IEC: 62053-11
Revised

PAKISTAN STANDARD

ELECTRICITY METERING EQUIPMENT

(AC)- PARTICULAR REQUIREMENTS –

PART 11: ELECTROMECHANICAL METERS FOR ACTIVE ENERGY

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ELECTRICITY METERING EQUIPMENT
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0 FOREWORD

1. This Pakistan Standard was adopted by the authority of the Board of Directors of Pakistan Standards and Quality Control Authority after the draft prepared by the Technical Committee for “Electrical Measurements (EDC-4)” had been approved & endorsed by the Electro-technical National standard Committee on 31 January 2018.

2. This Pakistan Standard was adopted on the basis of revised IEC: 62053-11/2018 Standard. So, it was deemed necessary to revised 2016 this standard in order to keep abreast with latest technological development in industry.

3. This Pakistan Standard is an adoption of revised IEC: 62053-11/2018 “Electricity Metering Equipment (Ac)-General Requirements, Test and Test Conditions-Part-11: Electromechanical Meters For Active Energy” and it use hereby acknowledge with thanks.

4. This Standard is subject to periodical review in order to keep pace with the changing requirements and latest development in the industry. Any suggestion for improvement will be recorded and placed before the revising committee in due course.

5. This Standard covers the technical provisions and it does not purport to include all the necessary provision of a contract.

CONTENTS

HOUSEHOLD REFRIGERATING APPLIANCES – CHARACTERISTICS AND TEST METHODS –

Part 3: Energy consumption and volume

1 Scope

This part of IEC 62552 specifies the essential characteristics of household and similar **refrigerating appliances** cooled by internal natural convection or forced air circulation, and establishes test methods for checking these characteristics.

This part of IEC 62552 describes the methods for the determination of **energy consumption** characteristics and defines how these can be assembled to estimate **energy consumption** under different usage and climate conditions. This part of IEC 62552 also defines the determination of **volume**.

2 Normative references

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEC 62552-1:2015, *Household refrigerating appliances – Characteristics and test methods – Part 1: General requirements*

IEC 62552-2:2015, *Household refrigerating appliances – Characteristics and test methods – Part 2: Performance requirements*

3 Terms, definitions and symbols

3.1 Terms and definitions

For the purposes of this document, the terms and definitions given in IEC 62552-1, as well as the following apply.

3.1.1
specified auxiliaries
functions or features that affect the **energy consumption** of a **refrigerating appliance** and where their actual **energy consumption** depends on the conditions of use or operation

Note 1 to entry: This standard makes optional provision for determining the **energy consumption** impacts of these functions or features in accordance with regional requirements.

Note 2 to entry: Test requirements for specified auxiliaries, where applicable, are set out in Annex F and their application specified in 6.8.4. The only specified auxiliaries in this edition of the standard are ambient controlled anti-condensation heaters and tank type automatic icemakers.

3.1.2
defrost interval
the measured or estimated length of a **defrost control cycle**, starting from the point of initiation of one **defrost control cycle** to the point of initiation of the subsequent **defrost control cycle**, expressed in hours of elapsed (clock) time

3.2 Symbols

For the purposes of this document, the following symbols apply.

E electrical **energy consumption** over a specified period (day, year, etc.) in Wh or kWh

P average steady power consumption over a defined period in W

T **compartment** temperature average over a specified period in degrees Celsius (°C)

TMP_n temperature measurement position of a specific temperature sensor

t time at a specific moment

Δt time interval in hours between two defined times or for a defined period

ΔE_{df} additional energy associated with a **defrost and recovery period**, over and above the relevant **steady state** power consumption at the same **temperature control settings**, in Wh

$\Delta Th_{df\text{-}i}$ the accumulated temperature difference over time (relative to the **steady state** temperature) during a **defrost and recovery period** in Kh for **compartment** *i*

Rt actual compressor run time in hours for a defined period (actual compressor on period)

CRt percentage of compressor run time for a defined period (Rt/total time interval as %)

P_{Hi} average heater power associated with an ambient controlled anti-condensation heater at a specified temperature and humidity in W (Annex F)

M mass of water used for a **processing load** (Annex G) or the mass of water or ice during an ice making test (Annex F)

4 Applicable test steps for determination of energy and volume

4.1 Setup for energy testing

Prior to the measurement of **energy consumption** for a **refrigerating appliance**, it shall be set up in a test room as specified in Annex A.

4.2 Steady state power consumption

The **steady state power consumption** of the **refrigerating appliance** shall be determined in accordance with Annex B.

4.3 Defrost and recovery energy and temperature change

For products with one or more defrost systems (each with its own **defrost control cycle**), the incremental **defrost and recovery** energy for a representative number of **defrost and recovery periods** shall be determined in accordance with Annex C for each system. The temperature change associated with **defrost and recovery** shall also be determined in accordance with Annex C for each system.

4.4 Defrost frequency

For products with one or more defrost systems (each with its own **defrost control cycle**), the **defrost interval** for each system shall be determined in accordance with Annex D, depending on the control type.

4.5 Number of test points and interpolation

Where the **energy consumption** of a **refrigerating appliance** is interpolated in accordance with Clause 6, one of the methods specified in Annex E shall be used.

4.6 Load processing efficiency

Where the **load processing efficiency** of a **refrigerating appliance** is claimed or determined, it shall be measured in accordance with the method specified in Annex G.

4.7 Specified auxiliaries

Where a **refrigerating appliance** contains a specified auxiliary, the energy impact of this auxiliary shall be determined in accordance with Annex F.

4.8 Volume determination

The **volume** of each **compartment** of the **refrigerating appliance** shall be determined in accordance with Annex H.

5 Target temperatures for energy determination

5.1 General

The **energy consumption** of an appliance is determined from measurements taken when tested as specified in Clause 6 in an **ambient temperature** of 32 °C and an **ambient temperature** of 16 °C. The value for **energy consumption** determined in accordance with this standard shall be for a **temperature control setting** (or equivalent point) where all average **compartment** air temperatures are at or below the **target temperatures** specified in Table 1 for each **compartment** type claimed by the supplier. Values above and below **target temperatures** may be used to estimate the **energy consumption** at the **target temperature** for each relevant **compartment** by interpolation, as specified in Clause 6.

NOTE Refer to the requirements in IEC 62552-1:2015 Annex B for **variable temperature compartments**. For energy testing, these are operated on the function (continuous temperature operating range) that uses the most energy.

Table 1 – Target temperatures for energy determination by compartment type

Compartment type	Target average air temperature °C
Pantry	17
Wine storage	12
Cellar	12
Fresh food	4
Chill	2
Zero-star	0
One-star	–6
Two-star	–12
Three-star and Four-star	–18
For energy testing, each **compartment** shall be operated as the claimed **compartment** type, except as set out below. If a **compartment** operating range spans none of the **target temperatures** for the defined **compartment** types in Table 1 at either an **ambient temperature** of 16 °C or 32 °C (because it has no **user-adjustable temperature control** or a limited range of active control), then it shall be classified as the **compartment** type with the next warmest **target temperature** (based on the warmest test result for both **ambient temperatures**) and operated at its warmest setting while still staying at or below the **target temperature** of the next warmest **target temperature** (where adjustable) for the energy test at both **ambient temperatures**. The test report shall note that the claimed **compartment** type and the **compartment** type assumed for energy testing. Where the **compartment** is a **variable temperature compartment** type (that spans the operating range of several compartment types), the primary configuration for energy testing shall be the **compartment** type that has the highest **energy consumption**. A **variable temperature compartment** can be set and tested as other **compartment** types, if required, in addition to the primary configuration for energy testing. The test report shall note that the **compartment** is the **variable temperature compartment** type and the **compartment** type selected for each energy test.	

5.2 Temperature control settings for energy consumption test

When tested for **energy consumption** in accordance with Clause 6, the **refrigerating appliance** shall have at least one **temperature control setting** (or combination of **temperature control settings**) at which the average temperatures of each **compartment** is concurrently at or below the **energy consumption target temperatures** specified in Table 1. The data points used for **energy consumption** determination should demonstrate that the product is capable of meeting this requirement, but this specific point need not be measured directly.

Where an appliance has no **user-adjustable temperature controls**, **energy consumption** shall be determined from the results of one measurement test run of the appliance as supplied.

6 Determination of energy consumption

6.1 General

The key **energy consumption** components as specified in Clause 6 shall be determined for each **refrigerating appliance** tested in accordance with this standard. This shall be based on data measured in accordance with Annexes B to H, as applicable.

Clause 6 also specifies the method to be used to determine the components of **energy consumption** for a **refrigerating appliance** when tested in accordance with this standard.

The main components of **energy consumption** determined in accordance with this standard are:

- **Steady state power consumption** – this is determined at **ambient temperatures** of 16 °C and 32 °C – see Annex B.
- **Defrost and recovery** energy and temperature change – for products with one or more defrost systems (each with its own **defrost control cycle**), the **defrost and recovery** energy for a representative number of **defrost and recovery periods** for each system shall be determined – see Annex C.
- Defrost frequency – for products with one or more defrost systems (each with its own **defrost control cycle**), the **defrost interval** shall be determined for each system under a range of conditions – see Annex D.
- Specified auxiliaries – Where a **refrigerating appliance** contains a specified auxiliary, the energy impact of this auxiliary shall be determined – see Annex F.
- **Load processing efficiency** – where a **load processing efficiency** is measured or claimed, the specified method shall be used – see Annex G.

The lowest conceivable value of **energy consumption** for a **refrigerating appliance** under this standard (i.e. the theoretical optimum), is the value where the temperature of every **compartment** is exactly equal to its **target temperature** for **energy consumption** (see Clause 5). Not every appliance is capable of operating at this condition, nor is it practicable for a laboratory to continue testing in an attempt to precisely obtain this condition during a specific set of tests. Under this standard there is the option of undertaking several tests with different **temperature control settings** (where available). This is to facilitate interpolation to estimate the **energy consumption** for a point where all **compartments** are at or below their relevant target for **energy consumption** (see 6.3).

6.2 Objective

In order to determine the characteristics of a household **refrigerating appliance** in accordance with this standard, it is necessary to measure the temperature and **energy consumption** for a representative period of **steady state** operation that complies with the relevant requirements (i.e. **compartment** temperatures at or below their target for **energy consumption**). Several test points at different **temperature control settings** may be required to obtain the most favourable (optimal) result for **energy consumption**.

In the case of products with **automatic defrost** functions that affect the power consumption of the product (i.e. has a **defrost control cycle**), the incremental energy during **defrost and recovery** (i.e. the additional energy ΔE_{df} over and above the underlying **steady state** power) shall be determined for a specified number of representative and valid **defrost and recovery periods**.

These values are measured at each of the specified **ambient temperatures** for energy determination.

To assess whether a proposed period of test data is acceptable for the determination of **energy consumption**, the data are analysed and examined to assess whether changes in internal temperatures and power consumption are within acceptable limits. In terms of energy assessments, there are two alternative approaches to the determination of **steady state** power consumption:

- **SS1: Steady state** power and internal temperature determination where there is no **defrost control cycle** or where **steady state** conditions according to Annex B can be established between **defrost and recovery periods** (generally where defrost events are widely spaced);
- **SS2: Steady state** power and internal temperature determination where **steady state** conditions according to Annex B cannot be established between **defrosts and recovery periods** (generally where defrost events are more closely spaced).

The incremental **energy consumption** and temperature change during a **defrost and recovery period** also needs to be assessed (relative to the **steady state** power and internal temperatures before and after the **defrost and recovery period**).

In each case, criteria are established to determine whether the periods are representative of the operation of the appliance.

6.3 Number of test runs

The **energy consumption** shall be determined at **ambient temperatures** of 16 °C and 32 °C either:

a) directly from the results of a single test run during which the temperatures of all **compartments** of the appliance are at or below the **target temperatures** specified in Table 1; or
b) by interpolation between the results of two or more test runs, conducted at different settings of one or more **user-adjustable temperature controls**, as follows:
   - Where results have been measured at two **temperature control settings**, interpolation in accordance with Clause E.3.
   - Where the appliance has at least two independent **user-adjustable temperature controls** and results have been measured at three **temperature control setting** combinations, interpolation in accordance with Clause E.4.
   - Options for interpolating using three or more independent **user-adjustable temperature controls** are also set out in Clause E.4.

In the case of b) above, test results shall demonstrate that the temperatures of all **compartments** in the **refrigerating appliance** are at or below the **target temperatures** specified in Table 1 at the point of interpolation. There are several requirements associated with interpolation to ensure that this has been achieved.

6.4 Steady state power consumption

For a **refrigerating appliance** that does not have a **defrost control cycle**, the **steady state** power consumption at each **temperature control setting** selected and for each **ambient temperature** shall be determined in accordance with Annex B.

For a **refrigerating appliance** with one or more **defrost control cycles,** the **steady state** power consumption between **defrost and recovery periods** at each **temperature control setting** selected and for each **ambient temperature** shall be determined in accordance with Annex B.

The **steady state** power consumption is reported in watt (W).

6.5 Defrost and recovery energy and temperature change

For a **refrigerating appliance** with one or more defrost systems (each with its own **defrost control cycle**), the additional energy and temperature change associated with **defrost and recovery** shall be determined for each system for a representative number of **defrost and recovery periods** in accordance with Annex C, at **ambient temperatures** of both 16 °C and 32 °C.

Where there is more than one defrost system (each with its own **defrost control cycle**), the characteristics of each system shall be documented.

The additional energy associated with **defrost and recovery** is reported in watt-hour (Wh).

The temperature change associated with **defrost and recovery** is reported in degree Kelvin-hour (Kh).

6.6 Defrost interval

For a **refrigerating appliance** with one or more defrost systems (each with its own **defrost control cycle**)**,** the estimated **defrost interval** shall be determined in accordance with Annex D at an **ambient temperature** of 16 °C and at an **ambient temperature** of 32 °C.

Where there is more than one defrost systems (each with its own **defrost control cycle**), the **defrost interval** for each system shall be documented.

The **defrost interval** shall be expressed in hours, rounded to the nearest 0,1 h. Depending on the defrost control type, the **defrost interval** may be a function of a number of parameters.

6.7 Specified auxiliaries

Where the **refrigerating appliance** contains a specified auxiliary, the impact of this device shall be determined in accordance with Annex F.

The impact of specified auxiliaries is expressed in watt or watt-hour for a range of ambient conditions. These values are then weighted in accordance with regional requirements and conditions in order to provide a relevant estimate of energy associated with the auxiliary.

6.8 Calculation of energy consumption

6.8.1 General

The individual components of **energy consumption** and **steady state** power measured in accordance with this standard shall be combined using the following rules.

6.8.2 Daily energy consumption

All values of **energy consumption** and power shall be converted to daily **energy consumption** values in accordance with the following equations for each **temperature control setting** and **ambient temperature**.

For **refrigerating appliances** without a **defrost control cycle**, the daily **energy consumption** for each **ambient temperature** and each **temperature control setting** is given by:

$$E_{\text{daily}} = P \times 24 \tag{1}$$

Where

E_{daily} is the energy in Wh over a period of 24 h

24 is h/d

P is the **steady state** power in watt for the selected **temperature control setting** as per Annex B.

The measured **steady state** temperature for each **compartment** shall be recorded with this value (for the test report and/or for interpolation).

For **refrigerating appliances** with one defrost system (with its own **defrost control cycle**)**,** the daily **energy consumption** for each **ambient temperature** and each **temperature control setting** is based on the **steady state** power consumption as determined in accordance with Annex B, the incremental **defrost and recovery** energy determined in accordance with Annex C and the **defrost interval** determined in accordance with Annex D as follows:

$$E_{\text{daily}} = P \times 24 + \frac{\Delta E_{df} \times 24}{\Delta t_{df}} \tag{2}$$

Where

E_{daily} is the energy in Wh over a period of 24 h

24 is h/d

P is the **steady state** power in watt for the selected **temperature control setting** as per Annex B.

ΔE_{df} is the representative incremental energy for **defrost and recovery** in Wh in accordance with Annex C (see C.5).

Δt_{df} is the estimated **defrost interval** in hours in accordance with Annex D.

Where there are additional defrost systems (each with its own **defrost control cycle**), the value of term based on ΔE_{df} and Δt_{df} is also added in Formula (2) for each additional defrost system.

The average temperature for each **compartment** for this **temperature control setting** and **energy consumption** is given by:

$$T_{\text{average}} = T_{ss} + \frac{\Delta Th_{df}}{\Delta t_{df}} \tag{3}$$

Where

T_{average} is the average temperature for the **compartment** over a complete **defrost control cycle**.

T_{ss} is the average **steady state** temperature in the **compartment** for the **temperature control setting** in ° C in accordance with Annex B.

ΔTh_{df} is the representative accumulated temperature difference over time for **defrost and recovery** (relative to the **steady state** temperature) in degree Kelvin-hour (Kh) for the relevant **compartment** in accordance with Annex C (see Clause C.5).

Δt_{df} is the estimated **defrost interval** in hours in accordance with Annex D.

The value of ΔTh_{df} may be positive (if the temperature is warmer during **defrost and recovery**) or negative (if it is cooler, due to a pre-cool and low heat leakage during defrost).

Where there are additional defrost systems (each with its own **defrost control cycle**), the value of term based on ΔTh_{df} and Δt_{df} is also added in Formula (3) for each additional defrost system.

6.8.3 Interpolation

Where interpolation is performed in order to obtain a more optimum estimate of the daily **energy consumption** for a given **ambient temperature**, the calculations for each **compartment** temperature and **energy consumption** determined in accordance with 6.8.2 shall be used as set out in Annex E.

6.8.4 Specified auxiliaries

Where the **refrigerating appliance** contains specified auxiliaries, the increase in **energy consumption** associated with these auxiliaries is calculated according to the relevant local regional operating schedule specified and using the parameters set out in Annex F. The impact of these auxiliaries is typically estimated over a year, so care is required when attempting to add these to other energy values calculated in this standard – annual values need to be determined for the other energy values before these figures can be added.

6.8.5 Total energy consumption

The total **energy consumption** of an appliance can be estimated from the following values:

E_{daily16C} at an **ambient temperature** of 16 °C

E_{daily32C} at an **ambient temperature** of 32 °C

The value of E_{daily} at **ambient temperatures** of 16 °C and 32 °C may be calculated by interpolation in accordance with Annex E. Annex I provides some examples of how these two values can be combined to provide an annual energy estimate.

E_{aux} expressed as an integrated energy value over a year.

NOTE 1 The ice-making test is performed at **ambient temperatures** of 16 °C and 32 °C so E_{aux} is a regional function of $f\{E_{\text{aux16C}}, E_{\text{aux32C}}\}$.

The total annual **energy consumption** of a **refrigerating appliance** can be given by:

$$E_{\text{total}} = f\{E_{\text{daily16C}}, E_{\text{daily32C}}\} + E_{\text{aux}} \quad (4)$$

Where

f is a regional function to give the annual energy based on daily energy at 16 °C and 32 °C. This function is not defined in this standard and may vary by region. See Annex I for examples.

NOTE 2 Energy associated with load processing arising from user interactions is not included in these calculations. See Annex G for measurements and associated energy calculations.

7 Circumvention devices

A circumvention device is any control device, software, component or part that alters the refrigerating characteristics during any test procedure, resulting in measurements that are unrepresentative of the appliance's true characteristics that may occur during **normal use** under comparable conditions. Generally, circumvention devices save energy during an energy test but not during **normal use**. Examples of circumvention may include, without limitation, any variation to normal operation when the appliance is subjected to testing, and includes devices that

a) alter **compartment** temperature set points during the test; or

b) activate or de-activate heaters or other energy-consuming devices during the test; or

c) manipulate compressor cycle time or other operating parameters during the test; or

d) manipulate the **defrost interval**.

Devices that operate over a restricted range of conditions and which are:

– required for the maintenance of satisfactory food preservation temperatures within **compartments** (e.g. temperature compensation heaters in **fresh food compartments** that operate at low ambient conditions); or

– intended to reduce **energy consumption** during **normal use**

will generally not be treated as circumvention devices where the legitimate basis for their operation during **normal use** and under the test procedure for **energy consumption** is declared and can be demonstrated by the supplier.

Where the operation of a circumvention device is suspected, a laboratory should subject the appliance to measures such as door openings or other appropriate actions in an attempt to detect presence and operation of any such devices. Details of any such action and their effect shall be included in the test report. Where a circumvention device is suspected or detected during testing, a laboratory shall report that information to the client.

Circumvention devices, where present, may be subject to regional regulations and requirements. Such devices may be prohibited in some jurisdictions. Other jurisdictions may require the circumvention device to be defeated for energy tests or the product to be tested in such a way to obtain an assessment of the energy impact of the circumvention device operation. Any additional **energy consumption** associated with the circumvention device may be added to the measured **energy consumption** and there may be penalty factors associated with the additional energy associated with the circumvention device.

8 Uncertainty of measurement

For all energy measurements, the uncertainty of measurement of the measured value should be determined and stated with the measured result.

Where less stringent validity criteria have been applied to obtain an approximate result in a shorter time, the resulting increase in uncertainty shall be taken into account in any statement of uncertainty.

Verification tests should take into consideration the measurement uncertainty when assessing the energy result against any relevant validity criteria.

NOTE The calculation of uncertainty of measurement is not specified in this standard. Further guidance on this issue can be obtained from the ISO/IEC Guide 98-3:2008, *Uncertainty of measurement – Part 3: Guide to the expression of uncertainty in measurement (GUM:1995)*.

9 Test report

A test report that includes all of the relevant information listed in IEC 62552-1:2015 Annex F for tests undertaken in accordance with this standard should be prepared.

Annex A
(normative)

Set up for energy testing

A.1 General

For the purposes of energy determination in accordance with this standard, the **refrigerating appliance** shall be set up as specified below.

The **refrigerating appliance** shall be installed in a test room and with instrumentation as specified in IEC 62552-1:2015, Annex A.

The **refrigerating appliance** shall be prepared and set up in accordance with the requirements of IEC 62552-1:2015, Annex B.

The **refrigerating appliance** shall have air temperature sensors installed at the positions specified in IEC 62552-1:2015, Annex D. The determination of **compartment** air temperature during energy testing shall be as specified in IEC 62552-1:2015, Annex D.

A.2 Additional set up requirements for energy testing

A.2.1 Ice making trays

Any **ice cube trays** with a dedicated position, as specified in the instructions, shall remain in place but shall be empty for energy tests (except as specified in Annex G).

A.2.2 User adjustable controls

User-adjustable temperature control(s) that are not used for energy interpolations in accordance with Annex E shall be set in a single position that meets the relevant **compartment** temperature requirements set out in Clause 5 (**target temperatures**) for all test runs. Where interpolation between the results of two or more test runs is to be performed in accordance with Annex E, the only setting(s) to be changed between test runs shall be the relevant **user-adjustable temperature control(s)** used for interpolation. The position of all baffles and **user-adjustable temperature control(s)** not used for interpolation shall be recorded in the test report.

Where a **wine storage compartment** has setting options for both uniform temperature and multiple temperature zones, the uniform temperature setting shall be selected for testing.

A.2.3 Ambient temperature

For **energy consumption** determination, the nominal test room temperatures are 16 °C and 32 °C. The operational requirements for test room **ambient temperatures** are specified in IEC 62552-1.

A.2.4 Accessories and shelves

Any accessories, loose trays, bins or containers that have no dedicated position or essential function during **normal use**, as specified in the instructions, shall be removed.

Any thermal storage devices (e.g. ice-bricks or similar) that are removable without the use of a tool shall be removed for all tests, irrespective of instructions.

A.2.5 Anti-condensation heaters

Anti-condensation heaters which are permanently on during **normal use** shall be tested with the heater(s) operating for all energy tests.

Anti-condensation heaters that can be switched ‘on’ or ‘off’ by the user shall be tested at both the ‘on’ and ‘off’ setting.

Anti-condensation heaters that have a number of possible settings that can be selected by the user shall be tested at both the ‘highest energy’ and the ‘lowest energy’ setting.

Sufficient data shall be collected so that the additional power consumption associated with the anti-condensation heater(s) at each specified setting can be estimated with the **compartment**(s) operating at the same temperature(s). The additional power consumed by the **refrigerating appliance** when the anti-condensation heater(s) are operating at each **ambient temperature** shall be determined. Energy test values shall be separately reported for each specified setting.

NOTE A number of possible approaches can be used to determine the incremental impact of manually switched anti-condensation heater(s) as set out in Annex F (for example, measure energy without heaters then add calculated energy, measure energy with heaters then subtract actual energy before adding calculated energy). If there is any doubt about the most expedient method, the optimum energy in accordance with Annex B (using interpolation where necessary) should be determined with and without the anti-condensation heater(s) operating in order to determine this value (noting that their operation may have a small impact on **compartment** temperatures).

Anti-condensation heaters which are automatically controlled and vary in response to ambient conditions (e.g. temperature and/or humidity) are classified as specified auxiliaries and shall be tested in accordance with Annex F.

Anti-condensation heaters which are automatically controlled and vary in response to ambient conditions but are configured so that the user can select the underlying or base level of heater power shall be tested at highest and lowest user setting in accordance with Annex F (refer F.2.8).

A.2.6 Automatic icemakers – ice storage bins

A.2.6.1 General

Where an appliance includes an automatic ice-making feature that produces, harvests and stores ice, the space that the ice storage bin occupies shall be specifically treated as a separate **sub-compartment** for the purposes of energy testing.

Any automatic ice-making bin shall be separately declared under ‘**Compartment** Details’ in the test report.

For all energy tests, the ice delivery mechanism shall remain functional, i.e. all chutes and throats required for the delivery of ice shall be free of packing, covers or other blockages that may be fitted for shipping or when the ice-maker is not in use.

Where the ice storage space occupies a complete **compartment**, the temperature sensor placements shall be in accordance with IEC 62552-1:2015 Annex D (not A.2.6.5 of this part).

A.2.6.2 Intent and overview for energy testing

The intent is to make sure that during an **energy consumption** test to this standard the automatic ice-maker and its associated equipment behaves in a manner that is consistent with a value that would be obtained while the system is running but is not making new ice.

In order to achieve this condition during an energy test, automatic ice-makers shall function normally but shall not produce any new ice (but should be in a state that would automatically produce new ice on demand without any user intervention if some ice were removed). Only devices or components directly associated with the production or harvesting of new ice shall be inoperative during the energy test. All components not explicitly associated with the production or harvesting of new ice shall operate normally during the energy test and shall be energized in a manner consistent with the duty cycle necessary to perform their respective functions. The cooling of the icemaker area(s) shall remain unchanged from normal ice-storage conditions.

Other than for verification tests as specified in A.2.6.4, connection to a water supply may be omitted if it can be demonstrated that the absence or presence of a connection to a water supply will make no difference to the measured **energy consumption**.

A.2.6.3 Ice storage bin configuration

The ice storage bin shall remain in place and empty for all energy testing, except where otherwise specified in A.2.6.4. The automatic ice-making bin shall be treated as a **sub-compartment** and shall be fitted with a temperature sensor as specified in A.2.6.5.

Any action taken by the test laboratory (including settings or configuration) during the energy test to make the automatic ice-maker operative but to cease production of ice due to an ice-bin-full condition in accordance with A.2.6 shall be included in the test report.

A.2.6.4 Verification of energy consumption with an automatic ice-maker

For the purposes of verification of **energy consumption** of an appliance, the setup of the automatic icemaker should be configured in accordance with the setup specified by the manufacturer.

In order to detect whether there are any undeclared circumvention devices in operation during an energy test, irrespective of instructions, a test laboratory may undertake tests, including the test as set out below to assess the normal operation of the automatic ice-maker and its associated controls against the requirements of Clause 7 and the intent of A.2.6.2.

