.3 Verification of steady state effectiveness for air temperature, energy consumption, rated 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 that can be carried out either with or without a dummy produce load since the results should be identical. The system effectiveness test is carried out with a steady calculated representative internal heat load with calculation of refrigerating capacity and measurement of energy consumption.

Based on:
ATP, with modifications.

Test conditions:

- Ambient temperature stable at corresponding to the highest rated ambient temperature category (see Table 1).
- Storage temperature corresponding to the lowest rated storage temperature category (see Table 2).
- Cooling unit operating on normal thermostatic control with the preferred power supply.
- Heating inside WICR active at the representative heat load calculated as in 4.4.
- As this is a steady state test, the presence or not of a dummy load should not affect results. This test may therefore be done with or without a dummy load present depending on operational convenience for the test process, but the situation shall be recorded in the test report. Fan heaters shall not blow warm air directly onto any part of the dummy load that is closer than 2 metres (see 5.6). If a dummy load is present then temperature measuring instruments shall be placed as in 5.3.6 and M-bottle temperatures shall be taken into account in the assessment of stable operating conditions.
- Temperature measuring instruments protected against radiation shall be placed inside and outside the WICR at the points specified in 5.4.1 and 5.4.2. The air -on temperature to the condenser shall be measured as per 5.4.2. Temperature of the

air stream into and out of the evaporator and any thermal storage shall be measured as per 5.4.3 and 5.4.4 respectively.

- Thermal energy storage equipment shall be fully charged at the start of the effectiveness tests.

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 (8.2).

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 5.7 at the target temperature and thermal storage is fully charged in line with 5.4.4. 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 4.4.

Step 3 – determine if temperature is attained with representative heat load: Record the air temperature and thermal storage temperature not less than every 5 minutes. Continue the test until steady state conditions are achieved at the target storage temperature, as per section 5.7. If the target temperature is not achieved after running for [6] hours, then the WICR is deemed not capable of meeting the capacity requirements for that design purpose and combination of ambient temperature and storage temperature (as in Table 2, Table 3 and Table 4). The test may be abandoned, or restarted with a less demanding cooling capacity requirement (i.e., without a produce cooling capability and/or with a lower ambient temperature and/or with a higher produce storage temperature).

Step 4 – energy consumption: Measure energy consumption over a period of [6] hours of stable operating conditions (determined as per 5.7). 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 5.4.4).

Note 1: if the temperature requirements are not met, then an energy consumption measurement is not valid for that (failed) rated temperature. The energy test must be repeated to give a valid result associated with a temperature rating that the WICR can meet.

Note 2: if thermal storage temperature is varying cyclically but also with a rising trend then the unit is drawing on thermal storage to keep within temperature limits and so will later fail on temperature when store is exhausted – this means that the WICR should be reassessed for a lower design purpose. If thermal storage temperature shows a falling trend (i.e., moving towards fully charged) then stable conditions have not been reached and measured energy consumption and cooling capacity would be higher than at steady state (a non-representative value). Wait for steady state with no rising or falling trend for at least [one hour] and then start energy measurements.

Step 5 - cooling capacity under thermostatic control: When temperature of air and thermal storage are stable at the rated temperature, the cooling capacity under thermostatic control can be calculated as equal to the heat gain through the insulation (evaluated in 4.4, without the escalation factor applied) plus the total (electrical) energy input to the fan heaters. The calculation shall be made over a stable operating conditions period of at least [four hours].

Step 6- Delta-T and humidity: Record the temperature difference between the average storage temperature and the temperature of the air stream leaving the evaporator (Delta-T), the humidity inside and outside the WICR.

Step 7 (optional)– maximum cooling capacity: Adjust the thermostat of the WICR to its lowest setting so that the refrigeration unit runs continuously. Gradually increase the heat load whilst monitoring the storage temperature until the air target temperature is achieved and temperature of both air and thermal storage are stable as per 5.7 (if the temperature stabilizes higher than target then lower the heat load slightly; if the temperature stabilizes lower than target then raise the heat load slightly. The maximum cooling capacity can be calculated as equal to the heat gain through the insulation (evaluated in 4.4, without the escalation factor applied) plus the (electrical) energy input to the fan heaters. The calculation shall be made over a steady state period of at least [four hours].