The purpose of this test, where undertaken, is to assess the normal operation of the automatic ice-maker against the configuration used for energy testing as set out in A.2.6.4. The ice-maker is connected to a water supply, the ice-making function is operated until the bin is full and ice production has automatically stopped under its own control prior to commencing an energy test. To shorten the test time, pre-made ice cubes may be used to partially fill the ice storage bin before the start of the test, but only to a level that allows the icemaker to continue producing ice to fill the bin.

The automatic ice-making bin shall be fitted with a temperature sensor as specified in A.2.6.5.

The temperature in the ice-making storage bin should remain well below freezing during all stages of operation. As a guide, the **energy consumption** with the ice storage bin full of ice under this clause should not exceed by 2 % the **energy consumption** measured during energy testing for the same (or equivalent) **temperature control settings** and internal temperatures but with the ice storage bin empty.

A.2.6.5 Position of the temperature sensor in automatic ice-makers

An automatic ice-maker bin shall have a single additional temperature sensor located in the position specified as follows for all energy tests:

a) Vertical placement: Approximately 50 mm below the top of the estimated maximum ice storage level while maintaining at least 20 mm clearance from the base of the bin.

b) Horizontal placement: Approximately 20 mm clearance from the vertical centre line of the side of the bin that is closest to an external surface or warmer **sub-compartment** (e.g. door or wall or gasket or **sub-compartment**) or, where the bin is more than 50 mm from an external surface, approximately 20 mm clearance from the vertical centre line of the largest side of the bin (i.e. where the bin is wholly within the **compartment**).

c) Where the position specified in b) is affected by a direct air stream, it shall, as far as possible, be relocated to an alternative position that has 20 mm clearance from the side of the bin but away from a direct air stream that is colder than the bin contents.

If the position of the temperature sensor is moved so that it is away from the preferred positions specified in a) and b) above, the position of the sensor shall be noted in the test report.

NOTE In a verification test in accordance with A.2.6.4, ice will usually touch the temperature sensor in the storage bin. See A.2.6.1 regarding the placement of temperature sensors in separate **compartments** that are dedicated to ice storage.

Annex B
(normative)

Determination of steady state power and temperature

B.1 General

This Annex specifies the method to be used to determine the power consumption and temperature for a **refrigerating appliance** during stable operation that is tested in accordance with this standard.

B.2 Setup for testing and data collection

The objective is to select a representative period of operation in order to determine the average power and average internal temperatures (for all relevant **compartments**) for the selected **temperature control setting** and test **ambient temperature**.

The **refrigerating appliance** under test shall be set up and operated in accordance with Annex A.

There are two possible cases with respect to the determination of **steady state** power consumption:

- Case SS1 (see Clause B.3) applies to products without a **defrost control cycle** and products with a defrost system (with its own **defrost control cycle**) where the **defrost control cycle** is long and the **steady state** test period of interest may not be bounded by **defrost and recovery periods**. Quite stringent internal validity criteria are applied to the data to ensure that a representative period of operation is selected.
- Case SS2 (see Clause B.4) applies to products with a defrost system (with its own **defrost control cycle**) where the **steady state** test period of interest commences with a valid **defrost and recovery period**. Case SS2 shall be used where stability between defrosts cannot be established using Case SS1. In Case SS2 the whole period from defrost to defrost is used to determine the **steady state** power consumption by deduction of initial incremental **defrost and recovery** energy (see DF1 in Annex C). In Case SS2, the **steady state** operation before the initial defrost and before the following defrost are compared and they shall meet the relevant stability criteria. The initial defrost shall also meet the validity requirement of DF1 as specified in Annex C.

B.3 Case SS1: no defrost control cycle or where stability is established for a period between defrosts

B.3.1 Case SS1 approach

Case SS1 applies to all products without a **defrost control cycle**. It also can apply to products with a defrost system (with its own **defrost control cycle**) where the **defrost control cycle** is long and the **steady state** test period of interest is not bounded by **defrost and recovery periods**. In this case, no **defrost and recovery period** (or part thereof) shall occur during the selected test period under Case SS1.

Where the **steady state** power is determined under Case SS1, a **steady state** test period that is made up of 3 internal blocks of test data is selected that are adjacent but not overlapping. Each block of test data shall contain an equal number (n) of whole **temperature control cycles**. The minimum number of **temperature control cycles** per block is 1. A test period is selected where all relevant criteria for internal spread and slope for temperature and power can be established.

A block size of 1 **temperature control cycle** will have a total test period of 3 **temperature control cycles**, a block size of 2 **temperature control cycles** will have a test period of 6 **temperature control cycles**, and so on. The definition of **temperature control cycle** in IEC 62552-1:2015 should be considered carefully. It is generally recommended that for more complex refrigeration systems alternative **temperature control cycles** based on temperature maxima in each **compartment** be examined in addition to compressor cycles (where present) to see which one provides the most stable estimate of power over time. Selecting the most stable **temperature control cycle** can shorten the required testing time to achieve a valid result.

Where there are no discernable changes in temperature or power consumption over time, a test period that is made up of 3 internal blocks of test data is selected. Each block of test data shall be equal in length, adjacent and no less than 4 h in duration.

As an alternative to using **temperature control cycles**, fixed length periods may be used (referred to as fixed time slices) to make up each block.

A trial test period shall be made up of 3 blocks of data called A, B and C.

NOTE There is no maximum number of **temperature control cycles** per block, but a value of 10 is considered to be unusually long.

An example test period made up of blocks of 5 **temperature control cycles** is illustrated in Figure B.1.

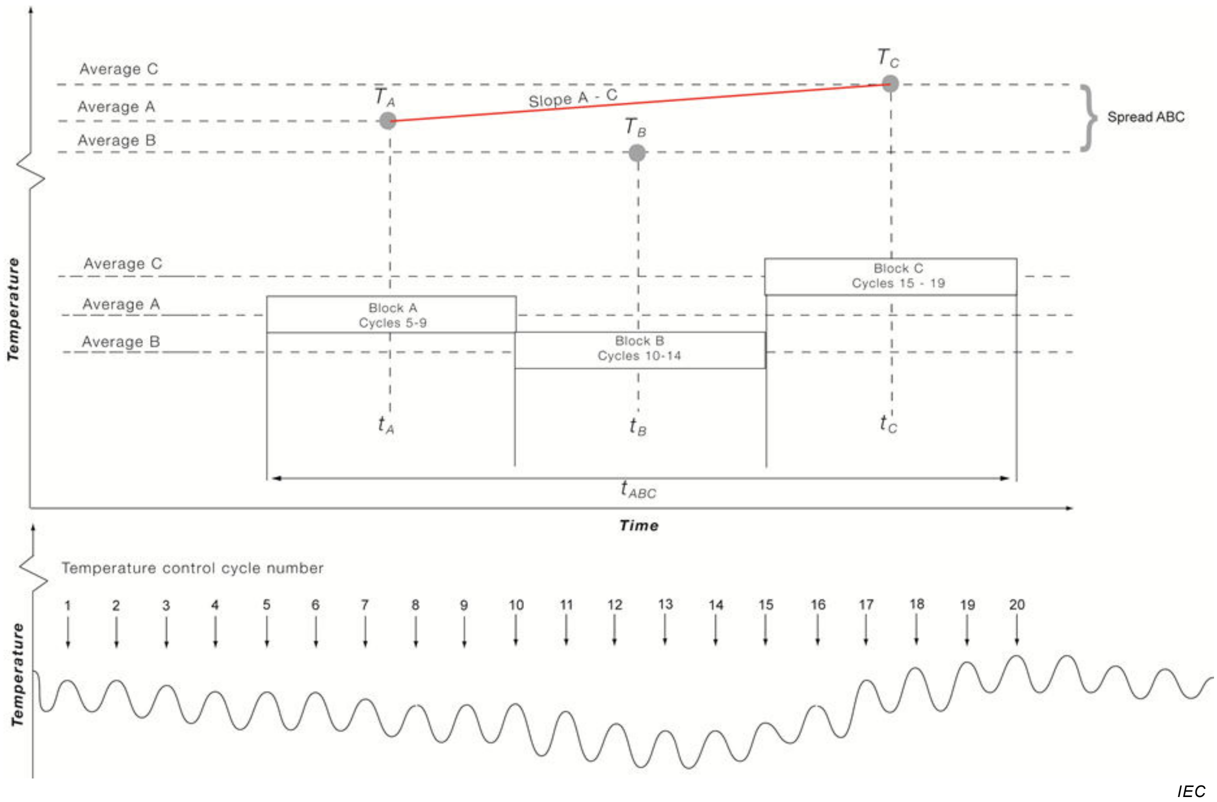


Figure B.1 – Illustration of a test period made of blocks of 5 temperature control cycles – temperatures for Case SS1

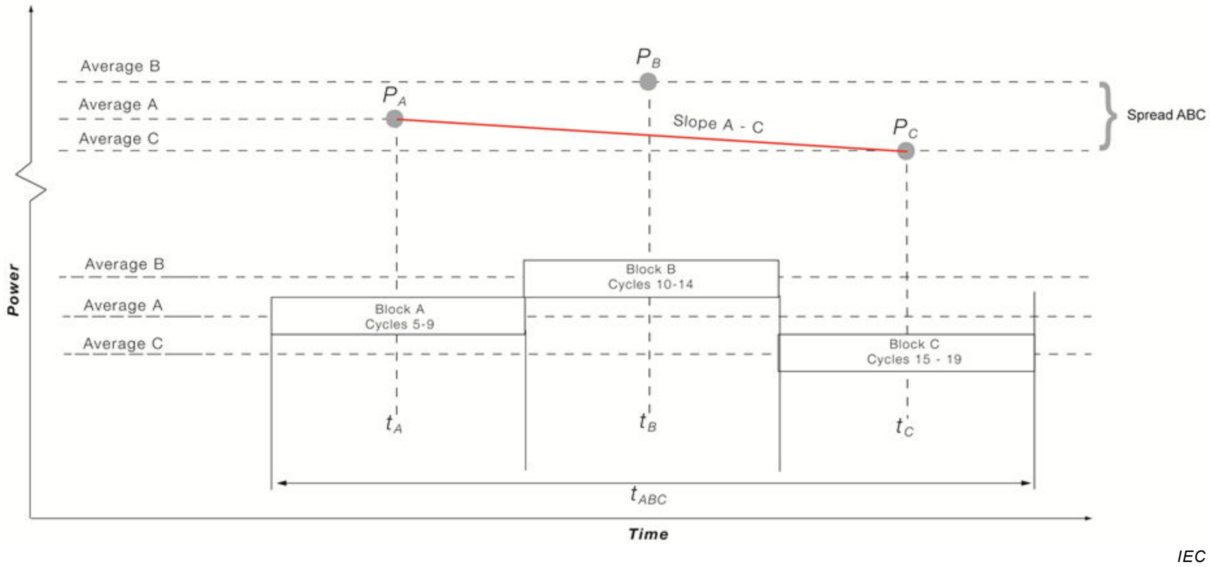


Figure B.2 – Illustration of a test period made of blocks of 5 temperature control cycles – power for Case SS1

For each block of data (A, B and C), calculate the average power and the average temperature in each relevant **compartment**.

Calculate the following characteristics across the test Blocks A, B and C:

- Spread of temperature for each **compartment**: calculated as the difference between the average temperature of the warmest Block (A, B or C) and the average temperature of the coldest Block (A, B or C). All temperature differences (spread) are in K. Refer to Equation (5).
- Slope of temperatures from Block A to Block C: calculated as [the absolute value of the difference between the average temperature of Block A and the average temperature of Block C] divided by [the test time at the middle of Block C minus the test time at the middle of Block A]. All temperature slopes are in K/h. Refer to Equation (6).
- Spread of power (watt): calculated as the difference between the average power of the highest power Block (A, B or C) and the average power of the lowest power Block (A, B or C) divided by [the average power for the whole test period (A, B and C)], expressed as a percentage. Refer to Equation (7).
- Slope of power from Block A to Block C: calculated as [the absolute value of the difference between the average power of Block C and the average power of Block A] divided by [the test time at the middle of Block C minus the test time at the middle of Block A] and divided by [the average power for the whole test period (A, B and C)]. All power slopes are expressed as a percentage per hour (%/h). Refer to Equation (8).

$$\text{Spread of temperature } = T_{\max(A,B,C)} - T_{\min(A,B,C)} \text{ (K)} \quad (5)$$

$$\text{Slope of temperature } = \frac{ABS[T_C - T_A]}{[t_C - t_A]} \text{ (K/h)} \quad (6)$$

$$\text{Spread of power } = \frac{P_{\max(A,B,C)} - P_{\min(A,B,C)}}{P_{av(A,B,C)}} \text{ (\%)} \quad (7)$$

$$\text{Slope of power} = \frac{ABS[P_C - P_A]}{[t_C - t_A] \times P_{av(A,B,C)}} \text{ (\%/h)} \quad (8)$$

Where for each block A, B and C:

T is the temperature

t is the test time (the centre point of the block)

P is the power

% is the result of the quotient (expressed as a percentage, where 1,0 = 100 %)

B.3.2 Case SS1 acceptance criteria

Based on the characteristics calculated in B.3.1, assess the validity of the whole test period (made up of 3 blocks, each consisting of n **temperature control cycles**). The test period shall be valid if all of the following criteria are met:

- Total test period t_{ABC} (sum of length of Blocks A, B and C) is no less than 6 h where there are **temperature control cycles** and no less than 12 h where there are no **temperature control cycles** (or where fixed time slices are used);
- Spread of temperature (across Blocks A, B, C) is less than 0,25 K for each **compartment**;
- Slope of temperature (from Block A to Block C) is less than 0,025 K/h for each **compartment**;
- Spread of power (across Blocks A, B, C) where **temperature control cycles** are present is less than: for a total test period t_{ABC} of 12 h or less, a spread of not more than 1 %; for a total test period t_{ABC} from 12 to 36 h, a spread of not more than 1 % + (t_{ABC} – 12) / 1 200; for a total test period t_{ABC} of 36 h or more, a spread of not more than 3 %;
- Spread of power (across Blocks A, B, C) where no **temperature control cycles** are present or where fixed time periods are selected is less than 1 %, irrespective of the total test period;
- Slope of power (from Block A to Block C) is less than 0,25 %/h;
- Where **temperature control cycles** are present, the two comparable test periods that start one and two **temperature control cycles** earlier than the period selected also meet all of the above criteria (i.e. the selected test period is the third possible period that meets all other validity criteria);
- Where **temperature control cycles** are not present (or where fixed time slices are used), the two comparable test periods that start one hour and two hours earlier than the period selected also meet all of the above criteria.

The requirement for the test period to remain valid when moved along for 3 consecutive **temperature control cycles** ensures that compliance with all criteria for the selected period is not a chance or random occurrence. In the example illustrated in Figure B.1, if the test period starting at **temperature control cycle** 5 and ending at **temperature control cycle** 20 was the first period to meet the above criteria 1 to 5, the test period from 6 to 21 and 7 to 22 would also have to meet all criteria. In this case the test period from 7 to 22 is the first valid test period.

NOTE 1 The full set of criteria above were developed on the basis of extensive testing and review of data for more than 100 **refrigerating appliances**.

The **temperature control setting(s)** shall remain unchanged for all the test period used to determine the value for SS1 (Blocks A, B and C).

Where there are more than two **compartments**, assessment of temperature stability as set out above is required for:

- The largest **unfrozen compartment** and largest **frozen compartment** (where applicable), or
- The largest two **compartments** (where all **compartments** are **frozen** or **unfrozen**).

In addition, temperature stability shall be achieved as specified above for all **compartments** that are used for interpolation for **energy consumption** in accordance with Annex E.

If the above criteria cannot be met, the size of n is increased (and therefore the length of the test period is increased) and/or more test data is collected until all criteria can be met simultaneously.

The recommended approach during the collection of test data is to continually look (backwards) at all of the data collected to that moment in order to assess all possible test periods for all possible block sizes (n) to establish the earliest possible point in the test data that can meet the above validity criteria. While it is not generally recommended that data from a warm start (pull down when the power is first connected) be included in these assessments, these criteria should ensure that any pull down prior to the establishment of stable operation is automatically excluded from a valid test period.

Where there are a number of possible test periods that meet the above criteria, the test period with the minimum spread of power from the available test data should be selected.

Where the criteria of power spread cannot be met by extending the total test period (with or without **temperature control cycles**), a valid result may be obtained by using 3 blocks of data with each block no less than 36 h in length (total test period no less than 108 h).

NOTE 2 A worked example to select the optimum test period characteristics is included in Annex I.

B.3.3 Case SS1 calculation of values

Where a test period, made up of Blocks A, B and C, meets the relevant acceptance criteria in B.3.2, then the temperature T_{i} for each **compartment** i and the average power P_{SS1} is determined as the average of all measured values included in the time period covered by Blocks A, B and C.

The **steady state** power used for subsequent energy calculations P_{SS} is determined by modifying the value of P_{SS1} using Formula (15) in Clause B.5 where the measured **ambient temperature** is not equal to the nominal **ambient temperature** during the test.

The total test time for Blocks A, B and C shall be reported.

The **steady state** compressor run time CRt_{SS} is calculated as the percentage of time that the compressor is on during the total time for all **temperature control cycles** in Blocks A, B and C.

B.4 Case SS2: steady state determined between defrosts

B.4.1 Case SS2 approach

Case SS2 applies to products with one or more defrost systems (each with its own **defrost control cycle**) where the **steady state** test period of interest is bounded by **defrost and recovery periods**. While it may be used for all products with one or more defrost systems, Case SS2 shall be used if stability cannot be established using Case SS1.

For products with long **defrost intervals**, the use of Case SS1 may considerably shorten the required test time.

Case SS2 uses all data between the start of two **defrost and recovery periods** to calculate the **steady state** power (see Formula (12)). Checks are undertaken to compare the characteristics of the **steady state** operation prior to each **defrost and recovery period** (Periods X and Y in Figure B.3) to ensure that they meet the relevant stability requirements before undertaking any further analysis. The initial **defrost and recovery period** within the test period SS2 shall comply with the validity requirements of Annex C and the incremental energy associated with this **defrost and recovery period** shall be determined in accordance with Annex C (DF1) in order to determine the value for P_{SS2} (which is the whole test period less the value for DF1).

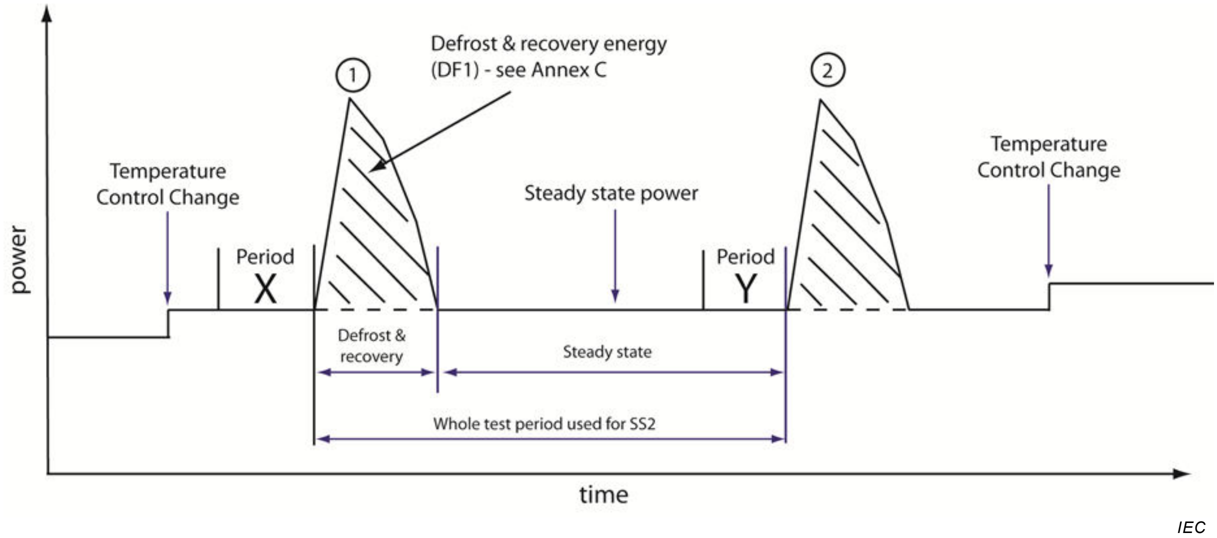


Figure B.3 – Case SS2 – typical operation of a refrigerating appliance with a defrost control cycle

A period of **steady state operation** (called Period X), ending at the start of a **defrost and recovery period** and made up of no less than 4 whole **temperature control cycles** (where **temperature control cycles** are present) and no less than 4 h in length, is selected. A second period of **steady state** operation (called Period Y), ending at the start of the next **defrost and recovery period** and made up of no less than 4 whole **temperature control cycles** (where **temperature control cycles** are present) and no less than 4 h in length, is selected. Periods X and Y shall always consist of the same number of **temperature control cycles** (where **temperature control cycles** are present) and should be approximately the same length. Periods X and Y shall be exactly the same length where no **temperature control cycles** are present.

Where no subsequent **defrost and recovery period** has been initiated within 48 h, Period Y may be selected at a point during **steady state** operation where the elapsed time from the end of Period X to the end of Period Y exceeds 48 h but where Period Y is not adjacent to a subsequent **defrost and recovery period**. Where Period Y is selected in this manner, it shall be noted in the test report.

The temperature in each **compartment** and power for Period X are then compared to the temperature in each **compartment** and power for Period Y.

Calculate the following characteristics across the Periods X and Y:

- Spread of temperature for each **compartment**: calculated as the difference between the average temperature of the warmer period (X or Y) minus the average temperature of the colder period (X or Y). All temperature differences (spread) are in degrees K. Refer to Equation (9).
- Spread of power: calculated as the difference between the average power of the higher power period (X or Y) minus the average power of the lower power period (X or Y) divided

by the average power for the Periods X and Y. The spread of power is expressed as both a percentage and as an absolute spread (W). Refer to Equations (10) and (11).

$$\text{Spread of temperature } = T_{\max(X,Y)} - T_{\min(X,Y)} \text{ (K)} \tag{9}$$

$$\text{Spread of power } = \frac{P_{\max(X,Y)} - P_{\min(X,Y)}}{P_{av(X,Y)}} \text{ (\%)} \tag{10}$$

$$\text{Spread of power } = P_{\max(X,Y)} - P_{\min(X,Y)} \text{ (W)} \tag{11}$$

Where for each period X and Y:

T is the temperature

P is the power in W

% is the result of the quotient (expressed as a percentage, where 1,0 = 100 %)

B.4.2 Case SS2 acceptance criteria

For the period selected for determination of P_{SS2} **steady state** power to be valid, the following criteria shall be met:

- Period X and Y shall be made up of no less than 4 whole **temperature control cycles** (where **temperature control cycles** are present) and shall have the same number of **temperature control cycles**. Where no **temperature control cycles** are present (or where fixed time slices are used), X & Y shall be the same length.
- Period X and Y shall not be less than 4 h in length.
- The ratio of the total length of Period X (in hours) to the total length of Period Y (in hours) shall be in the range 0,8 to 1,25 where **temperature control cycles** are present.
- The spread of temperature of the two selected Periods X and Y shall be less than 0,5 K for each **compartment**;
- The spread of power of the two selected Periods X and Y shall be less than 2 % or less than 1 W, whichever is the greater value.
- The initial **defrost and recovery period** which is included in period SS2 shall qualify as a valid **defrost and recovery period** in accordance with Annex C.
- The value of ΔE_{df} for the initial **defrost and recovery period** which is included in period SS2 shall be determined in accordance with Annex C.

The **temperature control setting** shall remain unchanged for all the test period used to determine the value for SS2, including the period used to determine the incremental **defrost and recovery** energy (ΔE_{df} for DF1) specified in Annex C (including all of Periods X and Y).

Where the initially selected Period X and Period Y do not comply with the acceptance criteria specified above, the minimum length of time for Period X and Y shall both be increased in steps of 1 **temperature control cycle** (in 1 h steps where there are no **temperature control cycles** or where fixed time slices are used) to see if there are any possible complying periods. Where the size of X and Y are increased, the first valid value using the sequence specified above shall be used. The length of X and Y shall not exceed 50 % of the defrost interval or 8 h, whichever is the longer.

Where there are more than two **compartments**, assessment of temperature stability as set out above is required for:

- The largest **unfrozen compartment** and largest **frozen compartment** (where applicable), or
- The largest two **compartments** (where all **compartments** are **frozen** or **unfrozen**).

In addition, temperature stability shall be achieved as specified above for all **compartments** that are used for interpolation for **energy consumption** in accordance with Annex E.

In rare cases where there is no **steady state** operation between defrosts, it may not be possible to ever confirm the validity of the initial **defrost and recovery period** at the start of SS2 in accordance with Annex C. An alternative approach to deal with such cases is outlined in Annex K, but this should only be used if compliance with Annex C can never normally be achieved.

B.4.3 Case SS2 calculation of values

Where the acceptance criteria in B.4.2 have been met, the determination of **steady state** power and **steady state** temperature in each **compartment** are calculated from the whole test period used for SS2 (including the initial **defrost and recovery period**) as set out in Formula (12) and Formula (13) below. The calculation determines the **energy consumption** over whole **defrost control cycle** and subtracts the incremental defrost and recovery energy in accordance with Annex C in order to determine the **steady state** power consumption P_{SS2}. Similarly, each **compartment** temperature is determined over the whole **defrost control cycle** and the accumulated temperature difference during the **defrost and recovery period** in each **compartment** (in accordance with Annex C) is subtracted in order to determine the **steady state** temperature in each **compartment** T_{SS2-i}.

The average power during the **steady state** period shall be calculated from the whole test period used for SS2 as follows:

$$P_{SS2} = \frac{(E_{end-Y} - E_{end-X}) - \Delta E_{df}}{(t_{end-Y} - t_{end-X})} \tag{12}$$

Where

P_{SS2}	is the **steady state** power for the selected **defrost control cycle** in W
E_{end-X}	is the accumulated energy reading at the end of Period X in Wh
E_{end-Y}	is the accumulated energy reading at the end of Period Y in Wh
t_{end-X}	is the test time at the end of Period X in h
t_{end-Y}	is the test time at the end of Period Y in h
ΔE_{df}	is the incremental **defrost and recovery** energy in Wh in accordance with Annex C for the **defrost and recovery period** commencing at the end of Period X.

The length of the test period used (t_{end-Y} – t_{end-X}) shall be separately reported. Where applicable, it shall be noted whether Period Y was adjacent to a subsequent defrost.

The **steady state** power used for subsequent energy calculations P_{SS} is determined by modifying the value of P_{SS2} using the formula in B.5 where the measured **ambient temperature** is not equal to the nominal **ambient temperature** during the test.

The average temperature during the **steady state** period shall be calculated from the whole test period used for SS2 as follows:

$$T_{SS2-i} = (T_{av-endX-endY-i}) - \left[\frac{\Delta Th_{df-i}}{(t_{end-Y} - t_{end-X})}\right] \tag{13}$$

Where

$T_{SS2\text{-}i}$ is the **steady state** temperature in **compartment** i that occurs in the whole test period used for SS2 in degrees C

$T_{av\text{-}endX\text{-}endY\text{-}i}$ is the average temperature in **compartment** i over the period from the end of Period X to the end of Period Y in degrees C

$\Delta Th_{df\text{-}i}$ is the accumulated temperature difference over time in each **compartment** i in Kh as determined in accordance with Annex C for the **defrost and recovery period** commencing at the end of Period X

$t_{end\text{-}X}$ is the test time at the end of Period X in h

$t_{end\text{-}Y}$ is the test time at the end of Period Y in h

For products with a compressor run time defrost controller, the **steady state** compressor run time CRt_{SS} is calculated as the percentage of time that the compressor is on for the whole **defrost control cycle** less the value for Δt_{dr} determined in Annex C as set out in Equation (14).

$$CRt_{SS2} = \frac{Rt_{end-Y} - Rt_{end-X} - \Delta t_{dr}}{(t_{end-Y} - t_{end-X})} \tag{14}$$

Where

CRt_{SS2} is the average percentage compressor run time that occurs in **steady state** in %

$Rt_{end\text{-}X}$ is the total accumulated compressor run time (on period) at the end of period X in h

$Rt_{end\text{-}Y}$ is the total accumulated compressor run time (on period) at the end of period Y in h

Δt_{dr} is the additional compressor run time associated with a **defrost and recovery** in h in accordance with Annex C

$t_{end\text{-}X}$ is the test time at the end of the Period X in h

$t_{end\text{-}Y}$ is the test time at the end of the Period Y in h

Care is required not to count defrost heater on time as compressor on time in these calculations (although it is possible that some controllers include the defrost heater operation as run time – each product should be checked to see how it is configured).

B.5 Correction of steady state power

The **steady state** power used for subsequent energy calculations P_{ss} is based on the measured **steady state** power (B.3 or B.4 as applicable) after adjustment using Formula (15) below. This adjustment takes into account the difference between the measured **ambient temperature** during the test and the nominal ambient test temperature.

$$P_{SS} = P_{SSM} \times \left(1 + \left[T_{at} - T_{am}\right] \times \frac{\sum_{i=1}^{n} \left[\frac{V_i}{(c_1 \times (18 + T_{it}) + c_2)} \right]}{\sum_{i=1}^{n} \left[\frac{V_i \times (T_{am} - T_{im})}{(c_1 \times (18 + T_{it}) + c_2)} \right]} \right) \times \frac{1}{\left[1 + (T_{at} - T_{am}) \times \Delta COP\right]} \tag{15}$$

Where

P_{SSM} is the measured **steady state** power for the period in W as specified in B.3 (P_{SS1}) or B.4 (P_{SS2}) as applicable

T_{at} is the target test room **ambient temperature**

T_{am} is the measured test room **ambient temperature** during the test period

V_i is **rated volume** of **compartment** i (for **compartments** 1 to n)

T_{im} is the measured temperature in **compartment** i to n during the test period

T_{it} is the **target temperature** for **energy consumption** in **compartment** i to n (refer Table 1)

c_1 is a constant given as 0,011 364

c_2 is a constant given as 1,25

ΔCOP is the adjustment given in Table B.1 for the product type and test condition.

All temperatures are in degrees Celsius (°C).

Table B.1 – Assumed ΔCOP adjustment

Product Type	ΔCOP adjustment at 16 °C	ΔCOP adjustment at 32 °C
Two or more **compartments**	0,000 per K increase	–0,014 per K increase
One **compartment**	–0,004 per K increase	–0,019 per K increase

This formula is not valid for corrections that are outside the permitted ambient test temperature range specified in IEC 62552-1:2015 (nominally ±0,5 K). This correction is only applied to the **steady state** power. No correction is applied to measured temperatures or any **defrost and recovery** calculations in Annex C. The value(s) of **volume** that are used in the correction equation are the **rated** values in accordance with this standard as specified in the instructions or other product literature. More information on the derivation of this equation is included in Annex L.

Annex C
(normative)

Defrost and recovery energy and temperature change

C.1 General

This Annex specifies the method to be used to determine the additional energy associated with **defrost and recovery periods** that occur in **refrigerating appliances** with one or more **defrost control cycles**. It also specifies the determination of the temperature change by **compartment** that is associated with those **defrost and recovery periods**. Normally, test data for these calculations is collected as part of the testing for **steady state** power consumption in Annex B. Individual **defrost and recovery periods** that occur at any time during the normal testing program can be used as long as these meet the relevant validity criteria. Where there is more than one defrost system (with its own **defrost control cycle**), the characteristics of each shall be separately determined (or in combination, where appropriate).

NOTE As **cyclic defrost** systems do not have a **defrost control cycle**, Annex C is only applicable to **compartments** or **refrigerating appliances** with **automatic defrost** systems other than **cyclic defrost**.

C.2 Setup for testing and data collection

The objective is to measure and select a number of representative **defrost and recovery periods** in order to determine a representative value for the additional (incremental) energy associated with **defrost and recovery** (over and above the **steady state power** consumption) and the change in average internal temperatures (for each relevant **compartment**) associated with **defrost and recovery** (relative to the **steady state** temperature) for each test **ambient temperature**.

The **refrigerating appliance** under test shall be set up and operated in accordance with Annex A. Where the cumulative time that the **refrigerating appliance** under test has been disconnected from power exceeds 6 h during the 24 h prior to the occurrence of a **defrost and recovery period**, then data from that **defrost and recovery period** shall be deemed invalid and shall not be used to determine representative values for incremental **defrost and recovery** energy and temperature change in accordance with Annex C.

To characterise the additional energy required, and the average temperature change, during a **defrost and recovery period** (relative to **steady state** conditions) at each test **ambient temperature**, a specified number of representative **defrost and recovery periods** need to be measured. In order to be considered representative, the **steady state power** and temperature before and after the **defrost and recovery period** shall meet the relevant stability or acceptance criteria. The number of **defrost and recovery periods** to be measured at each **ambient temperature** is specified in this Annex. A minimum of one **defrost and recovery period** is required for each test point used for energy determination for each **ambient temperature** condition. Alternatively, at least four **defrost and recovery periods** are required and at least half of all **defrost and recovery periods** have to have the coldest **compartment** at or below **target temperature** for each **ambient temperature**.

Conceptually, the additional energy associated with **defrost and recovery**, over and above the underlying **steady state** power consumption, is determined as illustrated in Figure C.1.

The main case considered is called Case DF1, where the **refrigerating appliance** can demonstrate **steady state** operation before and after the **defrost and recovery period**.

In rare cases (called DF2) it may not be possible to reliably demonstrate **steady state** operation before and after the **defrost and recovery period** for any defrost. Only in this case, may the methodology set out in Annex K be used.

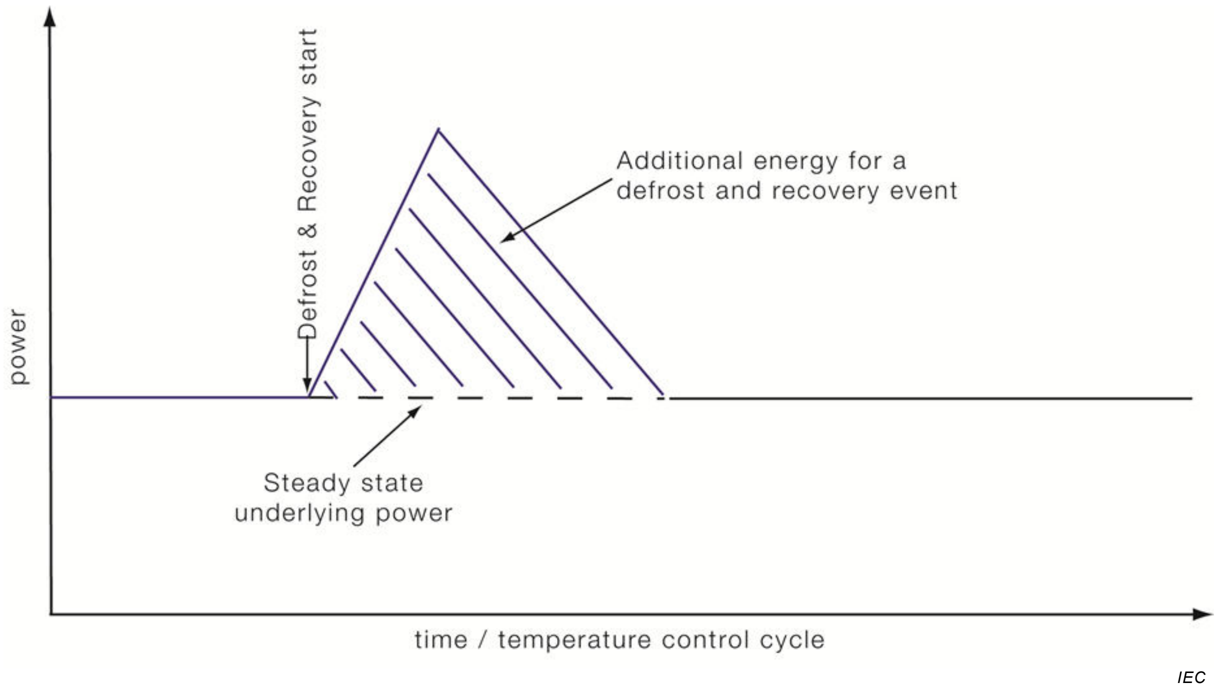


Figure C.1 – Conceptual illustration of the additional energy associated with a defrost and recovery period

C.3 Case DF1: where steady state operation can normally be established before and after defrosts

C.3.1 Case DF1 approach

Case DF1 is where the **refrigerating appliance** normally operates in a **steady state** condition prior to defrost and returns to **steady state** operation some time after the defrost. Effectively, **steady state** operation occurs on either side of a **defrost and recovery period.** Each **defrost and recovery period** is examined in isolation. This approach is used for all types of **refrigerating appliances** that have one or more **compartments** with a defrost system (with its own **defrost control cycle**).

A period of **steady state** operation (called Period D), ending well before the start of a **defrost and recovery period** is selected to be the minimum possible size that meets the criteria set out in C.3.2. A period of **steady state** operation (called Period F), starting well after the end of the same **defrost and recovery period** is selected to be the minimum possible size that meets the criteria set out in C.3.2.

For the purposes of validity assessment in C.3.2, the nominal centre of the **defrost and recovery period** is defined as 2 h after the initiation of the defrost heater or, in the case where there is no defrost heater, after the interruption of the refrigeration system related to the **automatic defrost**. This is illustrated in Figure C.2 – time interval Δt_{D1} and time interval Δt_{F1} shall be approximately the same, but will vary depending on the exact time of the selected **temperature control cycle** (where applicable) at the end of Period D and the start of Period F.

NOTE C.3.2 sets out cases where the length of Periods D and F and time for Δt_{D1} and Δt_{F1} can be adjusted in order to find complying values.

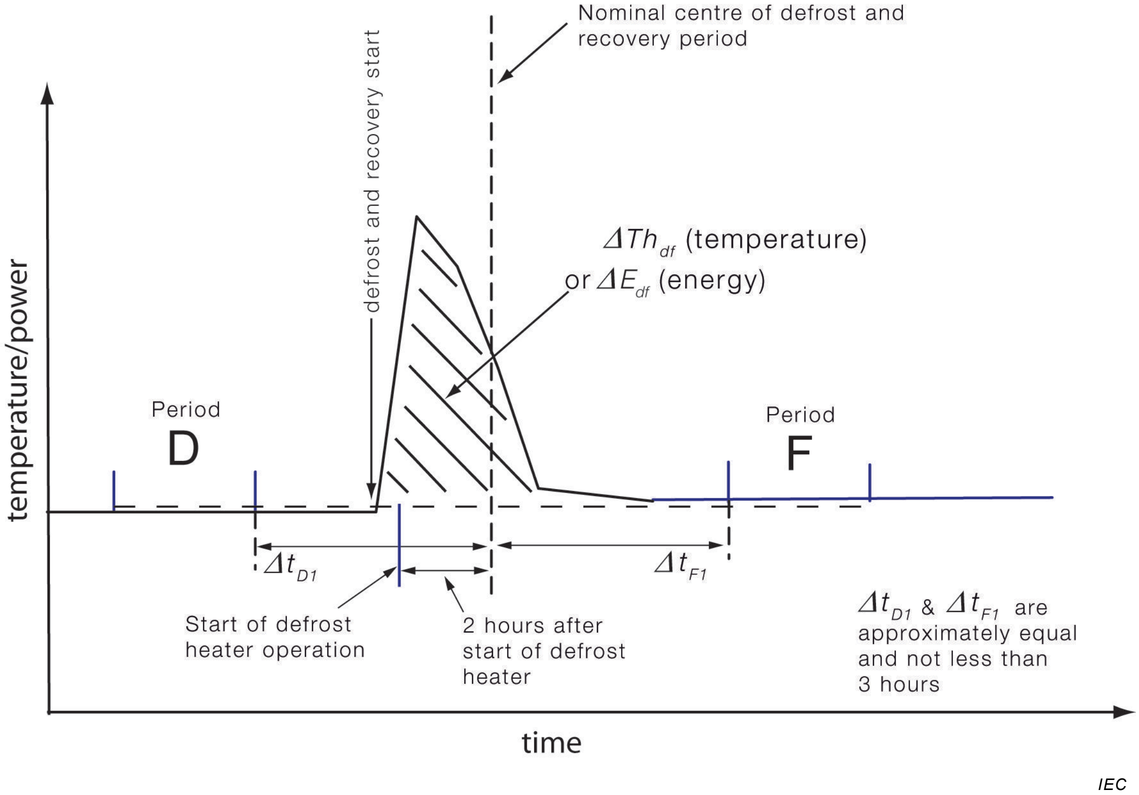


Figure C.2 – Case DF1 with steady state operation before and after a defrost

The temperature in each **compartment** and the power for Period D are then compared to the temperature in each **compartment** and power for Period F and assessed in accordance with C.3.2.

It is important to note that the average power for Period D will never be exactly equal to the average power for Period F (as illustrated above in Figure C.2). By spacing Periods D and F evenly around the nominal centre of the **defrost and recovery period**, the average power for Periods D and F provides a reasonable estimate of the underlying **steady state** power during the **defrost and recovery period**. This methodology allows individual **defrost and recovery periods** to be examined in isolation, which makes testing faster and more convenient.

Strict validity limits on the differences between Periods D and F are required to ensure that there are no significant changes in product behaviour during the assessment period (set out in C.3.2). Such differences may be due to a range of causes such as: **user-adjustable temperature control** change just before Period D or before Period F, inclusion of some residual pull down (from a warm start), some residual **processing load** in the **defrost and recovery period** (and in Period D) or automatic changes in the operation of the product (e.g. step changes in inverter speed, change in heater operation, significant temperature or power drift etc. that may give significantly different values in Period D and F). In all of these cases, the validity criteria should correctly reject the selected defrost, so it cannot be used for energy calculations. In this case testing has to continue until another **defrost and recovery period** is recorded.

Calculate the following characteristics across the Periods D and F:

- Spread of temperature for each **compartment**: calculated as the difference between the average temperature of the warmer period (D or F) minus the average temperature of the colder period (D or F). All temperature differences (spread) are in degrees K. Refer to Equation (16).

- Spread of power: calculated as the difference between the average power of the higher power period (D or F) minus the average power of the lower power period (D or F) divided by the average power for the Periods D and F. The spread of power is expressed as both a percentage and as an absolute spread (W). Refer to Equation (17) and Equation (18).

$$\text{Spread of temperature } = T_{\max(D,F)} - T_{\min(D,F)} \text{ (K)} \tag{16}$$

$$\text{Spread of power } = \frac{P_{\max(D,F)} - P_{\min(D,F)}}{P_{av(D,F)}} \text{ (\%)} \tag{17}$$

$$\text{Spread of power } = P_{\max(D,F)} - P_{\min(D,F)} \text{ (W)} \tag{18}$$

Where for periods D and F:

T is the temperature

P is the power

% is the result of the quotient (expressed as a percentage, where 1,0 = 100 %).

C.3.2 Case DF1 acceptance criteria

For the **defrost and recovery period** to be valid, the following criteria shall be met:

a) Period D and F shall be made up of no less than 3 whole number of **temperature control cycles** (where **temperature control cycles** are present) and shall have the same number of **temperature control cycles**. Where no **temperature control cycles** are present or where fixed time slices are used, Periods D and F shall be the same length.

b) Period D and F shall not be less than 3 h in length.

c) Period D shall finish no less than 3 h before the nominal centre of the current **defrost and recovery period** (Δt_{D1} ≥ 3 h).

d) Period F shall start no less than 3 h after the nominal centre of the **defrost and recovery period** (Δt_{F1} ≥ 3 h).

e) The spread of temperature for Periods D and F shall be less than 0,5 K for each **compartment**.

f) The spread of power for Periods D and F shall be less than 2 % or less than 1W, whichever is the greater value.

g) The ratio of the total length of Period D (in hours) to the total length of Period F (in hours) shall be in the range 0.8 to 1.25 where **temperature control cycles** are present.

h) The start of any selected Period D shall be no less than 5 h after the initiation of the previous defrost heater on or, in the case where there is no defrost heater, no less than 5 h after the interruption of the refrigeration system related to the **automatic defrost**.

i) The end of any selected Period F shall not be after the initiation of the subsequent **defrost and recovery period**.

NOTE In this case, spread is the difference between the average values for Period D and F. Refer to B.3.1 for more information on the term spread.

Where the initially selected Period D and Period F do not comply with the acceptance criteria specified above, the minimum length for Periods D and F shall both be increased in steps of 1 **temperature control cycle** (in 1 h steps where there are no **temperature control cycles** or where fixed time slices are used) to see if there are any possible complying periods with Δt_{D1} and Δt_{F1} set to a minimum of 3 h.

Where it is not possible to find complying periods D and F (e.g. because the **defrost and recovery period** is long), the minimum size of interval Δt_{D1} and Δt_{F1} (see points c) and d) above) shall be increased in 30 min steps and validity for varying sizes of Periods D and F reassessed for each increase.

Where the size of Periods D and F are increased or the length of Δt_{D1} and Δt_{F1} increased, the first valid value using the sequence specified above shall be used.

Where no complying selections for Periods D and F can be found using the above sequence, the distance from the initiation of the defrost heater or, in the case where there is no defrost heater, after the interruption of the refrigerating system related to the **automatic defrost**, to the nominal centre of the **defrost and recovery period** may be adjusted from the default value of 2 h. The adjusted value shall not be less than 1 h and not more than 4 h and shall be a multiple of 30 min.

EXAMPLE If the distance from the start of the **defrost and recovery period** to the nominal centre of the **defrost and recovery period** was set to 3 h in order to obtain complying data (because the **defrost and recovery period** was long), the **defrost and recovery period** is considered to start at the same time as before but the nominal centre of the **defrost and recovery period** is set at 1 h later.

Where any non-standard parameters are used to select Periods D and F (i.e. they vary from the requirements specified in C.3.1), then this shall be noted in the test report.

Where there are more than two **compartments**, assessment of temperature stability as set out above is required for:

- The largest **unfrozen compartment** and largest **frozen compartment** (where applicable), or
- The largest two **compartments** (where all **compartments** are **frozen** or **unfrozen**).

In cases where there is no **steady state** operation between defrosts, it may not be possible to ever confirm the validity of the **defrost and recovery period** by examining symmetrically placed Periods D and F. An alternative approach (DF2) to deal with such cases is outlined in Annex K, but this should only be used if compliance with Clause C.3 can not normally be achieved.

C.3.3 Case DF1 calculation of values

Where the acceptance criteria in C.3.2 have been met, the determination of additional energy associated with each **defrost and recovery period** is calculated as set out below.

$$\Delta E_{dfj} = (E_{end-F} - E_{start-D}) - \frac{(P_{SS-D} + P_{SS-F})}{2} \times (t_{end-F} - t_{start-D}) \qquad (19)$$

where

ΔE_{dfj}	is the additional energy consumed by the **refrigerating appliance** for **defrost and recovery period** j in Wh
$E_{start-D}$	is the accumulated energy reading at the start of Period D in Wh
E_{end-F}	is the accumulated energy reading at the end of Period F in Wh
P_{SS-D}	is the **average power consumption** for Period D in W
P_{SS-F}	is the **average power consumption** for Period F in W
$t_{start-D}$	is the test time at the start of Period D in h
t_{end-F}	is the test time at the end of Period F in h

NOTE In the above equation, the power for Period D and the power for Period F are averaged. A time weighted average for both periods is not used.

The determination of the temperature change in each **compartment** i associated with the **defrost and recovery period** j is calculated as follows:

$$\Delta Th_{dfj-i} = (t_{end-F} - t_{start-D}) \times \left[(T_{av-startD-endF-i}) - \frac{(T_{av-D-i} + T_{av-F-i})}{2} \right] \quad (20)$$

where

$\Delta Th_{dfj\text{-}i}$	is the accumulated temperature difference over time in **compartment** i (for 1 to n **compartments**) associated with **defrost and recovery** in Kh (note that this term may be positive or negative) for **defrost and recovery period** j
$T_{av\text{-}startD\text{-}endF\text{-}i}$	is the time weighted average temperature in **compartment** i over the period from the start of Period D to the end of Period F in degrees C (including the **defrost and recovery** temperature impacts)
$T_{av\text{-}D\text{-}i}$	is the average temperature in **compartment** i that occurs during Period D in degrees C
$T_{av\text{-}F\text{-}i}$	is the average temperature in **compartment** i that occurs during Period F in degrees C
$t_{start\text{-}D}$	is the test time at the start of Period D in h
$t_{end\text{-}F}$	is the test time at the end of Period F in h.

For products with a compressor run time defrost controller, the additional compressor run-time associated with **defrost and recovery period** j (over and above the **steady state** run time) (in hours) is calculated as follows:

$$\Delta t_{drj} = (Rt_{end-F} - Rt_{start-D}) - \frac{\left[(Rt_{end-F} - Rt_{start-F}) + (Rt_{end-D} - Rt_{start-D})\right]}{(t_{end-F} - t_{start-F}) + (t_{end-D} - t_{start-D})} \times (t_{end-F} - t_{start-D}) \quad (21)$$

where

Δt_{drj}	is the additional compressor run time associated with **defrost and recovery period** j in h (over and above the **steady state** compressor run time that would have occurred)
$Rt_{start\text{-}D}$	is the total accumulated compressor run time (on period) at the start of period D in h
$Rt_{start\text{-}F}$	is the total accumulated compressor run time (on period) at the start of Period F in h
$Rt_{end\text{-}D}$	is the total accumulated compressor run time (on period) at the end of Period D in h
$Rt_{end\text{-}F}$	is the total accumulated compressor run time (on period) at the end of Period F in h
$t_{start\text{-}D}$	is the test time at the start of the Period D in h
$t_{start\text{-}F}$	is the test time at the start of the Period F in h
$t_{end\text{-}D}$	is the test time at the end of the Period D in h
$t_{end\text{-}F}$	is the test time at the end of the Period F in h.

Care is required not to count defrost heater on time as compressor on time in these calculations (although it is possible that some controllers include the defrost heater operation as run time – each product should be checked to see how it is configured). The value of Δt_{dr} could be zero or negative for continuously running products.

C.4 Number of valid defrost and recovery periods

For Case DF1 and Case DF2 the minimum number of valid **defrost and recovery periods** required for each ambient test temperature in order to calculate a representative value for **defrost and recovery** energy and temperature change is specified below:

Option 1: A valid value of ΔE_{df} shall be determined for each **temperature control setting** used for an energy determination on a single appliance in accordance with 6.8.2 and 6.8.3. The **defrost and recovery period** selected for each **temperature control setting** shall be adjacent to the **steady state** period used for energy determination in Annex B (this may occur before or after the **steady state** period for Case SS1; it shall be before the **steady state** period for Case SS2). The representative value for ΔE_{df} for the appliance shall be the average of all valid values for test points used for energy determination.

Option 2: Where there is more extensive data available for a particular model (either through longer tests or tests on several units of the same model), then the representative value for ΔE_{df} for the appliance shall be the average of at least 4 valid values. In this case at least 50 % of all values of ΔE_{df} shall have the coldest **compartment** at or below **target temperature**. A separate value for ΔE_{df} shall be determined for each **ambient temperature**.

Subject to regional regulations and requirements, Option 1 or 2 may be used.

C.5 Calculation of representative defrost energy and temperature

Calculations of a representative value for **defrost and recovery** energy and **defrost and recovery** temperature changes are given as follows:

$$\Delta E_{df} = \frac{\sum_{j=1}^{m} \Delta E_{dfj}}{m} \tag{22}$$

where

ΔE_{df} is the representative incremental energy for **defrost and recovery** for the test **ambient temperature**

m is the number of valid **defrost and recovery periods** specified in C.4

ΔE_{dfj} is the incremental energy for each **defrost and recovery period** j (from 1 to m)

$$\Delta Th_{df-i} = \frac{\sum_{j=1}^{m} \Delta Th_{dfj-i}}{m} \tag{23}$$

where

ΔTh_{df-i} is the representative temperature difference for **defrost and recovery** in **compartment** i (from 1 to n) for the test **ambient temperature**

m is the number of **defrost and recovery periods** specified in C.4

ΔTh_{dfj-i} is the accumulated temperature difference over time for each **defrost and recovery period** j (from 1 to m) in **compartment** i (from 1 to n)

For products with a compressor run time defrost controller, the representative additional compressor run-time associated with **a defrost and recovery period** is calculated as follows:

$$\Delta t_{dr} = \frac{\sum_{j=1}^{m} \Delta t_{drj}}{m} \tag{24}$$

where

Δt_{dr} is the representative additional compressor run-time associated with **a defrost and recovery period** for the test **ambient temperature**

m is the number of valid **defrost and recovery periods** specified in C.4

Δt_{drj} is the additional compressor run-time associated with **defrost and recovery period** j (from 1 to m)

Annex D
(normative)

Defrost interval

D.1 General

This Annex specifies the method to be used to determine the **defrost interval** for **refrigerating appliances** where there are one or more **defrost control cycles.**

The three main types of defrost controllers are as follows:

- Elapsed time – the **defrost interval** is largely independent of ambient conditions or the load on the refrigeration system. These types are less common and the controls for them may be mechanical or electronic.
- Compressor run time – the **defrost interval** is dependent on the hours of operation of the compressor (i.e. a proxy for the load in the refrigeration system). These are relatively common and controllers for these are usually mechanical and only operate effectively where a single speed compressor is used.
- Variable – the **defrost interval** is adjusted under **normal use** by an automatic process that uses an operating condition variable (or variables) other than, or in addition to, elapsed time or compressor run time in order to better match the frost load on the **evaporator** arising from **normal use**. These types are now common and controls for these are usually electronic.

NOTE A defrost controller that directly measures the frost load on the **evaporator** is classified as a **variable defrost** controller.

The intent of this Annex is to establish the basis for operation of the defrost control and to then determine a representative **defrost interval** for each **ambient temperature**. In the case of compressor run time controllers, the **defrost interval** will also be partly affected by the **temperature control setting** when testing at a specified **ambient temperature**. The value determined in accordance with this Annex is then used for the determination of **energy consumption** in accordance with Clause 6.

D.2 Elapsed time defrost controllers

For these controllers, the **defrost interval** remains relatively fixed (in hours) under a wide range of operating conditions. While these types of controls are fairly unusual, they are found in some markets. In most cases the **defrost interval** is less than 24 h.

If the elapsed time controller is accessible, direct measurements may be undertaken in order to determine the actual elapsed time value of the controller. Acceptable tests to directly determine the elapsed time defrost controller period include:

- Direct measurement of the operation of the controller in the product (e.g. measurement of time that voltage is present)
- Operating the run time controller on the bench when removed from the product.

The value marked on an elapsed time controller may not be relevant, for example if a controller is **rated** at 60 Hz and the product operates on 50Hz. Elapsed time controllers of the same **rated** value can vary, but as they are generally a synchronous motor that operates on mains frequency, each controller should be very consistent once the interval has been determined.