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

Step 8 (optional)– repeat for alternative ambient or storage temperature rating points: Repeat Steps 1 to 3 plus 4, 5 and/or 6 under alternative ambient temperature class / storage temperature class rating points to characterise how the unit performs.

8.4 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.

> Note: 5K is proposed as a limit above which produce quality will be significantly affected. To be discussed if this should vary depending upon what storage temperature class is declared.

Based on:
E001/SDD CR-FR VP.1 Solar direct drive cold rooms and freezer rooms type examination under WHO PQS - a verification (testing) protocol.

Test conditions:

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

Test procedure:

- **Step 1:** WICR is set up inside a thermal chamber at its declared ambient operating temperature, running at target set point temperature and allowed to reach steady state condition with thermal storage and batteries fully charged.
- **Step 2:** The external power source is turned off. In the case of solar direct drive WICR, a power source equivalent to power generated on a rainy day at 5% of the maximum W/m^2 values to for the given array (sufficient to run controls and possibly fans, but not compressor(s)).
- **Step 3:** The autonomy is the time in hours taken for the average mean internal air temperature inside the WICR to rise by 5K above its measured average level at the start of the test.

9 Performance tests in the field

Reasons for having a field test methodology

A simple and cheap 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. To verify which performance category a WICR model should belong (long term storage; degree of precooling, based on cooling capacity and air flow)
vi. 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)
vii. Any other circumstances in which a test chamber is inaccessible or too expensive to consider and an indicative performance check would be useful.

In each of these cases, the test result will be combined with an assessment of uncertainty issues (see 9.1.2) to indicate whether the WICR:

A. Comfortably meets requirements (result is favourable even if uncertainties work against the result)
B. Is likely to meet requirements (favourable result within the uncertainty estimates)
C. Almost certainly does not meet requirements (‘red flag’ result; unlikely to meet requirements even if the uncertainties work in favour of the result)]

9.1 Preparation for the test

9.1.1 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.

9.1.2 Usefulness of field test results

Uncertainty of the results means that this test method is not suitable for:

- Setting reference benchmarks of performance
- Comparing performance of similar models
- Evaluation against a test result for another model measured in a thermal chamber.

9.1.3 Where to test and preparation of the test site

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 and humidity 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.

For either 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 ambient category target temperature.

9.1.4 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 ambient temperature
b) Humidity sensor
c) Data logger with average/max/min recording capability and number of channels to match the number of sensors
d) Stopwatch
e) Adhesive tape to manage cable positions including through door seals
f) Electrical power meter (kWh)
g) Support rig(s) to hold sensors at suitable heights and locations
h) Handheld temperature sensor (preferably infra-red spot sensor)
i) Multi-meter (for checks and troubleshooting during set up)
j) Torch (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.

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)

9.1.5 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 5.4.1 and 5.4.2. If insufficient temperature sensors are available to meet 5.4.1 and 5.4.2, 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 ambient 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 4.5.1.

iv. The average ambient temperature around the WICR to be recorded not less frequently than every 10 minutes. If the ambient temperature is measured as more than [10ºC] 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 ambient 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.

9.1.6 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.

9.1.7 Definition of stable operating conditions for field test measurements

The WICR undergoing field test is considered to operate under stable conditions if, during a period of 4 hours, the average air temperature inside the WICR agrees within ±1°C at the corresponding points on the time-temperature curve (example curve is shown in Figure 3). 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 2°C.

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 5°C.

9.2 Field test procedures

The following field tests are described:

1. Visual inspection of insulated enclosure and key components in the field (9.2.1)
2. Temperature pulldown field test without thermal load (9.2.2)
3. System effectiveness field test (9.2.3)
4. Autonomy field test (9.2.4)

9.2.1 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.

9.2.2 Empty pull-down field test (no heat load)

1. Prepare site and set up as per 9.1
2. Carry out the test as described in section 8.1 as far as field conditions allow.

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

1. Prepare site as per 9.1
2. Set up heating inside WICR active at the representative heat load calculated as in 4.4 (not switched on at this point).
3. Thermal energy storage equipment shall be fully charged at the start of the system effectiveness tests
4. Carry out the test as described in section 8.3, steps 1 to 6, as far as field conditions allow.

9.2.4 Autonomy field test

1. Prepare site as per 9.1
2. Carry out the test as described in 8.4 as far as field conditions allow.

10 Test Report

The test report shall contain the following sections as a minimum:

1. Physical description of the WICR under test with Bill of Materials assessment as per 7, with photographs, including measured goss volume according to 3.1.1.
2. Description of any thermal storage equipment: type, capacity (kWh or MJ), whether it includes phase change material(s), the phase change temperature(s), and whether a phase change is anticipated to occur during the tests.
3. Summary of the standard rating of the WICR under test (as per 4), including rated ambient conditions, storage temperature class(es) and temperature pull-down rating.
4. Calculation of the representative heat load as per 4.4.
5. Determination and description of the dummy load (if relevant, as per 5.3), with photographs
6. Description of how the WICR was mounted and positioned for test (as per 6.1), with photographs
7. Results of test carried out
8. Conclusion on temperature attainment at rated conditions (ambient temperature(s) and storage temperature(s), as per 8.3)
9. Annex: Temperature traces for key aspects of test.

11 WICR Product Information Sheet

This section provides a standard template for presentation of the supplier details and technical specification of a WICR model, with guidance on what is expected for many parameters.

11.1 Supplier information

1a. Manufacturer's name, brand or trademark (must appear on the product)	
1b. Supplier's physical address	
1c. Supplier's main contact (email and phone number)	
1d. Unique model name and/or model number of the WICR	
1e. Website or QR code for further details on the supplier and WICR	

1a. Manufacturer's name, brand or trademark (must appear on the product). Original manufacturer or dealer taking responsibility for the product on the local market.

1b. Supplier's physical address in the country or region that sales are occurring. Could be an appointed local agent taking responsibility for the product on the local market.

11.2 General product information

2a. Construction type	□ Pre-assembled □ Prefabricated kit □ Customised on site	□ Converted ISO container □ Other - description: □ Refrigerated container (Reefer)	With floor □ Yes □ No
2b. Gross storage volume (m^3)	m^3	Height (m) ____ Width (m) ____ Length (m) ____	
2c. Net storage capacity	Storage capacity _____ MT, metric tonnes of produce		
2d. Gross storage floor area that has >1.6m headroom (m^2)			
2e. Cooling services for which the unit is designed	□ Storage of pre-cooled produce at the rated chilled conditions □ Storage at the rated chilled conditions with produce cooling capability □ Storage of pre-frozen produce at the rated frozen conditions □ Storage of frozen produce at the rated frozen conditions with produce freezing capability		
2f. Humidifier function	□ Yes Type/Model of humidifier ________________________________ □ No		
2g. Weather protection for WICR	□ Indoor / protected use □ Exposed / outdoor use		
2h. Operational ambient temperature zone(s)	□ Hot zone to 43ºC □ Temperate zone to 32ºC □ Moderate zone to 27ºC		
2i. Refrigerant name	Common name	Chemical name	
2j. Refrigerant details	Mass of refrigerant in cooling system _______kg	ISO designation (R number) _______	GWP______ ODP _____