If the elapsed time controller is not accessible (or where it is not clear whether the controller is an elapsed time controller) or where the laboratory is not able to directly measure the controller operation, the value shall be estimated by testing as set out below. Sufficient data shall be collected during tests in accordance with Annex B and C in order to establish a representative average **defrost interval** as set out below. Initially a **defrost interval** is determined for a single test condition, which can be taken at any **ambient temperature** and any **temperature control setting**. At least two additional **defrost intervals** are then determined at other **ambient temperatures** and/or **temperature control settings**. Values for at least three **defrost intervals** shall be determined, with at least one value at an **ambient temperature** of 16 °C and one value at an **ambient temperature** of 32 °C.

Irrespective of whether the time of the elapsed time defrost controller is directly measured or determined via a whole product test, some additional testing should be undertaken at other **ambient temperatures** and/or **temperature control settings**. During these tests the **refrigerating appliance** may be subjected to some user related loads such as door openings and small **processing load**s during these tests. The observed **defrost interval** should be consistent with the measured elapsed time, otherwise it shall be classified as a **variable defrost** controller.

NOTE 1 These tests are to detect whether the elapsed time controller is over-ridden by some other control mechanism during **normal use** conditions.

To qualify as an elapsed time controller, the coefficient of variation (standard deviation divided by the mean) of all measured **defrost intervals** shall be less than 10 % for the three or more **defrost intervals** determined. Where the product does not comply with this requirement, it shall be classified as a **variable defrost** controller.

Care is required to determine whether or not the elapsed time controller advances while the defrost heater is activated – this can depend on individual product design.

NOTE 2 The same timers could be used as used as compressor run time controllers or as elapsed time controllers, depending on how they are configured in the **refrigerating appliance**.

D.3 Compressor run time defrost controllers

For these controllers, the **defrost interval** is defined by the compressor run time alone (or in some cases compressor run time plus time for defrost heater operation). For these controllers, a single speed compressor is used. The **defrost interval** is therefore approximately inversely proportional to the total heat load on the refrigeration system (**ambient temperature** and user loads). The most common defrost run time defrost controllers range from 6 h to 12 h of compressor run time (typically this would result in **defrost intervals** of the order of 12 to 30 h (elapsed time) at elevated **ambient temperatures** and somewhat longer at lower **ambient temperatures**).

If the run time controller is accessible, direct measurements may be undertaken in order to determine the actual run-time value of the controller. Acceptable tests to directly determine the run time defrost controller period include:

- Direct measurement of the operation of the controller in the product (e.g. measurement of time that voltage is present)
- Operating the run time controller on the bench when removed from the product.

The value marked on a compressor run time controller may not be relevant, for example if a controller is **rated** at 60 Hz and the product operates on 50 Hz. Run time controllers of the same **rated** value can vary, but as they are generally a synchronous motor that operates on mains frequency, each controller should be very consistent once the interval has been determined.

NOTE 1 The same timers could be used as used as compressor run time controllers or as elapsed time controllers, depending on how they are configured in the **refrigerating appliance**.

If the run time controller is not accessible (or where it is not clear whether the controller is a run time controller) or where the laboratory is not able to directly measure the controller operation, the value shall be estimated by testing as set out below.

Tests shall be undertaken over a whole **defrost control cycle**, at least one at each **ambient temperature**, in order to verify that it is a run time controller and estimate the value of Δt_{rt}. The period selected shall comply with the following requirements:

- The first defrost shall qualify as a valid defrost as specified in C.3
- The test period shall include at least part of the subsequent **defrost and recovery period** that is initiated automatically without any intervention
- The **temperature control settings** are not changed during the test period
- The appliance is not subjected to any **processing load** or door openings during the test period.

The estimated run time of the compressor run time defrost controller for a given set of test data that complies with these requirements is given by:

$$\Delta t_{rtj} = \Delta t_{crtj} + \Delta t_{dhj} \quad (25)$$

where

Δt_{rtj} is the estimated run time of the compressor run time defrost controller for the test period starting with **defrost and recovery period** j in h

Δt_{crtj} is the measured compressor run time in h from the initiation of **defrost and recovery period** j to the initiation of the subsequent **defrost and recovery period** $j + 1$

Δt_{dhj} if the timer advances during **defrost and recovery period** j, the time in h from when the compressor stops until it restarts during that **defrost and recovery period**; otherwise if the timer does not advance during the **defrost and recovery period**, a value of zero.

Care is required to determine whether or not the compressor run time controller advances while the defrost heater is activated – this can depend on individual product design. If the controller is accessible, this can be checked by measuring the voltage at the run time controller motor while the defrost heater is activated.

Irrespective of whether the run time of the compressor run time defrost controller is directly measured or determined via a whole product test, some additional testing should be undertaken at other **ambient temperatures** and/or **temperature control settings**. During these tests the **refrigerating appliance** may be subjected to some user related loads such as door openings and small **processing load**s during these tests. The observed **defrost interval** should be consistent with the measured run time, otherwise it shall be classified as a **variable defrost** controller.

NOTE 2 These tests are to detect whether the run time controller is over-ridden by some other control mechanism during **normal use** conditions.

Where the value of the run time of the compressor run time defrost controller is directly measured, the measured value of Δt_{rt} shall be used in subsequent calculations.

Otherwise, to qualify as a compressor run time defrost controller, the coefficient of variation (standard deviation divided by the mean) of the estimated values for compressor run time Δt_{rtj} shall be less than 10 % for the **defrost intervals** examined. Where the product does not comply with this requirement, it shall be classified as a **variable defrost** controller. Where the run time is estimated, the value of Δt_{rt} used in subsequent calculations shall be the average of all measured values.

Once confirmed, this value can be used to calculate the actual **defrost interval** for any **temperature control setting**, **ambient temperature** and load processing condition, as a function of the compressor run time. For all **refrigerating appliances** with compressor run time defrost controllers, the percentage run time shall be reported for **steady state** conditions in Annex B and the extra compressor run time (in hours) shall be calculated for **defrost and recovery periods** (in Annex C).

The **defrost interval** for each test condition and **temperature control setting** is given by:

$$\Delta t_{df} = \frac{\Delta t_{rt} - \Delta t_{dr} - \Delta t_{dh}}{CRt_{SS}} + \Delta t_{dxy} \tag{26}$$

where

Δt_{df} is the estimated **defrost interval** (elapsed time) for each **temperature control setting** and **ambient temperature** under test in hours, including the impact of **defrost and recovery**

Δt_{rt} is the stated, measured or estimated run time of the compressor run time defrost controller (in hours)

CRt_{SS} is the compressor run time (as a percentage) during the **steady state** operation for each **temperature control setting** and **ambient temperature** under test as determined in B.3.3 or B.4.3

Δt_{dr} is the representative incremental compressor run time (in hours) for **defrost and recovery** in accordance with Annex C (Clause C.5)

Δt_{dh} is a representative defrost heater on time in h during a **defrost and recovery period** where the timer advances when the defrost heater is operating, otherwise a value of zero

Δt_{dxy} is equal to Δt_{dh} where this is greater than zero, otherwise a representative compressor off time during a **defrost and recovery period**.

D.4 Variable defrost controllers

D.4.1 General

For this type of controller, the **defrost interval** is varied in proportion to the frost load on the **evaporator**. Most systems do not measure the frost load on the **evaporator** directly (but this is possible), so these types of systems are usually controlled by software which uses a number of parameters to indirectly estimate the frost load and adjust the **defrost interval** progressively. After the operation of the defrost heater, the system looks backwards at the relevant parameters during the previous usage period and adjusts the next **defrost interval**, if required, to optimise it and hence minimise the extra energy associated with defrosting. The product therefore may go through a learning sequence during test which progressively adjusts the **defrost interval**.

The intent of Clause D.4 is to estimate a representative **defrost interval** during **normal use** based on a range of parameters declared by the supplier.

Variable defrost controls should have available a range of possible **defrost intervals** that reflect the frost build up on the **evaporator**. If the **defrost interval** is consistently too short, energy is wasted. If the **defrost interval** is too long, the system may have increased **energy consumption** due to the poor heat transfer on the frosted-up **evaporator** and may even have problems removing all frost from the **evaporator**, leading to long term ice accumulation and performance degradation.

For a product to qualify as **variable defrost** under this standard, the **defrost interval** shall vary over a continuum of values (or a significant number of steps, appropriately spaced) that reflect the frost load on the **evaporator** when subjected to a range of actions associated with **normal use**, subject to any learning period for the **variable defrost** controller.

Variable defrost is a defined term in this standard. Products with defrost controls that exhibit significantly different characteristics during **normal use** from those exhibited under comparable test conditions may be considered to have circumvention devices.

D.4.2 Variable defrost controllers – declared defrost intervals

For the purposes of this standard, the **defrost interval** for these types of controllers is based on a calculation, which is a function of the declared shortest possible **defrost interval** and the declared longest possible **defrost interval** at an **ambient temperature** of 32 °C.

The defrost interval for a variable defrost system is given by:

$$\Delta t_{df32} = \frac{\Delta t_{d-max} \times \Delta t_{d-min}}{[0{,}2 \times (\Delta t_{d-max} - \Delta t_{d-min}) + \Delta t_{d-min}]} \tag{27}$$

where

Δt_{df32} is the **defrost interval** for an **ambient temperature** of 32 °C

Δt_{d-max} is maximum possible **defrost interval** at an **ambient temperature** of 32 °C as specified by the manufacturer, in hours of elapsed time

Δt_{d-min} is minimum possible **defrost interval** at an **ambient temperature** of 32 °C as specified by the manufacturer, in hours of elapsed time

The following limits are placed on the input variable Δt_{d-max} and Δt_{d-min}, irrespective of instructions:

- Δt_{d-min} is normally greater than 6 h and shall not exceed 12 h at an **ambient temperature** of 32 °C (elapsed time).
- Δt_{d-max} shall not exceed 96 h at an **ambient temperature** of 32 °C (elapsed time).

  Δt_{d-max} shall be greater than Δt_{d-min} at an **ambient temperature** of 32 °C.

The basis for the claim of the minimum possible **defrost interval** Δt_{d-min} shall be the shortest conceivable **defrost interval** under heavy usage conditions (i.e. heavy use, frequent door openings and high humidity) at an **ambient temperature** of 32 °C. Tests under heavy usage conditions to verify the claimed value may be undertaken. The value claimed for the maximum possible **defrost interval** Δt_{d-max} shall be achievable under test conditions with all **compartment** temperatures at or below **target temperatures** in **steady state** (see Annex B) at an **ambient temperature** of 32 °C. Manufacturers shall specify any special conditions required to achieve the claimed value.

Testing at other **ambient temperatures** and with some **processing load** (e.g. door openings) may be undertaken to verify that the defrost controller operates over a continuum of values, or a significant number of steps, appropriately spaced.

The value for Δt_{df16} at an **ambient temperature** of 16 °C shall be double the value of Δt_{df32}.

D.4.3 Variable defrost controllers – no declared defrost intervals (demand defrost)

Where a system is **variable defrost** but where no values for Δt_{d-max} and Δt_{d-min} can be declared by the manufacturer because the defrost controller has a form of demand defrost that directly measures the frost thickness on the **evaporator**, the default values are:

- Δt_{d-min} is 6 h at an **ambient temperature** of 32 °C (elapsed time).
- Δt_{d-max} is 96 h at an **ambient temperature** of 32 °C (elapsed time).

This gives a default value for Δt_{df32} of 24 h and Δt_{df16} of 48 h in Formula (27) and D.4.2 for **variable defrost** controllers that are of the demand defrost type.

NOTE This calculation procedure is used even though the system initiates a defrost solely on the amount of frost built up on the **evaporator** (rather than the use of a timing algorithm).

To qualify as a demand defrost system, the defrost controller shall operate over a continuum of **defrost intervals** in response to changes in the frost load. To qualify for the use of these values, suppliers may be asked to supply technical information on how the demand defrost system operates.

D.4.4 Variable defrost controllers – non compliant

Where a system is nominally **variable defrost** but where:

- no values for $\Delta t_{d\text{-}max}$ and $\Delta t_{d\text{-}min}$ have been provided/stated by the manufacturer and there is no evidence that the controller is demand defrost, or
- a product does not comply with the requirements for a **variable defrost** controller because it does not operate over a continuum of **defrost intervals** (or does not have a significant number of steps, appropriately spaced), or
- the declared values are found to be inconsistent with tested values.

In this case the values for Δt_{df32} and Δt_{df16} are:

- Δt_{df32} is the average of 3 observed **defrost intervals** at an **ambient temperature** of 32 °C with not more than one door opening per hour, but not exceeding 10,0 h
- Δt_{df16} is the average of 3 observed **defrost intervals** at an **ambient temperature** of 16 °C with not more than one door opening per hour, but not exceeding 20,0 h.

Annex E
(normative)

Interpolation of results

E.1 General

This Annex specifies the methods that shall be used where two or more results are interpolated in order to estimate a more optimum value of **energy consumption** that would occur if all the **compartments** had been at or below the **target temperatures** specified in Clause 6.

NOTE Interpolation is optional under this standard. A valid value for **energy consumption** can be determined from a single test run with all **compartments** at or below the specified **target temperatures** as specified in 6.3 a).

Two cases for interpolation are permitted in this standard:

- Case 1: linear interpolation between two test points, generally where one **user-adjustable temperature control** is adjusted (more than one control may be adjusted, but in this case there are special checks as set out in Clause E.3).
- Case 2: triangulation using three (or more) test points, where two (or more) **user-adjustable temperature controls** are adjusted.

Both Case 1 and Case 2 have validity requirements associated with them.

The objective of interpolation is to estimate the most optimum **energy consumption** using the information from the test points selected for analysis (the measured energy and **compartment** temperatures). Where there are additional controls that are not used for interpolation, then it may be possible that the resulting estimate of **energy consumption** may not be the most optimum possible. As a general recommendation, **user-adjustable temperature controls** that affect the **compartments** with the largest **volume** or the **compartment** that is the coldest should be used for interpolation in order to obtain the most optimum value for **energy consumption** (the temperature of the largest or coldest **compartment** tends to dominate the **energy consumption**). Where there are two or more **user-adjustable temperature controls** that affect two or more **compartments**, triangulation under Case 2 will generally provide a more optimum estimate of **energy consumption** than linear interpolation under Case 1.

Special conditions apply to the use of both Case 1 and Case 2. These are specified in Clause E.3 and Clause E.4 respectively. Extrapolation to estimate energy values at the **target temperature** where that point does not lie between or enclose the test points selected is not permitted.

Where interpolation is used, the following additional information shall be reported:

- Where results have been measured at two **temperature control settings** for interpolation in accordance with Clause E.3, the **compartment** that is used for interpolation (where interpolation gives a valid result) and the energy-temperature slope of that **compartment** S_i as defined in E.3.3;
- Where results of a product with two **user-adjustable temperature controls** have been measured at three **temperature control setting** combinations for interpolation in accordance with Clause E.4, the value of the coefficients E_0, A and B (or equivalent);
- Where results of a product with three **user-adjustable temperature controls** have been measured at four **temperature control setting** combinations for interpolation in accordance with Clause E.4, the value of the coefficients E_0, A, B and C.

E.2 Temperature adjustment prior to interpolation

Where a **refrigerating appliance** has one or more defrost systems (each with its own **defrost control cycle**), the average **compartment** temperature shall be determined in accordance with Formula (3) taking into account the impact of all defrost systems, prior to interpolation.

Calculate the daily **energy consumption** and average temperature in each **compartment** as set out in 6.8.2 for each test point. These resulting values are then used in the interpolation between test points.

E.3 Case 1: linear interpolation – two test points

E.3.1 General

This Clause sets out the method for determining a value of **energy consumption** of a **refrigerating appliance** by interpolation between the results of two test runs where the setting of one or more **user-adjustable temperature controls** are adjusted. The controls adjusted may affect the temperatures of several **compartments** at the same time, so each possible combination shall be checked for validity. Interpolation is performed mathematically.

The value determined by this method is an approximation of the value that would be obtained when the control(s) concerned is (are) adjusted to a setting that brings the temperatures of the **compartments** affected as close as possible to, while not above, the specified **target temperatures** for the **compartment** types for all **compartments**. Where the temperature in several **compartments** change together, the point selected for interpolation is where the first one reaches its **target temperature** (moving from colder to warmer settings).

E.3.2 Requirements

Linear interpolation using results for only two test runs may be undertaken where at least one **compartment** has one test point with a measured temperature that lies above the relevant **target temperature** while the other test point lies below the relevant **target temperature**. During the process of interpolation for two test runs, the temperature in all **compartments** is calculated as each **compartment**, in turn, is set to its **target temperature**. For interpolation to be valid, all **compartments** shall be at or below the **target temperature** at the point of interpolation.

For linear interpolation to be valid, the temperature difference between test runs in each **compartment** used for interpolation shall not exceed 4 K.

For linear interpolation, there are in principle no specific requirements to the relative position of the test points used for interpolation. In all cases, the point of interpolation shall lie between the two measured values for all parameters (energy and temperature). Extrapolation is not permitted under any circumstances. This means that not all combinations of two test points may provide a valid interpolation result. It is therefore good and prudent practice to select one test point with all **compartments** below their **target temperature**. This will ensure a valid result for linear interpolation where a second point is selected with at least some **compartments** temperatures above their **target temperature**.

E.3.3 Calculations

The general approach used for this method of interpolation is to interpolate each **compartment** at its **target temperature** and then to calculate the temperature at that point in all the remaining **compartments**. This process is then applied in turn to each additional **compartment**. The results when each **compartment** is at its **target temperature** are then reviewed and valid interpolation points can be selected where all **compartments** are at or below the **target temperature** for the particular interpolation point.

It is useful to plot the interpolation procedure to better understand the calculation approach. An example is shown in Figure E.1 for a cabinet with four **compartments** with a single result. Figure E2 illustrates an example with two valid values for interpolation while Figure E.3 illustrates an example with no valid values for interpolation.

The following calculation process shall be performed for each **compartment** i, where i runs from letter A, B, C etc. to n and n is the number of **compartments** for test Points 1 and 2.

1) Check that ABS(T_{i1} – T_{i2}) is 4 K or less. Where this condition is not met, linear interpolation is not permitted on this **compartment** (points may still be used if both T_{i1} and T_{i2} are below their **target temperature**).
2) Calculate the **compartment** interpolation factor f_i for each **compartment** as follows:

$$f_i = \frac{(T_{i-tar} - T_{i1})}{(T_{i2} - T_{i1})} \tag{28}$$

   Where

   T_{i1} is the measured temperature at test Point 1 in **compartment** i

   T_{i2} is the measured temperature at test Point 2 in **compartment** i

   $T_{i\text{-}tar}$ is the **target temperature** for **compartment** type i as set out in Table 1.

   In the case f_i is less than 0 or where f_i greater than 1, no valid interpolation on **compartment** i is possible with the combination of test Point 1 and 2. Another combination of test points may be required if T_{i1} and T_{i2} are not both below their **target temperature**.
3) Calculate for each of the other **compartments** 1 to j (from letter A, B, C to n) the interpolated temperature T_j, where **compartment** i is at its **target temperature** by:

$$T_j = T_{j1} + f_i \times (T_{j2} - T_{j1}) \tag{29}$$

   Where

   T_j is the interpolated temperature in **compartment** j when **compartment** i is at target

   T_{j1} is the measured temperature at test Point 1 in **compartment** j

   T_{j2} is the measured temperature at test Point 2 in **compartment** j

   f_i is **compartment** interpolation factor for **compartment** i
4) If all T_j values (from letter A, B, C to n) are at or below their respective target values ($T_j \leq T_{j\text{-}tar}$) then calculate the interpolated **energy consumption** where **compartment** i is at its **target temperature** by:

$$E_{i-tar} = E_1 + f_i \times (E_2 - E_1) \tag{30}$$

   Where

   $E_{i\text{-}tar}$ is the interpolated **energy consumption** from test Points 1 & 2 when **compartment** i is at its **target temperature**

   E_1 is the measured **energy consumption** at test Point 1 (**temperature control setting** combination 1)

   E_2 is the measured **energy consumption** at test Point 2 (**temperature control setting** combination 2)

   f_j is **compartment** interpolation factor for **compartment** i

After completion of the previous procedure for each **compartment** i there are three possibilities:

a) For none of the **compartments**, a valid interpolated **energy consumption** has been calculated. This means that Point 1 and 2 do not form a valid combination for interpolation and another combination of test points needs to be measured.

b) There is one valid interpolated **energy consumption** value found. This value represents the interpolated **energy consumption**.

c) There are two or more valid interpolated **energy consumption** values found. The minimum value of these represents the interpolated **energy consumption**:

$$E_{linear} = \min_{i=1}^{n}[E_{i-tar}] \tag{31}$$

Where

E_{linear} is the **energy consumption** determined by linear interpolation

$E_{i\text{-}tar}$ is the interpolated **energy consumption** for **compartment** i as given above (invalid values are ignored)

NOTE 1 Where one point has all **compartments** below their **target temperature** and the second point has all **compartments** above their **target temperature**, there can only be a single solution (possibility (b) above). Two solutions can occur, for example, when one point has **compartment** A below its **target temperature** and **compartment** B is above its **target temperature**, and where the second point has **compartment** A above its target and **compartment** B is below its target. The case of two (or more) valid solutions for linear interpolation of two points is relatively unusual. See examples in Annex I for a range of cases.

Where a valid value for interpolation E_{linear} is found using the above method, the following additional information shall be reported with the interpolated energy value:

- The **compartment** i that is used to give a valid value for $E_{i\text{-}tar}$ and E_{linear}
- The energy-temperature slope S_i of that **compartment** as given below.

$$S_i = \frac{(E_2 - E_1)}{(T_2 - T_1)} \tag{32}$$

NOTE 2 The value of S_i is normally negative, but this depends on the arrangement of test Points 1 and 2.

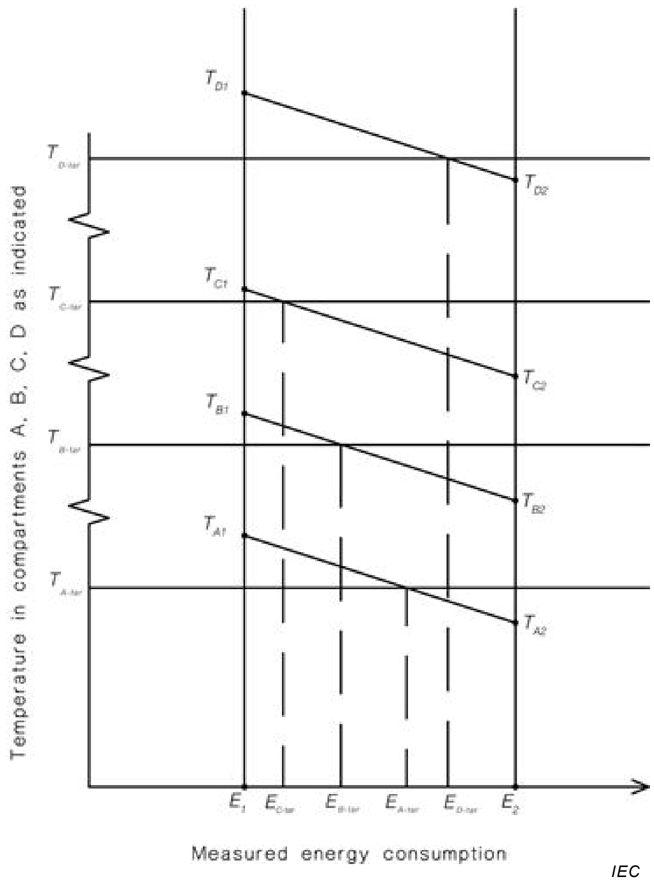


Figure E.1 – Interpolation where temperatures change in multiple compartments (compartment D critical)

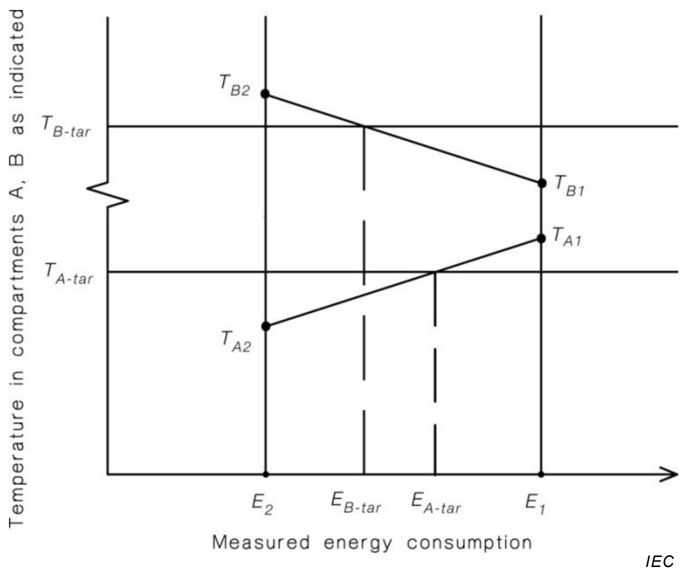


Figure E.2 – Interpolation with valid results in both Compartment A and B

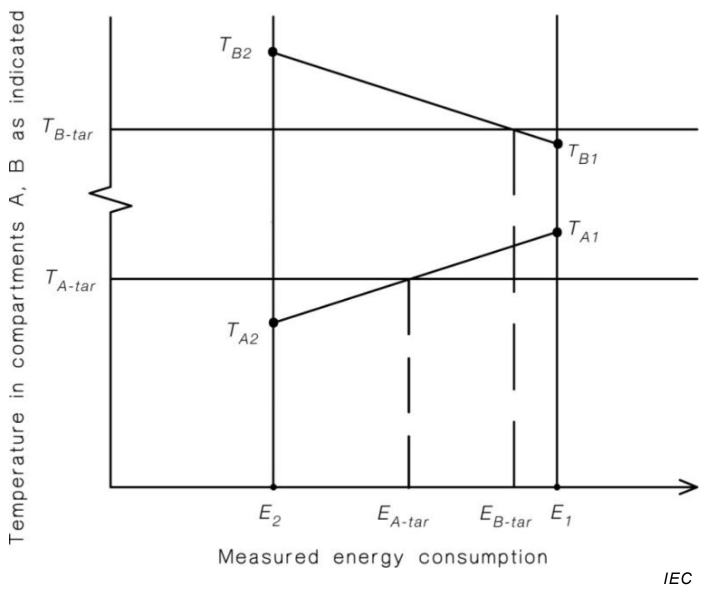


Figure E.3 – Interpolation with no valid results

E.4 Case 2: triangulation – three (or more) test points

E.4.1 General

This Clause sets out the method for determining a more optimum value of **energy consumption** of a **refrigerating appliance** by interpolation using triangulation of three (or more) test runs where the setting of two or more **user-adjustable temperature controls** are adjusted. The controls adjusted may affect the temperatures of several **compartments**, so each possible combination shall be checked for validity. Interpolation is performed mathematically.

The principle is that the three test points selected shall surround the intersection of the **target temperature** locus for both **compartments** being examined, called Point Q, which is the point where the optimum **energy consumption** will be obtained (for the two **compartments** in question). An estimate of the **energy consumption** at Point Q is obtained by a series of linear interpolations.

The value determined by this method is an approximation of the value that would be obtained when the two **compartments** concerned are adjusted to a setting that brings the temperatures of the **compartments** affected as close as possible to, while not above, the specified **target temperatures** for the **compartment** types (at Point Q).