<table>
<tr><td>2k. Autonomy (maintain temperature) after power cut (h)</td><td colspan="2">________ hours</td></tr>
<tr><td rowspan="4">2l. Thermal storage</td><td>☐ Thermal storage is included</td><td>Thermal storage capacity _____ MJ</td></tr>
<tr><td>Type of thermal storage (e.g., water, ice, other phase change material (PCM)): ___________________________</td><td>Temperature at which PCM freezes _________°C</td></tr>
<tr><td colspan="2">Length of time taken to fully charge thermal storage under normal operation with doors closed: ________ hours</td></tr>
<tr><td colspan="2">A means is provided to indicate the level of charge of the thermal storage:
☐ Yes ☐ No
Description of how charge level is indicated or determined:
__________________</td></tr>
<tr><td>2m. Electrical (battery) storage</td><td>☐ Battery is included to run cooling function (compressor)
☐ Small battery is included to run controls, or fans</td><td>A means is provided to indicate the level of charge of the battery:
☐ Yes ☐ No
Battery capacity _____ kWh</td></tr>
</table>

2a. Construction type.

- Pre-assembled WICR (arrive complete on site);
- Prefabricated kit WICR (assembled from ready-to-use jointed panels and pre-determined kit of components);
- Refrigerated container (self-contained temperature controlled ISO container); Converted ISO container (insulated and refrigerated);
- Customised construction (panels cut and built on site, components from one or more suppliers).

2b. Gross storage volume (m^3).

- The total volume inside the insulated enclosure measured in cubic metres. The space occupied by evaporator(s), ducts, racking and any other equipment located inside the WICR is included in the gross volume. See 3.1.1.

2c. Net storage capacity:

- Produce storage capacity in metric tonnes (MT). Ideally suppliers should state what produce or type of is considered for any declared produce capacity given in metric tonnes. Note: limited analysis of published figures implies that conversion between capacity and tonnage is as follows: 4,73 * [MT] + 3,75 = storage capacity in m^3. See 3.1.4.

2k. Autonomy time:

- The time in hours taken for the highest measured air temperature inside the WICR to reach the upper threshold of the target storage temperature range after the power supply is stopped, tested with the doors kept shut. Autonomy may be extended by presence of thermal storage and electrical (battery) storage. See 8.4.

2l. Thermal storage.

- Thermal storage is material specifically provided to increase the thermal capacity of the WICR beyond that achieved by its normal operational components. Thermal storage may be removable with or without use of tools but must have clearly designated permanent location(s) and be fixed in place during normal store usage. Loose water cans or freezer packs do not qualify as designated thermal storage. Only thermal storage included in the named WICR product model may be included here – thermal storage sold separately may not be included.
- Thermal storage capacity (MJ) is the total heat energy needed to raise the thermal storage from the declared storage temperature up to the declared ambient operating temperature.
- Sensible heat storage (fluid changing temperature)
- Phase change materials (PCM) transition between liquid and solid states within the foreseen operating temperatures of the WICR and so can store latent heat. Freezing temperature should be provided to assist determination of state of charge.

11.3 Cooling function

<table>
<tr><td>3a. Refrigeration system type and configuration</td><td colspan="3">Cooling technology (more than one could apply):
□ Vapour compression □ Absorption □ Thermo-electric □ Evaporative cooling □ Dessicant based

System configuration:
□ Monobloc (unitary, packaged) □ Split system □ If split: outdoor unit is weatherproof</td></tr>
<tr><td>3b. Cooling capacity kW</td><td>Compressor cooling capacity (kW) ___________</td><td colspan="2">Refrigerating capacity of complete WICR refrigeration unit or condensing unit or monobloc (kW) _________</td></tr>
<tr><td>3c. Air flow inside WICR</td><td colspan="2">Number of fans inside WICR. _______
Total fan input power, all fans added together ________kW
□ Variable speed fans used</td><td>Air recirculation rate (empty air changes per hour) ________ /hr</td></tr>
</table>

3c. Air flow inside the WICR.

- Total fan input power kW of all air circulation fans (rating plate figures) that are included inside the WICR, added together.

- Number of fans included inside the WICR (in air cooling unit(s), evaporators, fan coil units). Option: state if variable speed fans are used.
- Empty air changes per hour. The number of times per hour the volume of air in the cold room should theoretically pass through the heat exchanger as a result of its fan power - equal to the air volume flow of the evaporator(s) in m3/hr. divided by the gross empty volume of the storage compartment in m3.

11.4 Electrical power source(s)

4a. Input supply type(s)	More than one may apply: ☐ DC ☐ AC single phase ☐ AC 3-phase
4b. Input voltage range(s) for full normal operation	DC voltage input range (lowest to highest) ______ V AC input voltage range (lowest to highest) _______ V
4c. Input power supply type(s) accommodated (all that apply)	☐ Off-grid power, source included ☐ Off-grid power compatible, source sold separately ☐ Suitable for unreliable grid (Voltage stabilisation and protection included) ☐ Suitable for time-limited supply (energy storage included) ☐ Only suitable for reliable grid (good quality and reliable supply) ☐ Suitable for hybrid power without further adaptation (state which if not identified above)
4d. Overall system input power (rated peak) kW	Rated peak demand (rating plate) _______ kW

4c. Power source:

- Off-grid (power source included or sold separately; solar direct drive (SDD); generator; photovoltaic array; other)
- Suitable for unreliable grid (a connection to an electrical grid is available but power is subject to highly variable power quality and reliability, often without prior notice of problems) with indication of immunity / protection that is included
- Limited supply means an electrical supply of reasonable or good quality but operating 22 hours or less per day , for example at a set number of hours per day on virtually every day and known in advance. Maximum current limits may also apply. 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.

11.5 Energy performance and efficiency

5a. Energy consumption (kWh/24 hrs)	_______ kWh/24 hrs, at highest rated ambient temperature and lowest rated storage temperature

5b. Thermal loss rate of the insulated enclosure (kW)	Total thermal loss rate _______ kW, at rated ambient and storage temperature combination(s)				
5c. Ratio of cooling capacity to heat leakage (kW/kW)	______ kW/kW				
5d. Insulation material type, walls (common name of insulating material)					
5e. U-value of insulation panel components (W/m^{2}K), new material rating (non-aged)	Walls ____	Door ____	Ceiling ____	Floor ____	Window _____
5f. U-value of insulation panel components U-value (‘aged value’, also called ‘design value’) (W/m^{2}K)	Walls ____	Door ____	Ceiling ____	Floor ____	
5g. Thickness of insulation panels (mm)	Walls ____	Door ____	Ceiling ____	Floor ____	Window glazing: ☐ Single ☐ Double ☐ Triple
5h. Features to reduce air infiltration when door opens	☐ Simple manual door. ☐ Automatic door closure ☐ Strip curtain				

5a. Energy consumption (kWh/24 hrs). See 8.3.

5b. Thermal loss rate through the insulated enclosure, kW at steady state. The quantity of heat flowing per unit time through insulated envelope when the temperature gradient across thickness of the insulated enclosure is equivalent to the temperature difference between rated ambient operating condition and the rated storage temperature. See 4.3.

5f. U-value (‘aged value’, also called ‘design value’). This is to provide the market with accurate information on the long-term performance of the panel. As opposed to the initial U-value of the material immediately after its manufacture, when its insulation effectiveness is at its highest. A value valid at four years aging should be quoted. For polyurethane (PUR) foam insulation, this can be assumed to be 7% worse (higher) than the U-value for the new material (see 4.3).

12 ANNEX 1: Tests in a thermal chamber for additional functionalities

These tests are included in outline - details not yet fully developed

12.1 Maximum ambient shade operating condition

Aim of test:
To verify that the refrigeration unit can continue to operate at the manufacturers maximum rated ambient temperature without tripping out.

Based on:
IS 2370

Test conditions:

- No additional heat load is added.
- Storage temperature as per manufacturers declared category.

Test procedure:

- Step 1: Increase the temperature inside the thermal chamber to the maximum operating temperature declared by the supplier (e.g., 50ºC)
- Step 2: Run the WICR refrigeration unit at its target set point for the storage temperature class.