Multi-dimensional triangulation can be performed on three or more **compartments** in a similar fashion, but the mathematics using manual interpolation (as set out in E.4.3) is complicated and is not documented in this standard. However, three or more **compartments** can be interpolated using matrices as set out in E.4.6. Generally, the improvement of the estimate of optimum energy is only small where three or four **compartments** are interpolated as the energy impact of smaller **compartments** usually becomes very small. The likely small improvements in optimum energy have to be weighed against the significant marginal cost obtaining 4 or 5 complying and suitable energy test points (which are required for interpolation on 3 and 4 **compartments** with independent **user-adjustable temperature controls** respectively).

E.4.2 Requirements for two (or more) compartment triangulation

E.4.2.1 General requirements

The temperature in each **compartment** used in interpolation shall lie within the range T_{tar} ±4 K for all **temperature control setting** combinations selected.

E.4.2.2 Triangulation for a refrigerating appliance with two compartments

The requirements for interpolation using triangulation on a **refrigerating appliance** with only two **compartments** (Case 2-0) are as follows:

a) The **refrigerating appliance** shall have two **user-adjustable temperature controls** that affect the temperature in two compartments.
b) There shall be a minimum of three **energy consumption** measurements (test points) at three combinations of the **temperature control settings** being adjusted.
c) The test points selected for analysis shall form a triangle which encloses the intersection of the **target temperatures** for those two **compartments** (see Figure E.4, Point Q, Formula (33)).

Where these conditions are met, triangulation in accordance with E.4.3 or E.4.4 shall be undertaken.

To verify that Point Q lies inside the triangle enclose by the three test points, the following values *Check1* and *Check2* are calculated:

$$\begin{aligned} Check\,1 = {} & [(T_{B-tar} - T_{B1}) \times (T_{A2} - T_{A1}) - (T_{A-tar} - T_{A1}) \times (T_{B2} - T_{B1})] \times \\ & [(T_{B-tar} - T_{B2}) \times (T_{A3} - T_{A2}) - (T_{A-tar} - T_{A2}) \times (T_{B3} - T_{B2})] \end{aligned}$$

$$\begin{aligned} Check\,2 = {} & [(T_{B-tar} - T_{B2}) \times (T_{A3} - T_{A2}) - (T_{A-tar} - T_{A2}) \times (T_{B3} - T_{B2})] \times \\ & [(T_{B-tar} - T_{B3}) \times (T_{A1} - T_{A3}) - (T_{A-tar} - T_{A3}) \times (T_{B1} - T_{B3})] \end{aligned}$$

where

T_{A1} is the measured temperature at test Point 1 in **Compartment** A

T_{A2} is the measured temperature at test Point 2 in **Compartment** A

T_{A3} is the measured temperature at test Point 3 in **Compartment** A

$T_{A\text{-}tar}$ is the **target temperature** for **Compartment** A

T_{B1} is the measured temperature at test Point 1 in **Compartment** B

T_{B2} is the measured temperature at test Point 2 in **Compartment** B

T_{B3} is the measured temperature at test Point 3 in **Compartment** B

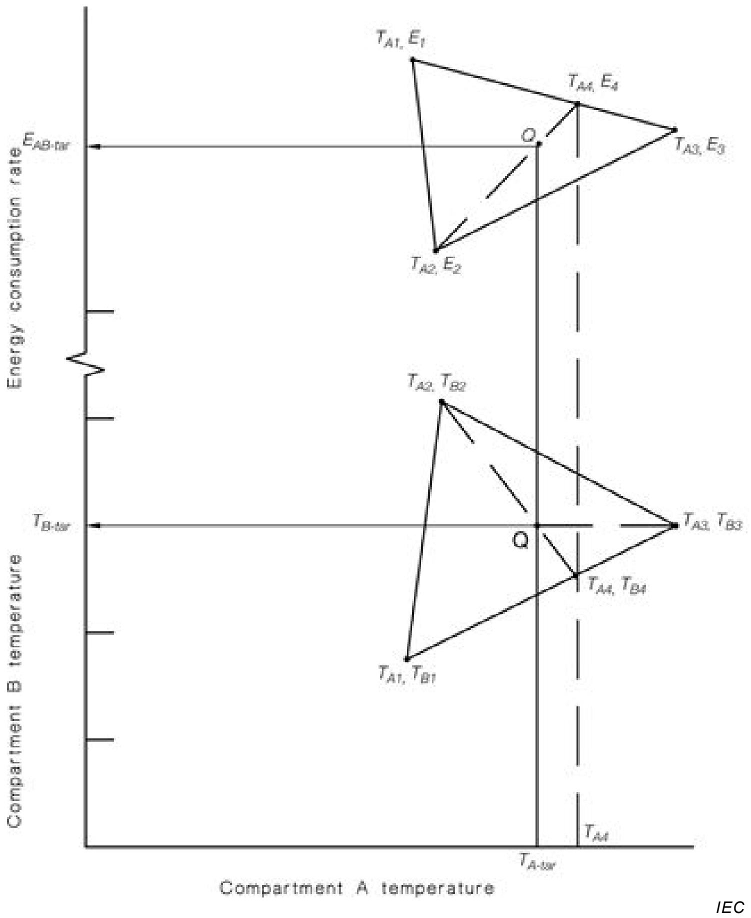
$T_{B\text{-}tar}$ is the **target temperature** for **Compartment** B

Point Q lies within the triangle formed by Points 1, 2 and 3 if the following inequality is true:

$$\text{IF } \{[Check1 \geq 0] \text{ AND } [Check2 \geq 0]\} = \text{TRUE} \qquad (33)$$

NOTE This verification procedure is based on the Barycentric coordinate system. It is recommended that these equations be entered into a spreadsheet for regular use to avoid errors. A value of 0 for *Check1* or *Check2* indicates that the Point Q lies exactly on one of the triangle sides and that linear interpolation could yield the same result with less data.

Plotting the test values with the two **compartment** temperatures on the orthogonal axes is recommended and is a useful way of quickly checking that the **target temperature** (Point Q) is within the triangle formed by the three test points. Where any doubt exists, the mathematical validity set out in Formula (33) takes precedence over any graphical verification procedure.



NOTE Calculation of values for Point 4 is only required in the case of manual interpolation on 2 **compartments**.

Figure E.4 – Schematic representation of interpolation by triangulation

E.4.2.3 Triangulation for a refrigerating appliance with more than two compartments

Where there are more than two **compartments** in a **refrigerating appliance**, there are several possible cases that may apply, depending on the product configuration, the **temperature control setting** combinations selected and the data available.

Case 2-0: Three test points, triangulation on two compartments

See E.4.2.2.

Case 2-1: Three test points, triangulation on two compartments, additional compartments always below target temperature

Where three test points have been selected such that two of the **compartments** meet the requirements of E.4.2.2 and the temperature of all additional **compartments** remain at or below **target temperature** for all three test points, then triangulation in accordance with E.4.2.2 shall be used and no further checks are required.

Case 2-2: Three test points, triangulation on two compartments, additional compartments not always below target temperature

Where three test points have been selected such that two of the **compartments** meet the requirements of E.4.2.2 but the temperature of one or more additional **compartments** does not remain below **target temperature** for all three test points, then the following procedure shall be undertaken:

a) There shall be three **energy consumption** measurements (test points) at three combinations of the **temperature control settings** being adjusted; and.

b) The test points for the **compartments** selected for triangulation shall form a triangle which encloses the intersection of the **target temperatures** (see Figure E.4, Point Q, Formula (33)); and

c) Triangulation of the **compartments** selected shall be in accordance with E.4.4; and

d) The calculated temperature of all additional **compartments** at Point Q are at or below their relevant **target temperature** as specified in E.4.5 (the temperature in **Compartment** C, D etc. is calculated at Point Q and checked).

Where the above requirements are not met, the following options may yield complying results from the available data:

e) Select different **compartment** combinations for triangulation and check that the calculated temperature of all additional **compartments** at Point Q are at or below **target temperature** in accordance with a) to d) above; or

f) Undertake additional testing to obtain more test data that complies with the requirements of Case 2-1 or Case 2-2; or

g) Undertake linear interpolation in accordance with E.3 for each pair of test points. Where more than one valid result can be obtained using this approach, the minimum value may be selected. While linear interpolation may yield a valid result, this may not be close to the optimum energy (depending on the available data).

Case 2-3: Four test points, triangulation on three compartments, no additional compartment(s) or additional compartment(s) always below target

Where four test points have been selected such that three **compartments** meet the following requirements:

h) The **refrigerating appliance** shall have three **user-adjustable temperature controls** that affect the temperature in three or more **compartments**; and

i) There shall be four **energy consumption** measurements (test points) at four combinations of the **temperature control settings** being adjusted; and

j) The test points selected for analysis shall form a three dimensional triangular pyramid which encloses the intersection of the **target temperatures** for those three **compartments**); and

k) Triangulation shall be performed using matrices as set out in E.4.6.

Case 2-4: Four test points, triangulation on three compartments, additional compartment(s) not always below target

Where four test points have been selected such that three **compartments** meet the following requirements:

l) The **refrigerating appliance** shall have three **user-adjustable temperature controls** that affect the temperature in three or more **compartments**; and

m) There shall be four **energy consumption** measurements (test points) at four combinations of the **temperature control settings** being adjusted; and

n) The test points selected for analysis shall form a three dimensional triangular pyramid which encloses the intersection of the **target temperatures** for those three **compartments**; and

o) The calculated temperature of all additional **compartments** at Point Q are at or below their relevant **target temperature** as specified in E.4.6 (the temperature in **Compartment** D, E etc. is calculated at Point Q and checked); and

p) Triangulation shall be performed using matrices as set out in E.4.6.

E.4.3 Calculations for two compartment triangulation – manual interpolation

The approach used for this method is to undertake a series of linear interpolations to estimate the **energy consumption** at Point Q, where both **compartments** are at their **target temperatures** for **energy consumption** (T_{tar}) as specified in Table 1. Test Points 1, 2 and 3 used for these calculations shall surround the intersection of the **target temperatures** (T_{tar}) for each **compartment**, called Point Q.

An alternative approach using matrices is set out in E.4.4. This does not require the calculation of values for Point 4.

Three steps are manually undertaken in this process:

- Step 1: Calculate the temperature of a new Point 4, which lies at the intersection of the line through Point 2 and Point Q and the line from Point 1 and Point 3.
- Step 2: Calculate the **energy consumption** at Point 4 by linear interpolation of energy between Point 1 and Point 3 (temperatures in **compartment** A or B may be used – **compartment** A has been used in the equations below).
- Step 3: Calculate the **energy consumption** at Point Q by linear interpolation of energy between Point 4 and Point 2 (temperatures in **compartment** A or B may be used – **compartment** A has been used in the equations below).

The calculations for these three steps are set out below.

The terms used in the following formulae are:

$T_{i\text{-}tar}$ **target temperature** in **compartment** i (temperature at Point Q)

T_{i1} temperature of Point 1 in **compartment** i (measured value)

T_{i2} temperature of Point 2 in **compartment** i (measured value)

T_{i3} temperature of Point 3 in **compartment** i (measured value)

T_{i4} temperature of Point 4 in **compartment** i (calculated value)

E_1 **energy consumption** measures at Point 1 (measured value)

E_2 **energy consumption** measures at Point 2 (measured value)

E_3 **energy consumption** measures at Point 3 (measured value)

E_4 **energy consumption** measures at Point 4 (calculated value)

Step 1

For two **compartments** A and B, the calculated temperature at Point 4 in **compartment** A is:

$$T_{A4} = \frac{\left[T_{B-tar} - \dfrac{T_{A-tar} \times (T_{B2} - T_{B-tar})}{(T_{A2} - T_{A-tar})} - T_{B1} + \dfrac{T_{A1} \times (T_{B3} - T_{B1})}{(T_{A3} - T_{A1})} \right]}{\left[\dfrac{(T_{B3} - T_{B1})}{(T_{A3} - T_{A1})} - \dfrac{(T_{B2} - T_{B-tar})}{(T_{A2} - T_{A-tar})} \right]} \tag{34}$$

Care is required if undertaking this calculation by hand. It is recommended to enter these equations into a spreadsheet. The spreadsheet can then be checked using the examples in Annex I before use on test data.

Normally, Formula (33) or a graphical approach is used to check that Point Q lies within the triangle formed by Points 1, 2 and 3. An alternative for manual interpolationcheck is to ensure that the **target temperature** $T_{A\text{-}tar}$ lies between T_{A2} and T_{A4} plus T_{A4} lies between T_{A1} and T_{A3}. Mathematically, this is represented by:

- $T_{A4} < T_{A\text{-}tar} < T_{A2}$ or
- $T_{A4} > T_{A\text{-}tar} > T_{A2}$

and

- $T_{A1} < T_{A4} < T_{A3}$ or
- $T_{A1} > T_{A4} > T_{A3}$

Step 2

The calculated **energy consumption** at Point 4 using temperature data for Point 4 calculated in Step 1 and test Points 1 and 3 is determined as follows (**compartment** A temperatures are used):

$$E_4 = E_1 + (E_3 - E_1) \times \frac{(T_{A4} - T_{A1})}{(T_{A3} - T_{A1})} \tag{35}$$

Step 3

The calculated **energy consumption** at the **target temperature** using temperature and energy data for Point 4 (calculated in Steps 1 and 2) and test Point 2 is determined as follows (**compartment** A temperatures are used):

$$E_{AB-tar} = E_2 + (E_4 - E_2) \times \frac{(T_{A-tar} - T_{A2})}{(T_{A4} - T_{A2})} \tag{36}$$

$E_{AB\text{-}tar}$ is the **energy consumption** at the **target temperature** of **compartments** A and B using triangulation.

The order of **compartments** A and B does not affect the calculations. Examples are set out in Annex I.

E.4.4 Calculations for two compartment triangulation – matrices

A more efficient mathematical approach to determine the optimum **energy consumption** using interpolation for 3 test points in E.4.3 (manual triangulation) is by the use of matrices. This allows a fast solution and the approach automatically determines the energy – temperature coefficients for each **compartment** (i.e. the energy impact per degree K internal temperature change for each **compartment**, yielding more useful information). This approach can also be used to solve multi-dimensional interpolation for three or more **compartments** as set out in E.4.6.

The first step is to confirm that the data meets the validity requirements for triangulation i.e. the intersection of **target temperatures** for **Compartment** A and **Compartment** B (Point Q) lies within the triangle formed by test Points 1, 2 and 3. This is done using Formula (33) as set out in E.4.2.2.

The basic premise for using matrices for triangulation on two **compartments** is to assume that we have 3 simultaneous equations to describe the 3 test points as follows:

$$E_0 + A \times T_{A1} + B \times T_{B1} = E_1$$

$$E_0 + A \times T_{A2} + B \times T_{B2} = E_2$$

$$E_0 + A \times T_{A3} + B \times T_{B3} = E_3$$

where

T_{Ak} is the temperature in **compartment** A for test point k (1 to 3)

T_{Bk} is the temperature in **compartment** B for test point k (1 to 3)

E_k is the **energy consumption** for test point k (1 to 3)

E_0 is a constant value for the **refrigerating appliance** at the ambient test temperature (in theory this is the **energy consumption** when both **compartments** are at 0 °C, but in practice this is not normally possible to achieve nor accurate) – variable to be solved

A is a constant value for the **refrigerating appliance** at the ambient test temperature that provides an estimate of the influence of the temperature in **compartment** A on the energy consumption – variable to be solved

B is a constant value for the **refrigerating appliance** at the ambient test temperature that provides an estimate of the influence of the temperature in **compartment** B on the energy consumption – variable to be solved

These values can be organised into a matrices as follows:

$$[M_{33}] \times [C_{31}] = [E_{31}] \qquad (37)$$

where

$[M_{33}]$ is a 3 × 3 matrix of value of “1” (constant), T_A and T_B for each test point

$[C_{31}]$ is a 3 × 1 matrix of E_0, A and B (constants to be solved)

$[E_{31}]$ is a 3 × 1 matrix of E_1, E_2 and E_3

In longhand this is set out as follows:

$$\begin{bmatrix} 1 & T_{A1} & T_{B1} \\ 1 & T_{A2} & T_{B2} \\ 1 & T_{A3} & T_{B3} \end{bmatrix} \times \begin{bmatrix} E_0 \\ A \\ B \end{bmatrix} = \begin{bmatrix} E_1 \\ E_2 \\ E_3 \end{bmatrix}$$

To solve for the unknown constants matrix $[C_{31}]$, find the solution to the matrix multiplication

$$[M_{33}]^{-1} \times [E_{31}] = [C_{31}]$$

The inverse of a 3 × 3 matrix can be readily programmed into most spreadsheets. Solving for constants A, B and E_0 allows the energy consumption to be estimated for any compartment temperatures (with the proviso that the temperature combination lies inside the triangle). For the **target temperature** in **compartment** A and **compartment** B the energy consumption is given as:

$$E_{AB\text{-}tar} = E_0 + A \times T_{A\text{-}tar} + B \times T_{B\text{-}tar}$$

E.4.5 Checking temperature validity where there are more than two compartments for triangulation

Where a **refrigerating appliance** has more than two **compartments** as specified in E.4.2.3 Case 2-2 (where the temperature of at least one of the additional **compartments** is above its **target temperature** for at least one of the 3 test points), the temperature of these additional **compartments** at the point of interpolation shall be checked for validity prior to the calculation of **energy consumption**.

The validity of the points selected for **Compartments** A and B selected for triangulation shall be checked as specified in E.4.2.2 Formula (33) (i.e. that points surround Q).

The approach shall use matrices for triangulation on the primary two **Compartments** A and B to estimate the temperature in each additional **compartment** at the point of interpolation (Point Q). For the first additional **compartment** (**Compartment** C) the 3 simultaneous equations to describe the 3 test points are as follows:

$$K_C + L_C \times T_{A1} + M_C \times T_{B1} = T_{C1}$$

$$K_C + L_C \times T_{A2} + M_C \times T_{B2} = T_{C2}$$

$$K_C + L_C \times T_{A3} + M_C \times T_{B3} = T_{C3}$$

where

T_{Ak} is the temperature in **Compartment** A for test point k (1 to 3)

T_{Bk} is the temperature in **Compartment** B for test point k (1 to 3)

T_{Ck} is the temperature in **Compartment** C for test point k (1 to 3)

K_C, L_C and M_C are constants to be estimated for **Compartment** C.

$$[M_{33}] \times [C_{C31}] = [T_{C31}] \qquad (38)$$

where

$[M_{33}]$ is a 3 × 3 matrix of value of “1” (constant), T_A and T_B for each test point

$[C_{C31}]$ is a 3 × 1 matrix of constants for **Compartment** C – K_C, L_C and M_C (constants to be solved)

$[T_{C31}]$ is a 3 × 1 matrix of T_{C1}, T_{C2} and T_{C3}

In longhand this is set out as follows:

$$\begin{bmatrix} 1 & T_{A1} & T_{B1} \\ 1 & T_{A2} & T_{B2} \\ 1 & T_{A3} & T_{B3} \end{bmatrix} \times \begin{bmatrix} K_C \\ L_C \\ M_C \end{bmatrix} = \begin{bmatrix} T_{C1} \\ T_{C2} \\ T_{C3} \end{bmatrix}$$

To solve for the unknown constants matrix $[C_{C31}]$, find the solution to the matrix multiplication:

$$[M_{33}]^{-1} \times [T_{C31}] = [C_{C31}]$$

The temperature in **Compartment** C is calculated when **Compartment** A and **Compartment** B are at their respective **target temperatures** as follows:

$$T_{Cx} = K_C + L_C \times T_{A\text{-}tar} + M_C \times T_{B\text{-}tar}$$

For triangulation on **Compartment** A and **Compartment** B to be valid, the following requirement shall be met:

$T_{C\text{-}tar} \geq T_{Cx}$

Where there are more than 3 **compartments** (**Compartments** A, B and C), the values for each additional **compartment** (**Compartment** D, E, F etc. as applicable) are substituted for **Compartment** C in the above equations and specific values for K, L and M for each additional **compartment** are calculated.

For triangulation on **Compartment** A and **Compartment** B to be valid, the temperature in each additional **compartment** (**Compartment** C, D, E, F etc.) shall be at or below their respective **target temperatures** when **Compartment** A and **Compartment** B are at their respective **target temperatures**.

NOTE It is only necessary to perform checks on **compartments** that have a measured temperature that is above its **target temperature** for one or two of the three test points. **Compartments** that are above their **target temperature** for all three test points will never give a valid result.

E.4.6 Calculations for three compartment triangulation – matrices

The approach with matrices can be readily expanded to cover three dimensional triangulation as well. Where temperatures in n **compartments** are simultaneously interpolated, there shall be $n + 1$ test points that surround the intersection of all relevant **target temperatures** for each **compartment** in n dimensional space.

Where a **refrigerating appliance** has three **compartments** and four test points obtained from four **temperature control setting** combinations as specified in E.4.2.3 Case 2-3, analysis shall be undertaken using matrices. This approach also applies where all additional **compartments** are at or below their **target temperature** for all four test points (additional **compartments** can be ignored in this case).

For three **compartments**, the test data required would be:

$$E_0 + A \times T_{A1} + B \times T_{B1} + C \times T_{C1} = E_1$$

$$E_0 + A \times T_{A2} + B \times T_{B2} + C \times T_{C2} = E_2$$

$$E_0 + A \times T_{A3} + B \times T_{B3} + C \times T_{C3} = E_3$$

$$E_0 + A \times T_{A4} + B \times T_{B4} + C \times T_{C4} = E_4$$

T_{Ak} is the temperature in **compartment** A for test point k (1 to 4)

T_{Bk} is the temperature in **compartment** B for test point k (1 to 4)

T_{Ck} is the temperature in **compartment** C for test point k (1 to 4)

E_k is the **energy consumption** for test point k (1 to 4)

E_0 is a constant value for the **refrigerating appliance** at the ambient test temperature (in theory this is the **energy consumption** when all three **compartments** are at 0 °C, but in practice this is not normally possible to achieve nor accurate) – variable to be solved

A is a constant value for the **refrigerating appliance** at the ambient test temperature that provides an estimate of the influence of the temperature in **compartment** A on the energy consumption – variable to be solved

B is a constant value for the **refrigerating appliance** at the ambient test temperature that provides an estimate of the influence of the temperature in **compartment** B on the energy consumption – variable to be solved

C is a constant value for the **refrigerating appliance** at the ambient test temperature that provides an estimate of the influence of the temperature in **compartment** C on the energy consumption – variable to be solved

These values can be organised into matrices as follows:

$$[M_{44}] \times [C_{41}] = [E_{41}] \tag{39}$$

$[M_{44}]$ is a 4 × 4 matrix of 1 (constant), T_A, T_B and T_C for each test point

$[C_{41}]$ is a 4 × 1 matrix of E_0, A, B and C (constants to be solved)

$[E_{41}]$ is a 4 × 1 matrix of E_1, E_2, E_3 and E_4.

Solving for constants A, B, C and E_0 allows the energy consumption to be estimated for any compartment temperatures (with the proviso that the temperature combination lies inside the triangular prism). For the **target temperature** in **compartment** A, **compartment** B and **compartment** C the energy consumption is given as:

$$E_{ABC\text{-}tar} = E_0 + A \times T_{A\text{-}tar} + B \times T_{B\text{-}tar} + C \times T_{C\text{-}tar}$$

Checks are required to ensure that all 4 points fully surround the Point Q in three dimensional space. The approach below sets out a mathematical way to confirm that the data is valid.

Firstly, we define the 4 vertices of the tetrahedron in 3 dimensional space as a function of the 4 sets of temperature measurements as follows:

Vertex 1 = T_{A1}, T_{B1}, T_{C1}

Vertex 2 = T_{A2}, T_{B2}, T_{C2}

Vertex 3 = T_{A3}, T_{B3}, T_{C3}

Vertex 4 = T_{A4}, T_{B4}, T_{C4}

We want to check that Point Q (in this case, $T_{A\text{-tar}}$, $T_{B\text{-tar}}$, $T_{C\text{-tar}}$) is inside the tetrahedron.

To do this, calculate the Determinant of each of the following five matrices:

$$D_0 \text{ for } \begin{vmatrix} T_{A1} & T_{B1} & T_{C1} & 1 \\ T_{A2} & T_{B2} & T_{C2} & 1 \\ T_{A3} & T_{B3} & T_{C3} & 1 \\ T_{A4} & T_{B4} & T_{C4} & 1 \end{vmatrix}$$

$$D_1 \text{ for } \begin{vmatrix} T_{A\text{-tar}} & T_{B\text{-tar}} & T_{C\text{-tar}} & 1 \\ T_{A2} & T_{B2} & T_{C2} & 1 \\ T_{A3} & T_{B3} & T_{C3} & 1 \\ T_{A4} & T_{B4} & T_{C4} & 1 \end{vmatrix}$$

$$D_2 \text{ for } \begin{vmatrix} T_{A1} & T_{B1} & T_{C1} & 1 \\ T_{A\text{-tar}} & T_{B\text{-tar}} & T_{C\text{-tar}} & 1 \\ T_{A3} & T_{B3} & T_{C3} & 1 \\ T_{A4} & T_{B4} & T_{C4} & 1 \end{vmatrix}$$

D_3 for $\begin{vmatrix} T_{A1} & T_{B1} & T_{C1} & 1 \\ T_{A2} & T_{B2} & T_{C2} & 1 \\ T_{A\text{-tar}} & T_{B\text{-tar}} & T_{C\text{-tar}} & 1 \\ T_{A4} & T_{B4} & T_{C4} & 1 \end{vmatrix}$

D_4 for $\begin{vmatrix} T_{A1} & T_{B1} & T_{C1} & 1 \\ T_{A2} & T_{B2} & T_{C2} & 1 \\ T_{A3} & T_{B3} & T_{C3} & 1 \\ T_{A\text{-tar}} & T_{B\text{-tar}} & T_{C\text{-tar}} & 1 \end{vmatrix}$

NOTE The Determinant of a matrix can be readily programmed into most spreadsheets (for example the function MDETERM in Excel calculates this value).

As a check $D_0 = D_1 + D_2 + D_3 + D_4$

If D_1 and D_2 and D_3 and D_4 are the same sign as D_0, then Point Q is inside of the tetrahedron.

If D_0 = 0 then the points are a plane (not a tetrahedron)

If D_1, D_2, D_3 or D_4 = 0 then Q lies on that face of the tetrahedron (this is still a valid result).

The general approach can be expanded to apply to five points for four compartments.

The approach can also be contracted to assess three points for two compartments as follows (this is technically the same approach as set out in E.4.2.2, but in a long hand form):

To do this, calculate the Determinant of each of the following four matrices:

D_0 for $\begin{vmatrix} T_{A1} & T_{B1} & 1 \\ T_{A2} & T_{B2} & 1 \\ T_{A3} & T_{B3} & 1 \end{vmatrix}$

D_1 for $\begin{vmatrix} T_{A\text{-tar}} & T_{B\text{-tar}} & 1 \\ T_{A2} & T_{B2} & 1 \\ T_{A3} & T_{B3} & 1 \end{vmatrix}$

D_2 for $\begin{vmatrix} T_{A1} & T_{B1} & 1 \\ T_{A\text{-tar}} & T_{B\text{-tar}} & 1 \\ T_{A3} & T_{B3} & 1 \end{vmatrix}$

D_3 for $\begin{vmatrix} T_{A1} & T_{B1} & 1 \\ T_{A2} & T_{B2} & 1 \\ T_{A\text{-tar}} & T_{B\text{-tar}} & 1 \end{vmatrix}$

As a check $D_0 = D_1 + D_2 + D_3$

If D_1 and D_2 and D_3 are the same sign as D_0, then Point Q is inside of the triangle.

If D_0 = 0 then the points are a line (not a triangle).

If D_1, D_2 or D_3 = 0 then then Point Q lies on that side of the triangle.

Where a **refrigerating appliance** has more than three **compartments** and these are not always at or below their **target temperature** as specified in E.4.2.3 Case 2-4, the temperature of these additional **compartments** at the point of interpolation shall be checked for validity prior to the calculation of **energy consumption**. The general approach is similar to that set out in E.4.5.

The approach shall use matrices for triangulation on the primary three **Compartments** A, B and C to estimate the temperature in each additional **compartment** at the point of interpolation (Point Q). For the first additional **compartment** to be checked (**Compartment** D) the 4 simultaneous equations to describe the 4 test points are as follows:

$$K_D + L_D \times T_{A1} + M_D \times T_{B1} + N_D \times T_{C1} = T_{D1}$$

$$K_D + L_D \times T_{A2} + M_D \times T_{B2} + N_D \times T_{C2} = T_{D2}$$

$$K_D + L_D \times T_{A3} + M_D \times T_{B3} + N_D \times T_{C3} = T_{D3}$$

$$K_D + L_D \times T_{A4} + M_D \times T_{B4} + N_D \times T_{C4} = T_{D4}$$

Matrices are then used to solve for constants K_D, L_D, M_D and N_D . The temperature of **Compartment** D is then checked when **Compartments** A, B and C are at their **target temperatures**. **Compartment** D must be at or below **target temperature** at this point for the triangulation to be valid. This process is then undertaken on any additional **Compartments** E, F etc. that are not always below their **target temperature** for all test points.

In theory, the general approach of using matrices could be expanded to cover 4 or 5 dimension interpolations (requiring 5 or 6 suitable test points). In practical terms, there is likely to be little additional value beyond interpolation for 2, or sometimes 3, **compartments**.

Examples of calculations for triangulation are set out in Annex I.

Annex F
(normative)

Energy consumption of specified auxiliaries

F.1 Purpose

This Annex sets out the requirements for the determination of **energy consumption** of specified auxiliaries. The auxiliaries that are specified in this standard are ambient controlled anti-condensation heaters and tank-type automatic icemakers.

NOTE Other types of specified auxiliaries may be included in future.

Where a **refrigerating appliance** does not contain specified auxiliaries, no testing in accordance with this Annex is required.

F.2 Ambient controlled anti-condensation heaters

F.2.1 Outline of the method

The power consumption of the appliance is measured as specified in this Annex with any automatically controlled electric anti-condensation heaters switched off or otherwise disabled, where possible.

The supplier declares that an ambient controlled anti-condensation heater is included in the **refrigerating appliance** and provides data regarding the heater operation as a function of a wide range of ambient humidity and **ambient temperature** conditions, as applicable, as set out in Table F.1. Where a product has a user-adjustable setting that can change the power of the automatic ambient controlled anti-condensation heater, values at the highest and lowest power shall be reported as set out in F.2.8.

If a product has any ambient controlled anti-condensation heater which is not declared by the manufacturer, these may be treated as circumvention devices.

For declared auxiliaries, the power that the heater would use under local regional operating conditions can be synthesized using the distribution of these ambient conditions over a year (share of time at each combination of conditions, based on analysis of regional climate data). The resulting average annual power consumption is multiplied by a system loss factor to compensate for the extra refrigeration power that would be required to remove a portion of the heat from the heater that leaks into the **refrigerating appliance**. The total energy (corrected by the system loss factor) is then added to the estimated annual **energy consumption** for the region. The assumed system loss factor in this standard is 1,3.

NOTE The system loss factor is based on empirical measurements.

The operation of the anti-condensation heater can be verified through specific tests in a range of conditions to ensure that the manufacturer declaration is accurate.

Laboratories should check that the measured or implied values of heater power for different temperatures and humidity levels are consistent with the claimed heater power provided by the manufacturer in Table F.1.

F.2.2 Measurement procedure

Where specific measurements are required to confirm or check the operation of ambient controlled anti-condensation heater, these shall generally be conducted in accordance with Annex A and Annex B.

F.2.3 Data requirements

For products with an ambient controlled anti-condensation heater, the manufacturer is required to hold documentation on the operation of the heater power as a continuous or step function of **ambient temperature** and ambient humidity.

In order to calculate the energy impact of ambient controlled anti-condensation heaters in accordance with this international standard, the data on the operation of the heater power has to be converted into power data for a range of ambient humidity and temperature values. Typically this is in the format of a table of average power of the anti-condensation heater for each of the specified 10 humidity bands and the 3 specified **ambient temperatures**. If other factors in addition to humidity and/or temperature can affect the operation of the ambient controlled anti-condensation heater(s), these parameters are also required.

The **ambient temperature** values for calculation of anti-condensation heater energy in this international standard are 16 °C, 22 °C and 32 °C.

While the specified core ambient conditions are considered adequate to accurately estimate the **energy consumption** of such heaters under most conditions, some regions may wish to specify additional temperatures. The core temperatures are of most interest because at 16 °C and 32 °C they are energy test temperatures (and represent range of typical usage in many regions) and 22 °C is a typical indoor temperature for conditioned spaces.

An example of the format of the product heater data to be provided for the core **ambient temperatures** is set out in the last three columns of Table F.1.

F.2.4 Regional weather data

In order to undertake the required calculations for the operation of the ambient controlled anti-condensation heater(s), regions are required to prepare a map of probability of temperature and humidity data which is relevant for their local indoor conditions. Population-weighted probabilities should be used where possible. The intent is to provide a distribution that is most representative of annual indoor operating conditions that the **refrigerating appliance** is likely to encounter during **normal use**.

NOTE Obtaining representative indoor temperature and humidity data for a region can be onerous. The temperature distribution depends on the climate and the extent of indoor climate control used (heating and/or cooling). Some analysis has shown that indoor absolute humidity levels are broadly equivalent to outdoor absolute humidity levels (noting that these need to be corrected for temperature differences when calculating relative humidity levels).

An example of the format of the regional indoor data to be provided is set out in columns three, four and five of Table F.1.

Regions may choose to not use all of the three **ambient temperatures** specified in Table F.1. Regions may use additional **ambient temperatures** beyond those specified in Table F.1.

F.2.5 Calculation of power consumption

The data as set out in Table F.1 should be supplied.

NOTE Regional values (R_1 to R_{30}) are normally defined by the relevant regional authority. Power values that are specific to these regional values (P_{H1} to P_{H30} for bins R_1 to R_{30}) are normally provided by the product supplier or manufacturer.

It is generally recommended that the values of all humidity bins across all indoor **ambient temperatures** sum to a value of 1 (100 %) to assist in checking of data (i.e. sum of R_1 to R_{30} = 1). This requires the humidity bins at each **ambient temperature** to be weighted by the share of time at each **ambient temperature**.

Table F.1 – Format for temperature and humidity data – ambient controlled anti-condensation heaters

Relative Humidity	RH band mid-point	Probability at 16 °C	Probability at 22 °C	Probability at 32 °C	Heater W at 16 °C	Heater W at 22 °C	Heater W at 32 °C
0 to 10 %	5 %	R_1	R_{11}	R_{21}	P_{H1}	P_{H11}	P_{H21}
10 to 20 %	15 %	R_2	R_{12}	R_{22}	P_{H2}	P_{H12}	P_{H22}
20 to 30 %	25 %	R_3	R_{13}	R_{23}	P_{H3}	P_{H13}	P_{H23}
30 to 40 %	35 %	R_4	R_{14}	R_{24}	P_{H4}	P_{H14}	P_{H24}
40 to 50 %	45 %	R_5	R_{15}	R_{25}	P_{H5}	P_{H15}	P_{H25}
50 to 60 %	55 %	R_6	R_{16}	R_{26}	P_{H6}	P_{H16}	P_{H26}
60 to 70 %	65 %	R_7	R_{17}	R_{27}	P_{H7}	P_{H17}	P_{H27}
70 to 80 %	75 %	R_8	R_{18}	R_{28}	P_{H8}	P_{H18}	P_{H28}
80 to 90 %	85 %	R_9	R_{19}	R_{29}	P_{H9}	P_{H19}	P_{H29}
90 to 100 %	95 %	R_{10}	R_{20}	R_{30}	P_{H10}	P_{H20}	P_{H30}

The heater power can be calculated as follows:

$$W_{heaters} = \left[\sum_{i=1}^{k} (R_i \times P_{H\,i}) \right] \times 1{,}3 \qquad (40)$$

where

- $W_{heaters}$ is the annual average additional power consumption associated with the ambient controlled anti-condensation heater
- R_i is a regional factor to indicate the probability of the *ith* temperature and humidity bin in Table F.1
- P_{Hi} is the average heater power associated with the *ith* temperature and humidity bin in Table F.1
- k is the total number of temperature and humidity bins used (= 30 if all bins in Table F.1 are used)
- 1,3 is the assumed loss factor (is the energy used by the heater (1,0) plus a loss component of 0,3 to account for heat leakage into the **compartment** and its subsequent removal by the refrigeration system)

Some regions may wish to specify fewer or additional **ambient temperature** bins.

F.2.6 Where anti-condensation heater(s) cannot be disabled but their power consumption can be measured directly

The measured power of the automatically controlled anti-condensation heater(s) from the test run(s) when the **compartment** temperatures were closest to target shall be multiplied by 1,3 (the system loss factor) and shall be deducted from the interpolated energy test result. The power that the heater(s) would use at the required **ambient temperatures** and humidity levels is then synthesized and added to the test result in exactly the same way as for models where the heater(s) have been disabled.

Laboratories should check that the measured values of heater power for different temperatures and humidity levels are consistent with the claimed heater power provided by the manufacturer in Table F.1.

F.2.7 Where anti-condensation heater(s) cannot be disabled and their power consumption cannot be measured directly

The relative humidity of the test room shall be measured during an energy test. The claimed wattage of the automatically controlled anti-condensation heater(s) at that ambient and humidity shall be multiplied by 1,3 (the system loss factor) and shall be deducted from the interpolated energy test result. The power that the heater(s) would use at 16 °C, 22 °C and 32 °C and ten humidity band mid-points is then synthesized and added to the test result in exactly the same way as for models where the heater(s) have been disabled.

Laboratories should check that the implied values of heater power for different temperatures and humidity levels are consistent with the claimed heater power provided by the manufacturer in Table F.1.

F.2.8 Where anti-condensation heater(s) has a user-adjustable setting

Where the product has a user-adjustable setting that affects the power used by the anti-condensation heaters, which are otherwise automatically controlled in response to ambient conditions, the **energy consumption** at the highest and lowest energy value selectable by the user (in accordance with the rules for a manually switched heater) shall be calculated and separately reported. The approach set out in F.2.5, F.2.6 or F.2.7, as applicable, shall be used to determine the highest and lowest values for the anti-condensation heaters.

F.3 Automatic icemakers – energy to make ice

F.3.1 General

Automatic icemakers are split into two different types:

- Mains water connected – where fresh water from an external source is connected to the **refrigerating appliance**;
- Tank type – where fresh water is used from an internal tank which is filled by the user when it is empty.

NOTE Test methods for mains water connected ice makers are under consideration.

F.3.2 Tank type automatic icemakers

F.3.2.1 Purpose

The purpose of this test is to quantify the incremental energy required to make a defined quantity of ice in a tank type automatic icemaker. This subclause F.3.2 sets out:

- A description of the procedure
- Defines the preparation set up and starting conditions
- Assessment of when the test is completed
- Measurements and calculations to be performed
- Values to be reported.

Conceptually this test is similar to the **load processing efficiency** test defined in Annex G, but it only covers the ice making component for products that have an automatic ice maker and that use a tank water supply.

Where the **energy consumption** to make ice is stated or claimed for a tank type automatic ice maker in accordance with this standard, the procedure specified in this Annex shall be used.

F.3.2.2 General description

Tank type icemakers have a water storage tank in an **unfrozen compartment**. The icemaker continues to make ice until either the ice making bin (often configured as a separate external drawer) is full or the tank reaches its minimum water level (no more water can be pumped out beyond this level). For the ice making test, the ice making bin is emptied and a small amount of water is added to the tank so it makes ice and the water falls to the minimum water level of its own accord. The appliance is then operated under **steady state** conditions. At the start of the test, a specified amount of water at **ambient temperature** is added (default is 300 g or 0,300 kg). The appliance makes ice automatically until the minimum water level is again reached of its own accord. Measurements during this test are used to determine the additional energy used to make ice.

F.3.2.3 Test conditions

This test is undertaken in accordance with the requirements for a normal energy test, except that the product is configured to permit the making of ice in its automatic icemaker. This test is usually undertaken adjacent to (following or prior to) a normal **energy consumption** test. The test is conducted at **ambient temperatures** of 16 °C and 32 °C.

F.3.2.4 Set-up, equipment and preparation

Where a tank type automatic ice making test is used as the basis for a manufacturer claim, the average temperature of all **compartments** that are used to store water and make/store ice shall be at or below the relevant **target temperatures** specified in 5.1.

NOTE 1 All temperatures specified in this subclause are for **steady state** conditions and do not include the temperature impact of any **defrost and recovery period** (where applicable).

For verification tests, the temperatures of the ice making bin and the **fresh food compartments** (the **compartment** where the tank is stored) shall be within ±1 K of the relevant **target temperature**. Alternatively, the results of two ice making tests can be interpolated to the **target temperature** of the **fresh food compartment** while controls for other **compartments** are not adjusted.

NOTE 2 Typically, this test is conducted after an energy test under the same general conditions.

A set of scales is required to measure the mass of the water tank at the start and the end of the test.

The ice storage bin shall be emptied and largely free of ice. The automatic sensor that controls whether ice is made is allowed to operate normally.

While the appliance is operating, add water (about 100 g more than the minimum water level – sufficient to ensure that some ice can be made). The tank is put in its normal position and it is allowed to operate normally and make ice until the tank reaches its minimum water level and no more ice can be made. The appliance is then allowed to operate under **steady state** conditions for at least 6 h.

No short term settings, controls or functions may be initiated or changed during preparation or during the making of ice for the test.

If not limited by the **volume** of the tank or the capacity of the ice storage bin, the mass of ice to be made is 300 g (0,300 kg), unless otherwise specified in regional requirements or test conditions.

Water to be inserted into the tank at the start of the test shall be measured out into a 500 g PET bottle and shall be stored in the test room, which is operating at the relevant **ambient temperature**, for a period of no less than 15 h prior to the commencement of the ice making test. Refer to Annex G for a PET bottle specification.

F.3.2.5 Start of the test

For **refrigerating appliances** without any **defrost control cycle,** the ice making test shall be preceded by a period of operation, at the **temperature control setting** used for the ice making test, that could qualify as a valid energy test period in accordance with Clause B.3.

For a **refrigerating appliance** with one or more defrost systems (each with its own **defrost control cycle**) the ice making test shall be preceded by:

- An energy test period that complies with Clause B.3 at the **temperature control setting** used for the ice making test; or
- An energy test period that complies with Clause B.4 at the **temperature control setting** used for the ice making test; or
- A **defrost and recovery period** that complies with Clause C.3 at the **temperature control setting** used for the ice making test (as applicable).

For all product types, the **temperature control settings** shall remain unchanged for the duration of the ice making test.

For simple products with regular compressor cycles, a compressor on event can be taken as the start of the ice making test. For more complex products, a temperature maximum in the **compartment** that dominates the **energy consumption** can be taken as the start of the ice making test (see Annex B for more guidance). Where the tank is inserted during the **defrost and recovery period**, the start of the test is defined as the start of that **defrost and recovery period**.

NOTE Filling the water tank during the **defrost and recovery period** (prior to establishment of **steady state** conditions) is generally not recommended.

The door to the **compartment** where the tank is stored is opened at the relevant point as defined above in order to fill the tank. The door shall be left open at an angle of at least 90 degrees from the closed position for a duration that is as close as possible to one minute (±5 s). Where there are two doors provided to access the **compartment** where the tank is stored, both doors shall be opened together. During this one minute period:

- Where the tank is removable:
  - Measure and record the total mass of the tank and residual water.
  - Add the water from the PET bottles at **ambient temperature** to the tank
  - Measure and record the total mass of the tank and water again.
  - Put the tank back into its normal position.
- Where the tank is not removable:
  - Measure the mass of water added to the tank.
- Close the door.
- Allow the appliance to start making ice normally.

F.3.2.6 End of the test

The ice making test is concluded when a period of stable operation has been reached after the ice has been made and the tank is down to its minimum water level. The test period concludes at the end of a complete **temperature control cycle**. The **temperature control settings** shall remain unchanged for the duration of the ice making test.

The testing for the ice making test for a **refrigerating appliance** without any defrost system (each with its own **defrost control cycle**) shall be completed with an energy test period that complies with Clause B.3.

The testing for the ice making test for a **refrigerating appliance** with one or more defrost systems (with its own **defrost control cycle**) is completed with an energy test period that complies with:

- Clause B.3 (including validity requirements), or
- Clause B.4 (including validity requirements) which terminates with a **defrost and recovery period** that complies with the validity requirements of C.3 (as applicable).

For **refrigerating appliances** with one or more **defrost control cycles,** any **defrost and recovery period** that occurs during the ice making test (i.e. before all ice has been made and **steady state** conditions established) shall be allowed to continue to completion. The end of the ice making test is when **steady state** conditions are reached and after the completion of a valid **defrost and recovery period** as specified above.

Once the above conditions have been established, the door is opened and the tank is removed and weighed. The final mass of the tank and the residual water is recorded. The approximate mass of ice at the end of the test and quality of the ice cubes should be noted. Where the tank cannot be removed, the mass of additional ice made during the test shall be recorded.

The following additional validity criterion applies to the measured parameters at the start (prior to insertion of the water) and the stability period at the end of the automatic ice making test:

- The difference of the **steady state** power P_{SSM} shall not exceed 5 % or 2 W, whichever is the greater value.

In the case where the initial validity is determined using a defrost under Clause C.3 (refer F.3.2.5) because the validity to Clause B.3 or Clause B.4 cannot be established (e.g. due to insufficient test time), the initial **steady state** power P_{SSM} above is taken as the average power of Period D and Period F (Case DF1 in Clause C.3).

In the case of a **refrigerating appliance** with one or more defrost systems (each with its own **defrost control cycle**), where the above conditions are not met, the appliance shall be operated until the next **defrost and recovery period** has been completed and a new **steady state** condition established and assessed against this criterion.

If this validity criterion cannot be met after a subsequent defrost, the test shall be repeated. The result of the repeated test is used to determine the **energy consumption** for the ice making test. Remove the ice made from the previous test after **steady state** operation is established and weigh the ice. The door opening time should not exceed 20 s. Start the ice making test again, commencing with the **temperature control cycle** after the **temperature control cycle** where the ice was taken out. For **refrigerating appliances** with one or more **defrost control cycles**, any **defrost and recovery period** that occurs during the automatic ice making test (i.e. before the ice has been fully completed and **steady state** conditions established) shall be allowed to continue to completion.

The end of the automatic ice making test is when **steady state** conditions are reached and after the completion of a valid **defrost and recovery period** as specified above.

For this type of icemaker, it is assumed that all of the water pumped out of the tank is turned into ice in the ice making bin. The bin should be inspected to ensure that suitable ice cubes have been formed. It is recommended that the mass of ice formed be measured approximately (noting that some small shards and pieces of ice may be hard to remove). If there appears to be a significant discrepancy in the amount of ice formed (remembering that some ice will be made prior to the start of the test), the product should be examined closely ensure that there are no leaks or other paths for the water from the tank. The main factor that can influence the power before and after automatic ice making is a change of heater operation associated with ice making equipment. Analysis has shown that, within the validity limits set out below, these effects are small and can usually be ignored.

F.3.2.7 Calculations

The mass of ice formed during the test is determined as:

$$M_{ice\text{-}test} = M_{water\text{-}added} + M_{initial\text{-}tank} - M_{final\text{-}tank} \tag{41}$$

The principle used to quantify the additional energy used to make ice is to establish a period of **steady state** operation after all the ice has been made. The additional energy is then calculated as the difference between the actual **energy consumption** from the start of the ice making test (at the point of tank input) to the end of the **steady state** period (P_{after}) completion minus the power that would have been consumed over the same period if the power consumption had been at the **steady state** power (P_{after}) for the same period.

If one (or more) **defrost and recovery period(s)** has occurred during the ice making test, the energy associated with representative **defrost and recovery** at the test temperature as determined in accordance with Annex D is subtracted from the additional energy.

The additional energy to make the specific quantity of ice made during the test is given by:

$$\Delta E_{ice-test} = (E_{end} - E_{start}) - P_{after} \times (t_{end} - t_{start}) - z \times \Delta E_{df} \tag{42}$$

where

$\Delta E_{ice\text{-}test}$ is the additional energy consumed by the **refrigerating appliance** to make the specific quantity of ice made during the test in Wh

E_{start} is the accumulated energy reading at the start of the ice making test as defined in F.3.2.5 in Wh

E_{end} is the accumulated energy reading at the ice making test as defined in F.3.2.5 in Wh

P_{after} is the **steady state** power consumption that occurs after all ice has been made during the valid energy test period (B.3 or B.4) as defined in F.3.2.6 in W

t_{start} is the test time at the start of the ice making test as defined in F.3.2.5 in hours

t_{end} is the test time at the end of ice making test as defined in F.3.2.6 in hours

ΔE_{df} is the additional **energy consumption** associated with a **defrost and recovery period** as determined in accordance with Annex C (C.5)

z is a factor that equals the number of **defrost and recovery periods** that occur during and prior to the completion of the ice making load test. This value is zero for **refrigerating appliances** without a defrost system (with its own **defrost control cycle**) or where no **defrost and recovery period** occur during the ice making test.

The normalised additional **energy consumption** to make 1 kg is then calculated from the test data as follows:

$$\Delta E_{kg-ice} = \frac{\Delta E_{ice-test}}{M_{ice-test}} \tag{43}$$

where

$\Delta E_{kg\text{-}ice}$ is the additional energy consumed by the **refrigerating appliance** to make 1 kg of ice in Wh

$\Delta E_{ice\text{-}test}$ is the additional energy consumed by the **refrigerating appliance** to make the specific quantity of ice made during the test in Wh

$M_{ice\text{-}test}$ is the mass of water turned into ice during the test in kg.

The following calculations are optional and can be used to provide a common benchmark of the ice making efficiency of the appliance.

The energy to change the water added to ice for the specific quantity of ice made during the test can be calculated as follows:

$$E_{ice-enthalpy} = \frac{\left[M_{ice-test} \times (4{,}186 \times T_{amb} + 333{,}6 - T_{ice} \times 2{,}05)\right]}{3{,}6} \quad (44)$$

where

$E_{ice\text{-}enthalpy}$	is the energy removed from the water load to make the specific quantity of ice made during the test in Wh (as defined by physics)
$M_{ice\text{-}test}$	is the mass of water turned into ice during the test in kg
T_{ice}	is the average temperature of ice making bin after the ice making test is completed in °C (this shall be less than 0 °C)
T_{amb}	is the average ambient air temperature for the 6 h period before water is added to the tank (initial water temperature) in °C
4,186	is a factor for enthalpy change of water in kJ/(kg·K) (while unfrozen)
2,05	is a factor for enthalpy change of water in kJ/(kg·K) (while frozen)
333,6	is a factor for enthalpy water phase change in kJ/ kg (water to ice)
3,6	is a factor to convert kJ to Wh (s/h × 10^{-3}).

NOTE 1 The units of mass above are kg, whereas g are used in many places in this Annex, so care is required to ensure the correct units are used.

The overall efficiency of the ice making process can be determined as follows:

$$Efficiency_{ice} = \frac{E_{ice-enthalpy}}{\Delta E_{ice-test}} \quad (45)$$

where

$Efficiency_{ice}$	is the ice making efficiency for the specified **ambient temperature** and mass of ice made (unitless – Wh/Wh)
$E_{ice\text{-}enthalpy}$	is the energy removed from the water load to make to make the specific quantity of ice made during the test in Wh
$\Delta E_{ice\text{-}test}$	is the additional energy consumed by the **refrigerating appliance** to make the specific quantity of ice made during the test in Wh.

NOTE 2 The measured value of $Efficiency_{ice}$ may be greater than one.

F.3.2.8 Data to be recorded and calculations

The following values shall be included in the test report for each **ambient temperature** where the **energy consumption** for making ice for a tank type ice maker is measured and reported:

– Initial mass of the tank and residual water in kg
– Final mass of the tank and residual water in kg
– Mass of water load added to the tank in kg
– Nominal **ambient temperature** in °C
– Mass of ice made in kg
– **Ambient temperature** measured for the 6 h prior to the start of the test in °C
– Duration of the ice making test in h

- **Steady state** power at the end of the test in W
- Number of defrosts that occurred during the ice making test (z)
- Value of ΔE_{df} used in calculations (where applicable)
- Additional energy used to make ice $\Delta E_{ice\text{-}test}$ as defined in F.3.2.7
- Additional energy consumed per kg of ice made$\Delta E_{kg\text{-}ice}$ (Wh/kg) as defined in F.3.2.7.

The following parameters are recommended for inclusion in the test report:

- Energy removed from the water to make ice $E_{ice\text{-}enthalpy}$ as defined in F.3.2.7 in Wh
- $Efficiency_{ice}$ ice making efficiency for each specified ambient test temperature as defined in F.3.2.7.

F.3.2.9 Addition of automatic ice making into daily energy

This Annex provides an estimate of the incremental **energy consumption** required to make ice automatically. The user demand for ice is highly variable at a regional level as this depends on climate, season and indoor conditions, as well as user habits. Therefore, the measured incremental energy to make ice in this Annex is normally scaled so that the ice consumption more closely matches regional requirements.

Where a regional estimate of the consumed quantity of ice is given in kg/d, the impact on the daily **energy consumption** at a given **ambient temperature** can be estimated as follows:

$$\Delta E_{ice-making} = \Delta E_{kg-ice} \times M_{ice-making} \tag{46}$$

where

$\Delta E_{ice\text{-}making}$ is the additional energy consumed by the **refrigerating appliance** to make $M_{ice\text{-}making}$ kg of ice per day at the specified **ambient temperature** in Wh/day

$\Delta E_{kg\text{-}ice}$ is the estimated additional energy consumed by the **refrigerating appliance** to make 1 kg of ice in Wh as set out in F.3.2.7

$M_{ice\text{-}making}$ is the mass of water turned into ice per day in kg/day – this is a regional factor.

The value for $\Delta E_{ice\text{-}making}$ can be added to the daily **energy consumption** value to estimate a value for this user related usage element. If the values at an **ambient temperature** of 16 °C and 32 °C are both used, the annual factor could be expressed as:

$$\Delta E_{ice\text{-}making\text{-}annual} = f\{\Delta E_{ice\text{-}making16C}, \Delta E_{ice\text{-}making32C}\} \tag{47}$$

Annex G
(normative)

Determination of load processing efficiency

G.1 Purpose

This test quantifies the additional energy consumed by the **refrigerating appliance** to remove a known amount of energy which is contained in warm water, which is placed into **unfrozen** and/or **frozen compartments** in a defined way. The ratio of the energy in the water (which is removed) to the additional energy consumed by the **refrigerating appliance** is used to determine the **load processing efficiency**.