Criterion of satisfaction:
The unit passes if the refrigeration unit can continue operating (does not trip out) for a period of 2 hours whilst maintaining the storage set point temperature.

A variant test is possible (as used in ISO 1496-2) under which the average air temperature at condenser inlet shall be at least 50 °C for the duration of the test and the unit must not trip out, but storage temperature may drift outside of the target set point during the test.

12.2 Heat leakage rate

Aim of test:
To determine the heat leakage rate (thermal loss rate) of the overall insulated enclosure (walls, floor, ceiling, door) under steady state conditions with a fixed temperature differential of 25ºC across the thickness of the insulated envelope.

Based on:
ATP Annex 1 Appendix 2 part 2

Test conditions:

- No refrigeration unit is running during this test.
- Air is circulated by fans both inside and outside the WICR (with the internal fan energy taken into account in the calculations).

Test procedure:

- Step 1: The WICR is set up inside a refrigerated thermal chamber with a heat load inside the WICR and cooling of air in the thermal chamber that together create a temperature difference across the insulated enclosure boundary that is equal to the temperature difference that occurs when outside the WICR is the highest rated ambient temperature and inside is the lowest rated storage temperature.
- Step 2: The heat input to maintain this temperature difference is measured over 12 hours.
- Step 3: The average insulation effectiveness (K value, W/m^2K) can then be calculated using a defined measurement and calculation of the surface area of the enclosure as per ATP Annex 1 Appendix 2 part 2.

12.3 Air flow inside the WICR

Aim of test:

To confirm by a simple indicative test the approximate number of times per hour that the air volume in the empty store is drawn through the evaporator or fan unit (the declared 'air change ratio'). This ratio is calculated from the air circulation rate, the measured airflow immediately in front of the evaporator or DX air cooler (in cubic metres per hour, m^3/hour) divided by the gross storage volume inside the WICR in m^3.

Note: This simple test is intended to verify that the manufacturer's claim appears reasonable and is not designed to replace the normal free air flow test that evaporators are often subject to (such as specified under the Eurovent Certita programme[7]).

Based on:

Advice from ATP test lab staff, June 2024.

Test conditions:

[Not yet specified]

Test procedure:

- **Step 1:** Use a handheld hot wire anemometer to measure air speed immediately in front of the evaporator/fan unit.
- **Step 2:** Measurements to be 30 second averages on a grid spacing of not more than 100mm in the air path exiting the fan unit, across the throat area of the duct. Measurements are not to be taken closer than 50mm from the projected inner wall of the duct.
- **Step 3:** Calculate the cross-sectional area of the duct in m^2. *Question: should the full cross section area be used, or should a proportion be deducted to allow for boundary layer effects (slowing of air flow close to the duct liner)?*
- **Step 4:** Air flow m^3/hr = measured air speed (m/s) x cross sectional area (m^2) x 3600

[7] Technical Certification Rules of the Eurovent Certified Performance Mark – Heat Exchangers, ECP 02-HE, 12/2023, available from: https://www.eurovent-certification.com/en/third-party-certification/certification-programmes/he.

12.4 Air tightness test

Aim of test:
To measure the volume air loss through the insulated enclosure when all apertures are closed.

Based on:
ISO 1496-2 Test 13 – Airtightness, section 8.2

Test conditions:
- Door, drains, pressure relief valve etc. are closed
- The temperatures inside and outside the unit shall be stabilized within 3K of each other and in the range 15ºC to 25ºC.
- WICR in its normal operating condition and closed in the normal manner.
- Refrigeration equipment in place

Test procedure:
- Step 1: An air supply through a metering device and a suitable manometer shall be connected to the thermal container by a leak-proof connection. The manometer shall not be part of the air supply system.
- Step 2: Air shall be admitted to the container to raise the internal pressure to 250 Pa ± 10 Pa and the air supply regulated to maintain this pressure.
- Step 3: Once steady test conditions have been established, the airflow required to maintain this pressure shall be recorded.