The purpose of the **load processing efficiency** test is to quantify the incremental energy impact of user-related aspects of **refrigerating appliance** use such as door openings and cooling of warm food and drinks. This data can be used in conjunction with closed door tests to produce a total **energy consumption** estimate that more closely represents actual use in different regions. To use the **load processing efficiency** value, an estimate of typical regional user related **processing load** needs to be made. This is usually best done through regional end use measurement programs. The impact of the estimated regional **processing load** on the energy for the particular **refrigerating appliance** can then be estimated from the **load processing efficiency** value determined in this Annex.

If regional energy standards and labelling requirements do not incorporate this component in their calculations (i.e. set the **processing load** to zero), then this test is not required for that region.

Where a supplier provides data or makes a claim of **load processing efficiency**, it shall be based on measurements undertaken in accordance with this Annex.

NOTE For **refrigerating appliances** with **unfrozen** and **frozen compartments**, this Annex sets out a method to measure the combined **load processing efficiency** of both **compartments**. The procedure could, in principle, be used to separately measure the **load processing efficiency** of just the **unfrozen compartment** or just the **frozen compartment**.

G.2 General description

A **refrigerating appliance** is operated in a **steady state** condition with **temperature control settings** that are close to the relevant **target temperature** for **energy consumption** as specified in Table 1 for each **compartment** (see 5.1). The **temperature control settings** shall remain unchanged for the duration of the **load processing efficiency** test.

A specified mass of water (which is a function of the **volume** of the **unfrozen compartments** and/or **frozen compartments**) is placed in the test chamber with the **refrigerating appliance** and allowed to reach the ambient test temperature.

Once specified conditions are met, the door of the largest **unfrozen compartment** is opened for a specified time and the water containers placed in their specified positions. Then the door of the largest **frozen compartment** is opened for a specified time and the water-filled **ice cube trays** placed in specified positions.

The **refrigerating appliance** is allowed to operate until it reaches a **steady state** condition in terms of temperature and power consumption. The data collected is used to determine the **load processing efficiency** at the specified **ambient temperature**. The **load processing efficiency** is determined as the ratio of the processed heat load in the water (removed) divided by the additional **energy consumption** (over and above the **steady state** power) used by the **refrigerating appliance** to cool it down.

The general approach to measurements and the subsequent analysis is similar in concept to the determination of **defrost and recovery** energy as specified in Annex C.

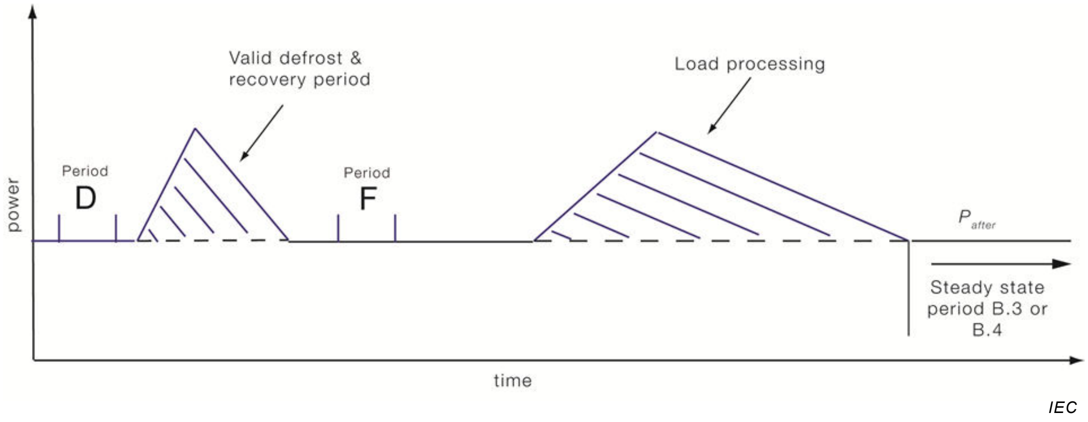


Figure G.1 – Conceptual illustration of the load processing efficiency test

NOTE An illustration of a defrost occurring prior to the completion of load processing is included in Figure G.5. Worked examples are contained in Annex I.

G.3 Setup, equipment and preparation

G.3.1 General

The test is carried out at ambient test temperatures of 16 °C and at 32 °C.

Where a **load processing efficiency** test is used as the basis for a manufacturer claim, the average temperature of all **compartments** that are used to process test load shall be at or below the relevant **target temperatures** specified in 5.1 during the **steady state** operation prior to the start of the **load processing efficiency** test.

NOTE 1 All temperatures specified in this Annex are for **steady state** conditions and do not include the temperature impact of any **defrost and recovery period** (where applicable).

For verification tests, the temperatures of all **compartments** that are used to process the test load shall be within ±1 K of the relevant **target temperature** during the **steady state** operation prior to **load processing efficiency** test. Alternatively, the results of two **load processing efficiency** tests can be interpolated to the value at the **compartment target temperature** of the coldest **compartment**, but one of the test points shall have all **compartments** that are used to process test load at or below **target temperatures**.

The principle included in this Clause is that a manufacturer is permitted to make a claim of **load processing efficiency** that is less than the optimum value possible (i.e. at a condition which may be somewhat colder than **target temperature**). This principle is set out for **energy consumption** tests in Clause 6 for a single energy test point.

Wherever possible, 3 **shelves** shall be used to hold the **processing load** in an **unfrozen compartment** (see Figure G.2) and shall be configured so that:

– Sensor TMP_3 is above **shelf** 3 (bottom) and below **shelf** 2
– Sensor TMP_2 is above **shelf** 2 and below **shelf** 1
– Sensor TMP_1 is above **shelf** 1.

NOTE 2 **Shelf** 3 may be the bottom of the appliance or it may be the top of a **convenience feature**, such as a crisper.

G.3.2 Equipment

The type of container used in **unfrozen compartments** is a thin walled plastic bottle made of PET (or equivalent material) with a nominal **volume** of 500 ml. The dimensions of the PET bottle shall be ≤220 mm in height and ≤90 mm in width/or diameter. All bottles shall be the same size and shape. Each bottle is filled with still water as specified below.

NOTE PET is polyethylene terephthalate. PET bottles can be any commercially available bottles with a nominal 500 ml capacity. They each contain a specified mass of drinking water. PET bottles that have a square cross section are preferred as they do not roll around when lying on their side.

The type of container used in **frozen compartments** is a plastic **ice cube tray** with a nominal working **volume** of about 200 ml per tray.

Ice cube trays are often supplied with a new product. For this test the **ice cube trays** used need to be able to comfortably hold 200 ml of water without risk of spillage. Nominal dimensions of approximately 120 mm × 275 mm × 40 mm are recommended. **Ice cube trays** that are smaller may be used if the recommended size does not fit.

Water used for all **processing loads** shall be potable, still water suitable for human consumption without added gas (i.e. uncarbonated), colour or additives.

Potable water from a tap is acceptable. Pure distilled water should be avoided in the **ice cube trays** as this can be difficult to freeze in some circumstances.

G.3.3 Quantity of water to be processed

G.3.3.1 Unfrozen compartments

The total **volume** of all **unfrozen compartments** and **sub-compartments** is summed. The water mass added to the largest **unfrozen compartment** shall be 12 g of water for each litre of total summed **unfrozen compartment volumes**. This equates to one PET bottle per 41,7 l or part thereof of unfrozen **volume**.

Where the total unfrozen **volume** is less than 41,7 l, all water is placed in one PET bottle. Where the total unfrozen **volume** is greater than 41,7 l but less than 83,4 l, all water is placed equally in two PET bottles. Where the unfrozen **volume** is greater than 83,4 l, 500 g ±1 g of water is placed in each PET bottle until the remaining water mass is less than 1 000 g. The remaining mass shall be divided evenly between the two remaining PET bottles.

The total mass of water placed in the largest **unfrozen compartment** and the number of 500 ml PET bottles shall be included in the test report.

G.3.3.2 Frozen compartments

The total **volume** of all **frozen compartments** and **sub-compartments** is summed. The water mass added to the largest **frozen compartment** shall be 4 g of water for each litre of **frozen compartment volume**. This equates to one **ice cube tray** per 50 l or part thereof of frozen **volume**.

Where the frozen **volume** is less than or equal to 50 l, all water is placed in one **ice cube tray**. Where the frozen **volume** is greater than 50 l but less than or equal to 100 l, all water shall be approximately divided evenly between the two **ice cube trays**. Where the frozen **volume** is greater than 100 l, approximately 200 g of water is placed in each **ice cube tray** until the remaining water mass is less than 400 g. The remaining quantity shall be approximately divided evenly between the two remaining **ice cube trays.**

The total **volume** of water placed in the largest **frozen compartment** and the number of **ice cube trays** shall be included in the test report.

G.3.4 Position of the water load in compartments

G.3.4.1 Position in unfrozen compartments

The PET bottles specified in G.3.3 shall be positioned in the largest **unfrozen compartment** as illustrated in Figure G.2.

Where there is 250 mm or more vertical clearance above the nominated **shelf**, PET bottles shall be placed standing in the following positions:

- The first bottle on each **shelf** on each side shall be placed as close as possible to the **compartment** liner while maintaining approximately 25 mm clearance from the side liner.
- Additional bottles in this position may be placed two or three deep while maintaining approximately 25 mm clearance between bottles and the front and rear of the **shelf** or **load limit**.
- Where more bottles are required in this position, additional rows of bottles (as required) are placed closer to the **compartment** centre while maintaining approximately 25 mm clearance between rows.
- All bottles shall be centred from front to back at even intervals on the **shelf** in their rows (taking account of the **shelf** edge and any **load limits** that may affect the depth).
- All bottles shall maintain at least 25 mm clearance in all directions from any **compartment** temperature sensor.

Where there is less than 250 mm vertical clearance above the nominated **shelf**, PET bottles shall be laid flat on the specified **shelf** with lids (caps) facing towards the **compartment** door (front) in the following positions:

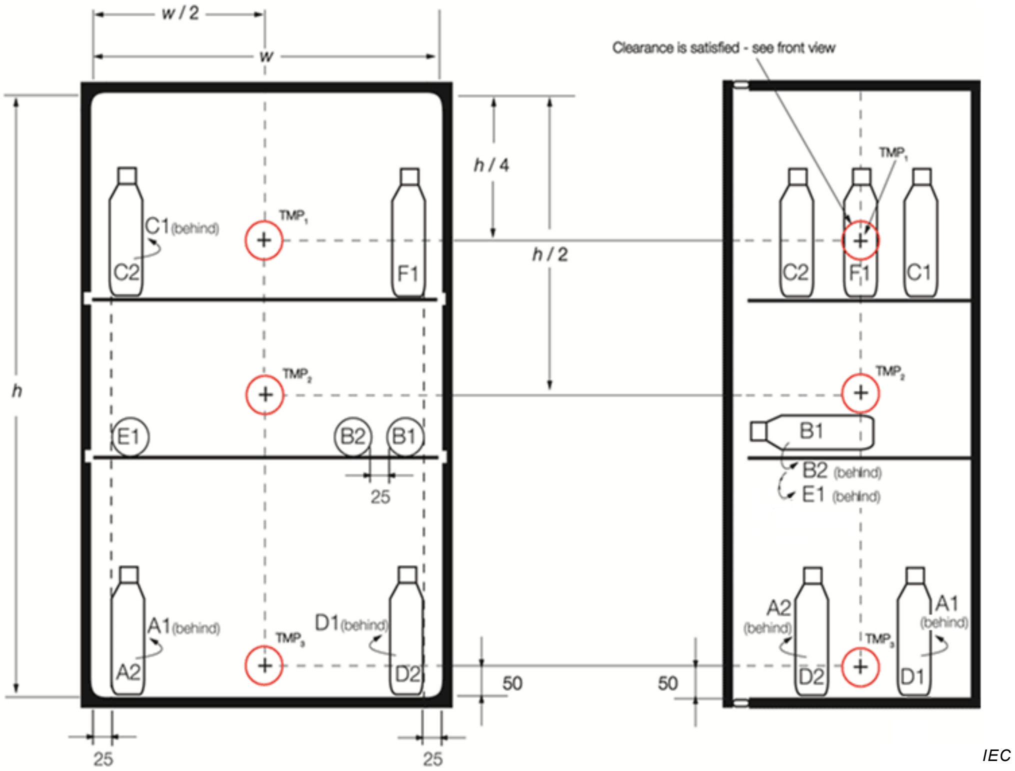
- The first bottle on each **shelf** on each side shall be placed as close as possible to the **compartment** liner while maintaining approximately 25 mm clearance from the side liner.
- Where more bottles are required in this position, additional bottles are placed closer to the **compartment** centre while maintaining approximately 25 mm clearance between bottles.
- No stacking or touching of bottles is permitted.
- All bottles shall maintain at least 25 mm clearance from any **compartment** temperature sensor.
- All bottles are aligned so that the top (cap) is at the front of the **shelf** or the **shelf load limit**. In the case of shallow **shelves**, the orientation of the bottle may be adjusted to ensure that no part protrudes past the front of the **shelf** or **load limit**, while maintaining 25 mm clearance from any temperature sensors.

All bottles should be placed in a position that minimises restriction of air flow from any ducts or vents. When it is not possible to place the PET bottles in the positions specified, equivalent positions are to be selected. Where equivalent positions are used, these shall be recorded in the test report. Where PET bottles have to be arranged differently because of space restrictions, they shall remain on the same **shelf** and shall be as close as possible to the specified position.

The PET bottles shall only be placed on **shelves** that are immediately below temperature sensor positions TMP_1, TMP_2 and TMP_3. Additional **shelves** that may be present are ignored. The PET bottles shall be placed in the following **shelf** positions in sequence until all bottles have been placed:

- One bottle in the sequence of positions ABCDEF
- Repeat the placement sequence until all bottles are placed.
- The two partially filled PET bottles (where applicable) are placed at the last two positions.
- All positions shall be noted in the test report.

NOTE The sequence above is to define the position or location of each bottle. The bottles may be loaded in any order into these specified positions when they are being placed into the **unfrozen compartment** in G.4.2. In the example illustrated in Figure G.2, 10 PET bottles would results in two bottles in positions A to D and one bottle in position E and F.



Dimensions in millimetres

NOTE Additional **shelves** may be present in the **refrigerating appliance** but are not shown in the figure.

Figure G.2 – Shelf locations and loading sequence (example showing 10 PET bottles)

G.3.4.2 Position in frozen compartments

The **ice cube trays** specified in G.3.3 shall be positioned in the largest **frozen compartment** as illustrated in Figure G.3. Where the largest **frozen compartment** has a combination of **shelves** and drawers, the **ice cube trays** shall be placed on **shelves** in preference to drawers (or baskets) as far as possible.

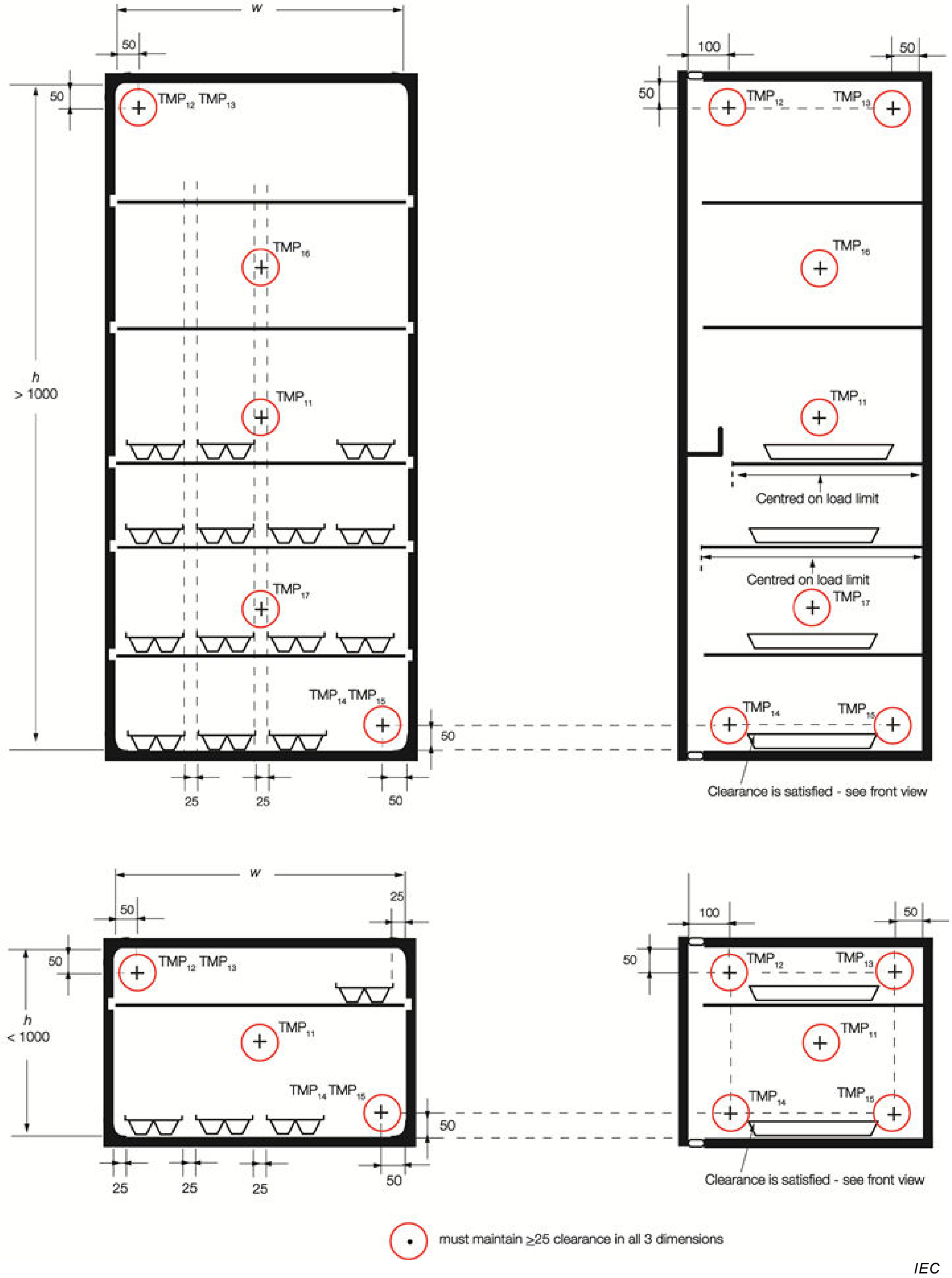
- The first **ice cube tray** on the lower level is placed on the opposite side to sensors TMP_{14} and TMP_{15} and as close as possible to the **compartment** liner while maintaining approximately 25 mm clearance. Additional **ice cube trays** are added next to the previous **ice cube tray** while maintaining approximately 25 mm clearance between **ice cube trays. Ice cube trays** may be oriented in any way that maximises the number of trays on each level while maintaining all necessary clearances.
- Where no more **ice cube trays** can be fitted onto the lower level (i.e. the number required results in the clearance to the temperature sensor positions of less than 25 mm in all directions), then **ice cube trays** are placed progressively on the next available level(s), as required.
- Where it is necessary to place **ice cube trays** on a **shelf** which sits below a central temperature sensor position (e.g. TMP_{11}, TMP_{16} or TMP_{17} as applicable), the first **ice cube tray** is placed adjacent to the left side liner, the second **ice cube tray** is placed adjacent to the right side liner. Additional **ice cube trays** on this level (if required) are placed progressively closer to the centre while maintaining approximately 25 mm clearance from each other and at least 25 mm from any temperature sensor position in all directions.

- Where it is necessary to place **ice cube trays** on a **shelf** which sits below the upper temperature sensor positions (e.g. TMP_{12} and TMP_{13}), the first **ice cube tray** is placed on the opposite side to sensors TMP_{12} and TMP_{13} and as close as possible to the **compartment** liner while maintaining approximately 25 mm clearance. Additional **ice cube trays** (if required) are added next to the previous **ice cube tray** while maintaining 25 mm clearance between **ice cube trays.**
- All **ice cube trays** are spaced approximately 25 mm from the **compartment** liner and each other on each level.
- The two partially filled **ice cube trays** (where applicable) are placed at the last two (upper most) positions required.
- No stacking or touching of **ice cube trays** is permitted.
- All **ice cube trays** shall maintain at least 25 mm clearance from any **compartment** temperature sensor position in all directions.
- All **ice cube trays** are centred from front to back of the **shelf** (taking account of the **shelf** edge and any **load limits** that may affect the depth) and shall not protrude beyond the front of the **shelf**.
- When **ice cube trays** are located inside a drawer or bin, the inside of the drawer or bin shall be treated as the inside of the liner with respect to placement.

NOTE As a practical example, a large **freezer** in a **refrigerator-freezer** with a **volume** of 180 l requires a total water mass of 720 g in 4 **ice cube trays.** The internal clearance of the **freezer** is 600 mm wide. Sensor positions TMP_{14} and TMP_{15} are 50 mm from the right hand lower wall. This leaves a space of 500 mm with clearances at each end for the placement of **ice cube trays.** Some 3 **ice cube trays** can be fitted at the lower level (120 mm + 25 mm minimum each, parallel to the sides), so one **ice cube tray** has to be placed on the upper level. If the **freezer** was deeper than say 460 mm, it would be possible to fit all 4 trays on the lower level (3 deep at right angles to the sides and one parallel to the sides) while maintaining clearances. See G.3.2 regarding the recommended size of **ice cube trays.**

All **ice cube trays** should be placed in a position that minimises restriction of air flow from any ducts or vents. When it is not possible to place the **ice cube trays** in the positions specified, equivalent positions are to be selected. Where equivalent positions are used, these shall be recorded in the test report. Where **ice cube trays** have to be arranged differently because of space restrictions, they shall remain on the same **shelf** and shall be as close as possible to the specified position. All **ice cube tray** positions shall be noted in the test report.

The sequence above is to define the position or location of each **ice cube tray**. The **ice cube trays** may be loaded in any order into these specified positions when they are being placed into the **frozen compartment** in G.4.2.



Dimensions in millimetres

NOTE Additional **shelves** may be present in the **refrigerating appliance** but are not shown in the figure. **Ice cube trays** are always placed on **shelves** in preference to drawers or baskets.

Figure G.3 – Ice cube tray locations and clearances

G.3.5 Temperature of the water to be processed

PET bottles with less than 500 g water should have the specified amount of water measured into the PET bottles prior to storage and temperature stabilization in the test room. Separate PET bottles containing sufficient water for all the **ice cube trays** (where applicable) shall be stored in the test room and (to avoid evaporation) shall only be decanted into the **ice cube trays** within 30 min of placement into the **frozen compartment**.

All PET bottles and **ice cube trays** shall be placed in the test room that is operating at the relevant **ambient temperature** in a position that is representative of the test room temperature. All PET bottles shall be placed vertically on a bench or the wooden test platform (floor) with no less than 50 mm clearance between them to allow free air circulation. This equipment shall remain in the test room for a period of no less than 15 h prior to the commencement of the **load processing efficiency** test.

NOTE The nominal ambient test temperatures for energy testing are 16 °C and 32 °C.

G.4 Load processing efficiency test method

G.4.1 Commencement of the load processing efficiency test

For **refrigerating appliances** without any **defrost control cycle,** the **load processing efficiency** test shall be preceded by a period of operation, at the **temperature control setting** used for the **load processing efficiency** test. The settings shall be such that it could qualify as a valid energy test period in accordance with B.3.

For a **refrigerating appliance** with one or more defrost systems (with its own **defrost control cycle**) the **load processing efficiency** test shall be preceded by:

- An energy test period that complies with B.3 at the **temperature control setting** used for the **load processing efficiency** test (including validity requirements); or
- An energy test period that complies with B.4 at the **temperature control setting** used for the **load processing efficiency** test (including validity requirements); or
- A **defrost and recovery period** that complies with C.3 at the **temperature control setting** used for the **load processing efficiency** test (as applicable).

NOTE Where stability is determined by DF1 (C.3), the load can only be inserted after confirmation of the defrost validity (i.e. after the end of Period F, which is at least 8 h after the operation of the defrost heater). Where stability has been established using **steady state** conditions or an earlier defrost, the load should be inserted as soon as practicable after the **defrost and recovery period** has been completed to minimise the chance of another defrost occurring prior to completion of the load processing test. As a guide, more than 5 h after the defrost heater operates (which could normally qualify as the start of Period F under C.3.1) is recommended (laboratories should use their experience of previous valid **defrost and recovery periods** to make an accurate judgment). In this case the previous **defrost and recovery period**, which is immediately prior to load insertion, is not included in the load processing test period.

For all product types, the **temperature control settings** shall remain unchanged for the duration of the **load processing efficiency** test.

For simple products with regular compressor cycles, a compressor on event can be taken as the start of the **load processing efficiency** test. For more complex products, a temperature maximum in the **compartment** that dominates the **energy consumption** can be taken as the start of the **load processing efficiency** test (see Annex B for more guidance). Where the **processing load** is inserted during the **defrost and recovery period**, the start of the test is defined as the start of that **defrost and recovery period**.

Insertion of the load during the **defrost and recovery period** (prior to establishment of **steady state** conditions) is generally not recommended.

G.4.2 Placement of the load

The load shall be prepared in accordance with Clause G.3. The load shall be placed in the **refrigerating appliance** as specified in Clause G.3 as soon as practicable after the start of a **temperature control cycle** as specified in G.4.1, but while the compressor is still operating (for simple products) or before a **compartment** temperature minimum is reached (for more complex products). The loading of each **compartment** shall be undertaken with one door opening and closing for that **compartment**. The door shall be left open at an angle of at least 90 degrees from the closed position for a duration that is as close as possible to one minute (±5 s) for each storage **compartment** being loaded, irrespective of the time taken to load the

compartment (usually considerably less than one minute). Where there are two doors provided to access the **compartment** to which the **processing load** is added, both doors shall be opened together. Where a **refrigerating appliance** has both **frozen** and **unfrozen compartment** types to be loaded, the **unfrozen compartment** shall be loaded first.

A recommended time for door opening and for door closing is 2,5 s, leaving 55 s to load each **compartment**. Adding the **processing load** near the start of a **temperature control cycle** is recommended as the load will then begin to be processed near the start of the **load processing efficiency** test period. Probable start times for future **temperature control cycles** can be readily predicted for products with regular behaviour, allowing load placement to be organised in advance. Care is required to meet the requirements of G.4.2 in cases where compressor runs are short. The exact number of load elements and their position should be planned out well before the door is opened and the load is placed.

G.4.3 Measurements to be taken

Prior to and for the duration of the **load processing efficiency** test, temperature and energy measurements shall be recorded as specified in accordance with Annex A as for an **energy consumption** test.

G.4.4 Conclusion of load processing efficiency test

The **load processing efficiency** test is concluded when **stable operating conditions** have been reached after the load has been fully processed (i.e. the water or ice has been brought to approximately the temperature in each **compartment**). The test period concludes at the end of a complete **temperature control cycle**. The **temperature control settings** shall remain unchanged for the duration of the **load processing efficiency** test.

The testing for the **load processing efficiency** test for a **refrigerating appliance** without a **defrost control cycle** shall be completed with an energy test period that complies with Clause B.3 (including validity requirements).

The testing for the **load processing efficiency** test for a **refrigerating appliance** with one or more defrost systems (each with its own **defrost control cycle**) is completed with an energy test period that complies with:

- Clause B.3 (including validity requirements), or
- Clause B.4 (including validity requirements) which terminates with a **defrost and recovery period** that complies with the validity requirements of C.3 (as applicable).

The end criteria for the **load processing efficiency** test are quite stringent as it is possible that the **compartment** temperature(s) may appear to have reached **steady state** values without the loads themselves being fully cooled down or frozen. Thus it is necessary to demonstrate that the **refrigerating appliance** has returned to **steady state** operation by checking both the **compartment** temperatures and the power consumption over a specified minimum period.