Note: ISO 1496-2 sets a maximum air leakage limit of 5 m^3 per hour for units with a single door. For each additional door (e.g. side doors), an extra allowance of 5 m^3/h is granted.

12.5 Assessment of thermal storage

No test is proposed since the test for autonomy (8.4**Error! Reference source not found.**) provides a good indication of the joint performance of WICR plus its default thermal storage, and no additional test of thermal storage is necessary.

In due course, testing could be developed to validate:
- Total thermal storage capacity (kWh)
- Time and energy taken to fully charge the installed thermal storage, for a given temperature difference
- Thermal energy discharge rate, or cooling capacity, when operating from thermal storage, for a given temperature difference.

12.6 Condensation and drainage assessment

High humidity is essential to maintain produce quality and avoid weight loss in a WICR, but condensation of the water held in air can cause several problems:

- If it comes into contact with produce, such as forming on produce, on crates or dripping from surfaces above, it can adversely affect produce quality.
- If condensation water accumulates on floors it causes a slip hazard.
- Corners, crevices and surfaces that remain wet and catch dirt can encourage growth of mould and so pose a food and staff safety hazard.

WICR designers can take steps to reduce condensation through effective air movement, ensuring surfaces are no colder than they need to be, and providing for any condensate to form and/or flow to where it does not cause a problem. Assessment of water. In addition, suitable drains in the floor enable condensate and washing water (for hygiene purposes) to safely flow out. An initial draft assessment methodology for condensation and drainage is therefore proposed but needs further development.

Assessment of condensation

Assessment of condensation is to be carried out at the end of the temperature stability test with the dummy load.

Assessment of condensation is only valid if the relative humidity inside the WICR at the start of the temperature stability test period was above [90%].

Step 1: At the end of the temperature stability test, open the WICR door and inspect internal surfaces of the insulated enclosure for evidence of condensation and ice build-up. A hand-held lamp may be shone at a shallow angle across the surface to enhance visibility of condensate. Record observations related to the following points:

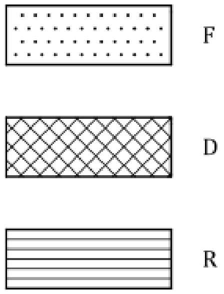
A. On a sketch of each internal surface of the insulated enclosure, including the floor, note areas of condensate according to the key shown in Figure 4.
B. Inspect the dummy load for condensate on the surface of bottles and note a summary observation for each crate, according to the key shown in Figure 4.
C. Note any points or areas from which condensate is dripping from surfaces that are above where produce could be stacked in normal use.
D. Note the size and location of any areas of the floor in which condensate is pooling.

Visual assessment of floor drainage

Note in the test report the location of any floor drainage holes.

6.3.12.3 Expression of results

During the test period, external surface areas exhibiting fog, droplets or running water shall be outlined and designated with the letters F, D and R respectively (see Figure 29). A coded sketch shall be made showing the maximum area and degree of condensation appearing during the test on all surfaces; the code shown in Figure 27 shall be used.



Key

F fog/mist

D droplets

R running

Figure 29 — Condensation code

Figure 4. Notation key for recording condensation on surfaces inside the WICR (source: ISO 22044 for beverage coolers).

13 ANNEX 2: Further aspects yet to be considered

Further issues to be considered by the Test Method Expert Group that are not mentioned in the text above include these below. A decision is required for each on whether to pursue it, and to draft the required approach. In approximate order of priority (most important first):

1. An alternative approach to determine a representative heat load is to base it on the storage volume (in m^3) or storage capacity (in kg or metric tonnes) of the WICR as declared by the supplier. This could have a mix of heat load elements, reflecting if/as applicable:
    a) the heat from respiration of stored produce (calculated assuming full store of a certain produce mix with known heats of respiration; applicable to all use cases)
    b) solar heat gain (perhaps assuming the heating power of 70% of the peak rate if an assumed largest face of the enclosure (proportioned from the storage volume) is in direct sun at a typical geographical location; applicable to all use cases)
    c) heat ingress from door openings (none for long term storage; several per day for short term storage)
    d) a produce pre-cooling demand (to reduce the temperature of warm produce, perhaps assuming 10% of the WICR tonnage capacity of some typical produce mix of known specific heat capacity, cooled over 6 hours; not applicable to long term storage).

An approach based on volume or capacity has not been evaluated nor discussed within the test method expert group but remains under consideration. Once a calculation methodology is established that relates heat load to volume or capacity, it could offer a simpler way to determine the representative heat load.

2. Assessment of defrost. Testing effectiveness of defrost functionality; Energy implications of defrost (additional consumption) and to verify effective drain-off of defrost water and condensate.
3. Reliability: Testing to examine likely modes of failure for the WICR. Note: Some types of food load are very high value and reliability is crucial for the business and so some customers would be prepared to invest in better equipment on this aspect. Less reliable equipment could be adequate for lower value loads. Aspects to assess include presence of failure and out of temperature alarm systems.
4. Repairability: Assessment of how well the system has been designed for ease of repair. This could follow the framework approach set out in EN 45554[8]. Assess accessibility of key components for repair and replacement (including location, fasteners used, disassembly time, whether repair can be done using a standard set of tools, availability of diagrams and parts lists, availability of spare parts, level of skill required (standard tool sets are prescribed in EN 45554, along with frameworks for quantified assessment of repairability). Set expectations for availability of spare parts and use of standard components wherever possible.
5. Verification of declared control functionality. For equipment with certain types of control, to verify function of that control (confirming that it achieves what is promoted). An example of controller functionalities that could be tested is freeze protection in low ambient temperatures. This could be based on WHO PQS E001/SDD CR-FR VP.1. Cold climate freeze prevention is defined as: any mechanism which prevents the temperature inside a cold room from dropping below +2°C, under low ambient temperature conditions, down to the temperature specified by the supplier, subject to a minimum ambient of -10°C.
6. Immunity to power supply reliability and power quality issues. (Matched solar PV system, generator, Voltage stabilisation, poor power quality and unreliable grid etc.). Assessment of performance under poor power quality could be based on IEEE immunity testing approaches and IEC 63437 for off grid and unreliable grid refrigerators.
7. Door opening tests. Door openings introduce high uncertainty and are unlikely to be included in a recommended test. Nevertheless, rules of thumb could usefully be included in an Annex to help designers and specifiers to make allowance for them in system specifications. DIN 8959 for multi-drop refrigerated vans includes estimation factors (C1) for the additional energy consumption caused by door openings during delivery rounds and so could provide reference values. ISO 23953 for commercial refrigerated retail display cabinets includes well tried and tested approach to managing door openings during testing and so could inspire or inform

[8] EN 45554:2020 General methods for the assessment of the ability to repair, reuse and upgrade energy related products.

an approach if it was deemed necessary. C1 factors could be indicative of the additional cooling capacity necessary under different levels of door opening of the WICR.

8. Indicative assessment of solar gain - Indicative assessment of the Solar Reflectance Index of the outer shell of the store (from a look up table based on colour and how shiny surface is).

Other resources to be reviewed for possible useful approaches:

1. Indian cold store draft spec[9] 'Draft Design Specifications for Solar Cold Storage (SCS)'
2. References to GDP testing[10], as used for pharmaceuticals.

[9] https://mnre.gov.in/notice/inviting-comments-from-public-stakeholders-on-draft-design-specifications-for-solar-cold-storage-scs-regarding/.
[10] Possible GDP resources: https://eur-lex.europa.eu/legal-content/EN/TXT/HTML/?uri=CELEX:52013XC1123(01)&from=EN#ntr1-C_2013343EN.01000101-E0001
And
https://www.who.int/medicines/areas/quality_safety/quality_assurance/ModelGuidanceForStorageTransportTRS961Annex9.pdf