It is common for the **compartment** temperature(s) and the power consumption to stabilise after the addition and complete processing of the load to a value that is slightly different from the conditions prior to the addition of the load. Usually these changes are quite small, but in some cases these can be significant. This can occur when the load added affects the air flow in the **compartment** or there is an indirect effect on the internal temperature sensor of the **refrigerating appliance**. In some cases the load can trigger the operation of a variable output compressor onto a higher step value, for example, which may result in higher power and lower **compartment** temperatures. To reduce these impacts, laboratories have the option of placing an initial **processing load** into the **refrigerating appliance** and replacing this with a new **processing load** once this initial load is fully stabilised (see details below). Data from the second **processing load** is used to determine the **load processing efficiency**.

Differences in internal temperature conditions and power before and after the addition of the load have little impact as the analysis only considers the **energy consumption** from the **temperature control cycle** that the load is added (therefore little, if any, operation in the condition prior to the insertion of the load is included in the **load processing efficiency** test period).

NOTE 1 The main energy effect from changes in internal **compartment** temperatures before and after the load has been processed is the associated change in thermal mass (or capacitance) of the **refrigerating appliance**. Analysis has shown that, within the validity limits set out below, these effects are small and can be ignored.

The following additional two validity criteria apply to the measured parameters at the start (prior to insertion of the load) compared with their values during the stability period at the end of the **load processing efficiency** test:

- The difference of the **steady state** power P_{SSM} shall not exceed 5 % or 2 W, whichever is the greater value; and
- The difference of the **steady state** temperature in each **compartment** shall not exceed 1 K.

In the case where the initial validity is determined using a defrost under C.3 (refer G.4.1) because the validity to B.3 or B.4 cannot be established (e.g. due to insufficient test time), the initial **steady state power** P_{SSM} and **steady state** temperature above is taken as the average power of Period D and Period F (Case DF1 in C.3).

In the case of a **refrigerating appliance** with one or more defrost systems (each with its own **defrost control cycle**), where the above conditions are not met, the appliance shall be operated until the next **defrost and recovery period** has been completed and a new **steady state** condition established and assessed against these criteria.

If both of these validity criteria cannot be met after a subsequent defrost, the test shall be repeated by replacing the existing load (already processed to the **compartment** temperature) with new load under the same control conditions (as set out in G.3, G.4.1 and G.4.2). As set out above, placing an initial **processing load** into the **refrigerating appliance** and (on completion of the processing of the load) replacing this with a new **processing load** is optional for all **load processing efficiency** tests.

For **refrigerating appliances** with one or more **defrost control cycles,** any **defrost and recovery period** that occurs during the **load processing efficiency** test (i.e. before the load has been fully processed and **steady state** conditions established) shall be allowed to continue to completion (see Figure G.5). The end of the **load processing efficiency** test is when **steady state** conditions are reached after the completion of a valid **defrost and recovery period** as specified above.

NOTE 2 The additional energy associated with **defrost and recovery periods** that occur during the **load processing efficiency** test is taken into account in G.5.3.

G.5 Determination of load processing efficiency

G.5.1 General

Once the **load processing efficiency** test has concluded, the data is then analysed in order to determine the **load processing efficiency**. The objective is to determine the additional **energy consumption** required by the **refrigerating appliance** to process the added load back to a **steady state** condition. This is illustrated in Figure G.4. This is then compared to the calculated energy change in the added water load (**volume** of water times the enthalpy change) in order to quantify the heat energy that has been removed from the **refrigerating appliance** during processing.

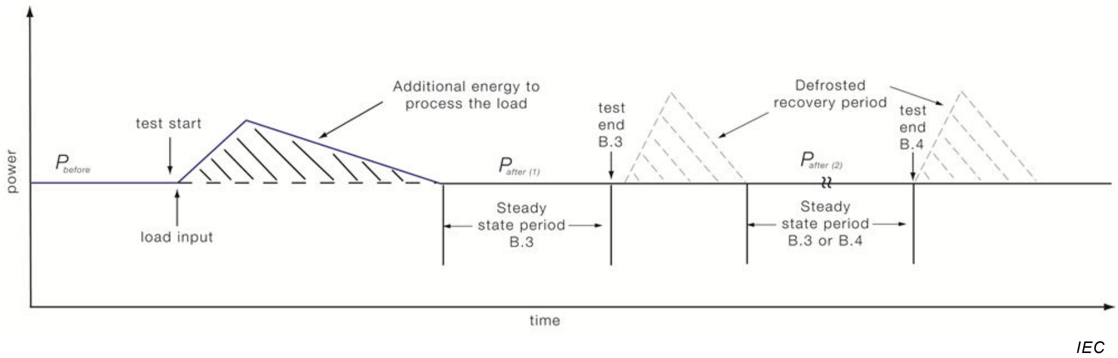


Figure G.4 – Representation of the additional energy to process the added load

The additional energy to process the load is always calculated from the value of P_{after} as illustrated in Figure G.4 back to the point where the load was added (test start).

In some cases the power before the load is added (P_{before}) can be higher or lower than the power after the load is added (P_{after}). This difference does not affect the calculations as the power difference is considered only back to the point where the load is added.

G.5.2 Quantification of input energy

The input energy is calculated by estimating the energy change in the water load, starting at the test room **ambient temperature** and finishing at the measured **compartment** temperature.

Simplified equations to estimate the energy change in the water are provided in G.5.2, based on standard enthalpy data. While these equations will give quite accurate results, test laboratories may find it more convenient to use software or add-ins that can automatically calculate the enthalpy change for water. Care is required for any **compartments** that operate close to freezing (0 °C) as the energy required for the phase change from liquid to ice is substantial. If the nominal final **compartment** temperature is below freezing, **ice cube trays** should be inspected to ensure that they are fully frozen.

The energy change of water in **unfrozen compartments** (where the final temperature is above freezing) is given by:

$$E_{unfrozen-test} = \frac{\left[M_1 \times (T_{amb} - T_1) + M_2 \times (T_{amb} - T_2) + M_3 \times (T_{amb} - T_3)\right] \times 4{,}186}{3{,}6} \qquad (48)$$

where

$E_{unfrozen\text{-}test}$ is the energy removed from the water load in the **unfrozen compartment** during the test in Wh

M_1 is the mass of water located adjacent to TMP_1 (positions C, F) in kg

T_1 is the average temperature of the temperature sensor at position TMP_1 during the valid energy test period (B.3 or B.4) after load processing in °C

M_2 is the mass of water located adjacent to TMP_2 (positions E, B) in kg

T_2 is the average temperature of the temperature sensor at position TMP_2 during the valid energy test period (B.3 or B.4) after load processing in °C

M_3 is the mass of water located adjacent to TMP_3 (positions A, D) in kg

T_3 is the average temperature of the temperature sensor at position TMP_3 during the valid energy test period (B.3 or B.4) after load processing in °C

T_{amb}	is the measured average **ambient temperature** for 6 h prior to the placement of the water load into the **refrigerating appliance** (nominal initial water temperature)
4,186	is a factor for enthalpy change of water in kJ/(kg.K) (while unfrozen)
3,6	is a factor to convert kJ to Wh (s/h $\times$ 10^{-3}).

The units of mass above are kg, whereas g are used in many places in this Annex, so care is required to ensure the correct units are used.

The energy change of water in **frozen compartments** (where the final temperature is below freezing) is given by:

$$E_{frozen-test} = \frac{\left\lfloor M_{tot-fz} \times (4{,}186 \times T_{amb} + 333{,}6 - T_{fz-av} \times 2{,}05) \right\rfloor}{3{,}6} \qquad (49)$$

where

$E_{frozen\text{-}test}$	is the energy removed from the water load in the **frozen compartment** in Wh
$M_{tot\text{-}fz}$	is the total mass of water placed in the **frozen compartment** in kg
$T_{fz\text{-}av}$	is the average temperature of all sensors in the **compartment** during the valid energy test period (B.3 or B.4) after load processing in °C
T_{amb}	is the measured average **ambient temperature** for 6 h prior to the placement of the water load into the **refrigerating appliance** (nominal initial water temperature)
4,186	is a factor for enthalpy change of water in kJ/(kg.K) (while unfrozen)
2,05	is a factor for enthalpy change of water in kJ/(kg.K) (while frozen)
333,6	is a factor for enthalpy water phase change in kJ/ kg (water to ice)
3,6	is a factor to convert kJ to Wh (s/h $\times$ 10^{-3}).

The value of temperature $T_{fz\text{-}av}$ shall be negative, which gives a greater energy change for a colder temperature. The above equation assumes a uniform average temperature in the **frozen compartment**, which is considered to be a sufficiently accurate estimate. The units of mass above are kg, whereas g are used in many places in this Annex, so care is required to ensure the correct units are used.

The total test input energy at a given ambient test room temperature is given as:

$$E_{input\text{-}test} = E_{unfrozen\text{-}test} + E_{frozen\text{-}test} \qquad (50)$$

G.5.3 Quantification of additional energy used to process the load

The principle used to quantify the additional energy used to process the load is to establish a period of **steady state** operation after the load has been fully processed. The additional energy is then calculated as the difference between the actual **energy consumption** from the start of the **load processing efficiency** test (at the point of load input) to the end of the **steady state** period (P_{after}) completion minus the power that would have been consumed over the same period if the power consumption had been at the **steady state** power (P_{after}) for the same period.

If one (or more) **defrost and recovery period(s)** has occurred while the load is being processed, the representative **defrost and recovery** energy at the test temperature as determined in accordance with Annex C is subtracted from the additional energy. This is illustrated in Figure G.5.

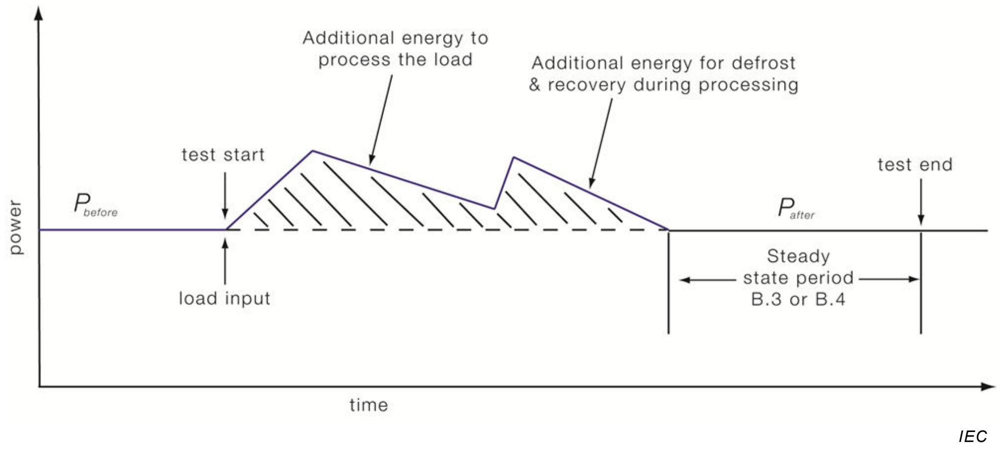


Figure G.5 – Case where a defrost and recovery period occurs during load processing

The additional energy to process the added load is given by:

$$\Delta E_{additional-test} = (E_{end} - E_{start}) - P_{after} \times (t_{end} - t_{start}) - z \times \Delta E_{df} \qquad (51)$$

where

$\Delta E_{additional\text{-}test}$ is the additional energy consumed by the **refrigerating appliance** during the test to fully process the loaded added as specified in Clause G.3

E_{start} is the accumulated energy reading at the start of **load processing efficiency** test as defined in G.4.1 in Wh

E_{end} is the accumulated energy reading at the end of **load processing efficiency** test as defined in G.4.4 in Wh

P_{after} is the **steady state** power consumption that occurs after the load has been fully processed during the valid energy test period (Clause B.3 or Clause B.4) as defined in G.4.4 in W

t_{start} is the test time at the start of **load processing efficiency** test as defined in G.4.1 in hours

t_{end} is the test time at the end of **load processing efficiency** test as defined in G.4.4 in hours

ΔE_{df} is the additional **energy consumption** associated with **defrost and recovery** as determined in accordance with Annex C (Clause C.5)

z is an integer that equals the number of **defrost and recovery periods** that occur during and prior to the completion of the **load processing efficiency** test (see Figure G.5). This value is zero for **refrigerating appliances** without a defrost system or where no **defrost and recovery period** occurs during the **load processing efficiency** test (see Figure G.4).

G.5.4 Load processing efficiency

The **load processing efficiency** is given by:

$$Efficiency_{load,ambient} = \frac{E_{input-test}}{\Delta E_{additional-test}} \qquad (52)$$

where

$Efficiency_{load,ambient}$ is the measured **load processing efficiency** for the specified **ambient temperature** (unitless, Wh/Wh)

$E_{input\text{-}test}$	is the heat energy removed from the **processing load** during the test as defined in G.5.2
$\Delta E_{additional\text{-}test}$	is the additional energy consumed by the **refrigerating appliance** to fully process the load during the test as defined in G.5.3.

The measured value of $Efficiency_{load,ambient}$ may be greater than one.

For a **load processing efficiency** value to be used to estimate the impact on the **energy consumption** of a **refrigerating appliance**, an estimate of the user related input load is required (in Wh).

G.5.5 Load processing multiplier

Alternatively, a **processing load** multiplier "a" may be used as a multiplier of the input load specified in this standard (based on 12 g/l of **unfrozen** and 4 g/l of **frozen compartment volume**). A value of "a" = 1 for example would mean that the user related load would be equal to E_{input} every 24 h (see 6.8 where all values are converted to a daily **energy consumption**). The load multiplier "a" is likely to be larger in hotter tropical climates and smaller in cooler temperate climates. Under this approach the value of E_{input} is different for every different **refrigerating appliance** as the **volume** of **unfrozen** and **frozen compartments** is different and this approach assumes usage (user related **processing load**) is directly proportion to **volume**. Other factors (such as the number of householders) may also have an impact on the assumed user related load. It is also likely that the multiplier may need to be different for some product configurations (e.g. separate **freezers**), as these may have significantly different usage in some regions.

Where a load multiplier is used to estimate the additional energy associated with a processing load, it is important to calculate a normalised value for $E_{input\text{-}nominal}$ in order to correct for small variations in **compartment** temperatures and **ambient temperature** conditions that occur during a test. This is calculated by assuming the input **processing load** starts exactly at the nominal **ambient temperature** and ends up exactly at the **compartment target temperature**.

$$E_{unfrozen-nominal} = \frac{\lfloor M_{tot-unfz} \times (T_{amb-tar} - T_{unfz-tar}) \rfloor \times 4{,}186}{3{,}6} \tag{53}$$

where

$E_{unfrozen\text{-}nominal}$	is the energy removed from the water load in the **unfrozen compartment** for nominal conditions in Wh
$M_{tot\text{-}unfz}$	is the total mass of water in the **unfrozen compartment** in kg
$T_{unfz\text{-}tar}$	is the **target temperature** for **energy consumption** of the **unfrozen compartment** in °C (see Table 1)
$T_{amb\text{-}tar}$	is the nominal **ambient temperature** for the test (16 °C or 32 °C as applicable)
4,186	is a factor for enthalpy change of water in kJ/(kg.K) (while unfrozen)
3,6	is a factor to convert kJ to Wh (s/h × 10^{-3}).

$$E_{frozen-nominal} = \frac{\lfloor M_{tot-fz} \times (4{,}186 \times T_{amb-tar} + 333{,}6 - T_{fz-tar} \times 2{,}05) \rfloor}{3{,}6} \tag{54}$$

where

$E_{frozen\text{-}nominal}$	is the energy removed from the water load in the **frozen compartment** at nominal conditions in Wh
$M_{tot\text{-}fz}$	is the total mass of water placed in the **frozen compartment** in kg

$T_{fz\text{-}tar}$ is the **target temperature** for **energy consumption** of the **frozen compartment** in °C (see Table 1)

$T_{amb\text{-}tar}$ is the nominal **ambient temperature** for the test (16 °C or 32 °C as applicable)

4,186 is a factor for enthalpy change of water in kJ/(kg.K) (while unfrozen)

2,05 is a factor for enthalpy change of water in kJ/(kg.K) (while frozen)

333,6 is a factor for enthalpy water phase change in kJ/kg (water to ice)

3,6 is a factor to convert kJ to Wh (s/h × 10^{-3}).

The total nominal input energy at a given ambient test room temperature is given as:

$$E_{input\text{-}nominal} = E_{unfrozen\text{-}nominal} + E_{frozen\text{-}nominal} \tag{55}$$

The following values shall be included in the test report where this value is measured and reported:

- **Volume** of all **unfrozen compartments** in l
- **Volume** of all **frozen compartments** in l
- Mass of water load added to **unfrozen compartments** in g
- Mass of water load added to **frozen compartments** in g
- $E_{input\text{-}test}$ for each specified ambient test temperature in Wh
- $\Delta E_{additional\text{-}test}$ for each specified ambient test temperature in Wh
- $Efficiency_{load,ambient}$ for each specified ambient test temperature
- $E_{input\text{-}nominal}$ for each specified ambient test temperature in Wh

All values used to determine the **load processing efficiency** shall be reported.

G.5.6 Addition of user related loads into daily energy

The impact of user related loads can be included in the daily **energy consumption**. User related loads arise from normal actions such as door openings (and the associated air exchange), the insertion of warm food and drink loads that are subsequently cooled (and sometimes frozen) and the production of ice.

The method of determining the **load processing efficiency** for the **refrigerating appliance** is set out in this Annex. This value provides an estimate of the incremental **energy consumption** required to remove each unit of user related heat load equivalent that arises from **normal use**. The magnitude of user related loads are highly variable at a regional level as they depend on climate, season and indoor conditions, as well as user habits. User related loads are also likely to vary to some extent depending on the size and type of the **refrigerating appliance** and some demographic factors such as the number of householders accessing the **refrigerating appliance** and occupancy (time of day people are at home). Average daily user related loads can vary from an average of 50 Wh/d to 500 Wh/d, depending on season, climate, product type, product size and demographics.

NOTE 1 Heavy usage can result in shorter **defrost intervals**. **Defrost intervals** are primarily a function of ambient conditions and door openings (and to a lesser extent uncovered liquid loads as well as fruit and vegetables) thus the relatively large loads added here with only a single door opening per **compartment** are not likely to simulate the usage that would prompt short **defrost intervals**. The impact of changes in **defrost interval** is not directly measured in the **load processing efficiency** test but is estimated through an adjustment to Δt_{df}. This is somewhat complicated as the **defrost interval** affects the **steady state power consumption** and the average temperature of the test points, so the exact impact cannot be directly calculated. Unless there is a large change in the **defrost interval** in response to user related loads (which may be a form of circumvention), the effect on **energy consumption** should be small and has been ignored in this calculation.

Where an estimate of user related loads is known in Wh/d, the impact on the daily **energy consumption** at a given **ambient temperature** can be estimated as follows:

$$\Delta E_{processing} = \frac{E_{user}}{Efficiency_{load,ambient}} \tag{56}$$

where

$\Delta E_{processing}$	is the additional daily **energy consumption** of the **refrigerating appliance** in Wh/d to process the user related load E_{user}
E_{user}	s the user related heat load equivalent entering the **refrigerating appliance** in Wh/d arising from normal usage (specified by region)
$Efficiency_{load,ambient}$	is the **load processing efficiency** at the specified **ambient temperature** in accordance with this Annex in Wh/Wh (dimensionless).

NOTE 2 The impact of user related loads at intermediate temperatures between the test **ambient temperatures** of 16 °C and 32 °C can be estimated by linear interpolation of the **load processing efficiency** $Efficiency_{load,ambient}$ between these temperatures. User related loads are generally much lower at a lower **ambient temperature** for the same tasks. To obtain a good estimate of the impact of user related loads over a whole year, an estimate of monthly average user related heat load equivalents (input) values is recommended.

Alternatively, the specified **processing load** in this Annex (which is dependent on **volume**) can be used as basis for scaling the **processing load** by region.

$$\Delta E_{processing} = \frac{E_{input-nominal}}{Efficiency_{load,ambient}} \times a \tag{57}$$

where

$\Delta E_{processing}$	is the additional daily **energy consumption** of the **refrigerating appliance** in Wh/d to process the specified load
$E_{input\text{-}nominal}$	is the nominal **processing load** for the specified water load at nominal ambient and **compartment target temperatures** in Wh/d (see G.5.4)
a	is a regional factor to scale the **processing load**
$Efficiency_{load,ambient}$	is the **load processing efficiency** at the specified **ambient temperature** in accordance with this Annex in Wh/Wh (dimensionless).

NOTE 3 The preferred value for "a" is 1, in the absence of local data. The value of "a" should not exceed 2.

The value for $\Delta E_{processing}$ can be added to the daily **energy consumption** value to estimate a value user related usage elements. If the values at an ambient of 16 °C and 32 °C are both used, the annual factor could be expressed as:

$$\Delta E_{processing\text{-}annual} = f\{\Delta E_{processing16C}, \Delta E_{processing32C}\} \tag{58}$$

In accordance with regional requirements, the total annual **energy consumption** of a **refrigerating appliance** (Formula (4), 6.8.5) can be expanded to include **processing load** as follows:

$$E_{total} = f\{E_{daily16C}, E_{daily32C}\} + E_{aux} + \Delta E_{processing\text{-}annual} \tag{59}$$

See Annex I for worked examples.

Annex H
(normative)

Determination of volume

H.1 Scope

This Annex describes methods for computing total **volume** of **refrigerating appliances**. This Annex is intended to provide a uniform means of determining the size, taking into consideration the special features and/or functional components which are located within the refrigerated **compartment**(s). It is not intended to provide a means of measuring the food-storage capacity, the usable **volume** or the usability of the **volume**.

The method set out in this Annex is based on the logic that anything not necessary for the control of temperature in the internal space has been removed and the space that it did occupy becomes part of the **volume**. Thus, for example, the light together with its housing is not necessary for the appliance to maintain internal conditions so is considered to be removed, while any **user-adjustable temperature control** and its housing as well as ductwork to distribute air is considered to be in place.

H.2 Total volume

H.2.1 Volume measurements

All measured **compartment volumes** shall be rounded to the nearest 0.1 l. The total **volume** shall be the sum of these rounded **compartment volumes** and the declared value for total **volume** shall be rounded to the nearest whole litre.

H.2.2 Determination of volume

The **volume** shall take into account the exact shapes of the walls including all depressions or projections. For through the door ice and water dispensers, the ice chute shall be included in the **volume** up to the dispensing function.

When the **volume** is determined, internal fittings such as **shelves**, removable partitions, containers and interior light housings shall be considered as not being in place.

The items below shall be considered as being in place and their **volumes** deducted:

– The **volume** of control housings.
– The **volume** of the **evaporator** space (which includes any space made inaccessible by the **evaporator**) (see H.2.3).
– The **volume** of air ducts required for proper cooling and operation of the unit.
– Space occupied by **shelves** moulded into the inner door panel.

For clarification, the through the door ice and water dispensers and the insulating hump are not included in the **volume**. No part of the dispenser unit shall be included as **volume**.

H.2.3 Volume of evaporator space

The **volume** of the **evaporator** space shall be the product of the depth, width and height.

The total **volume** to be deducted shall comprise the following:

a) In the case of a forced air **evaporator**, the total **volume** of the **evaporator** cover and behind the **evaporator** cover shall be deducted, including the **volume** occupied by the **evaporator** fan and the fan scroll.

b) In the case of plate style (e.g. roll-bond) **evaporators**, the **volume** behind vertically installed plate-style **evaporators** and the **volume** above horizontally installed plate-style **evaporators** if the distance between the horizontal plate-style **evaporator** and the nearest liner surface above is less than 50 mm. Removable drip trays/troughs shall be considered as not being present.

c) In the case of **refrigerant** filled shelving, the **volume** above the uppermost **shelf** and below the lowermost **shelf**, if the distance between the **shelf** and the nearest horizontal plane of the cabinet inner wall is less than or equal to 50 mm. All other refrigerated **shelves** are considered as not present.

H.2.4 Two-star sections and/or compartments

Two-star sections and/or **compartments** are permitted both in the door and in the remaining **volume** of a **refrigerating appliance** when all the following conditions are met:

a) the **two-star section** or **compartment** is marked with the appropriate identification symbol (see IEC 62552-1:2015, 5.2);

b) the **two-star section** and/or **compartment** is separated from the **three-star** of **four-star volume** by a partition, container, or similar construction;

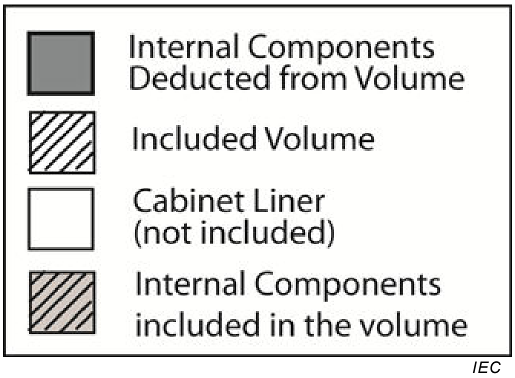
c) the **rated** total **two-star section volume** does not exceed 20 % of the total **volume** of the **compartment**;

d) the instructions give clear guidance regarding the **two-star section** and/or **compartment**;

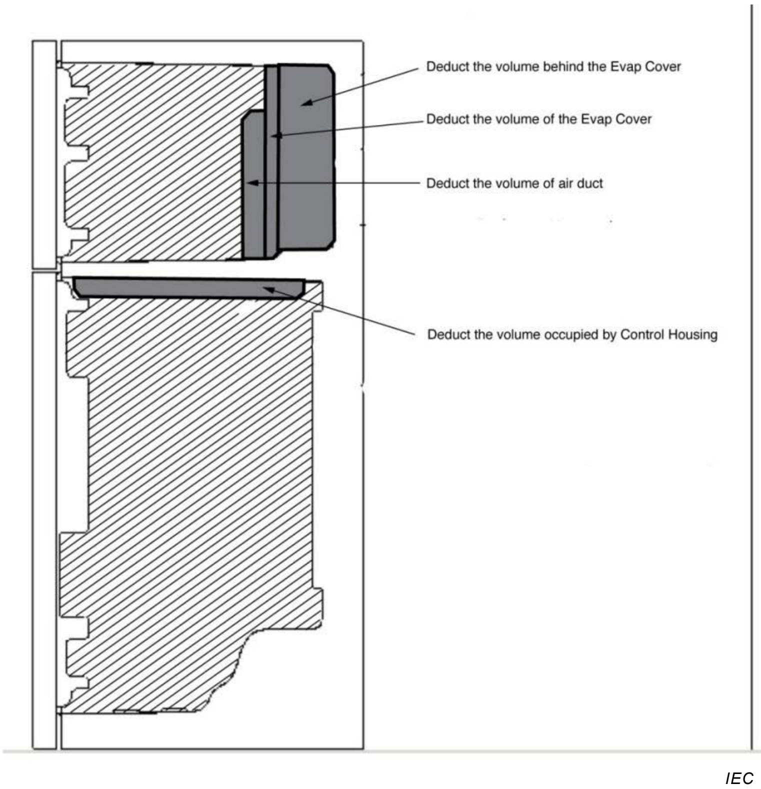
e) the **volume** of the **two-star section** and/or **compartment** is stated separately and is not included in the **three-star** or **four-star volume**.

H.3 Key for Figures H.1 through H.5

Figures H.1 through H.5 show typical configurations and are not intended to cover all design variations. A combination of components from the various figures may be used for other designs. The key to the drawings in this Annex is set out below:

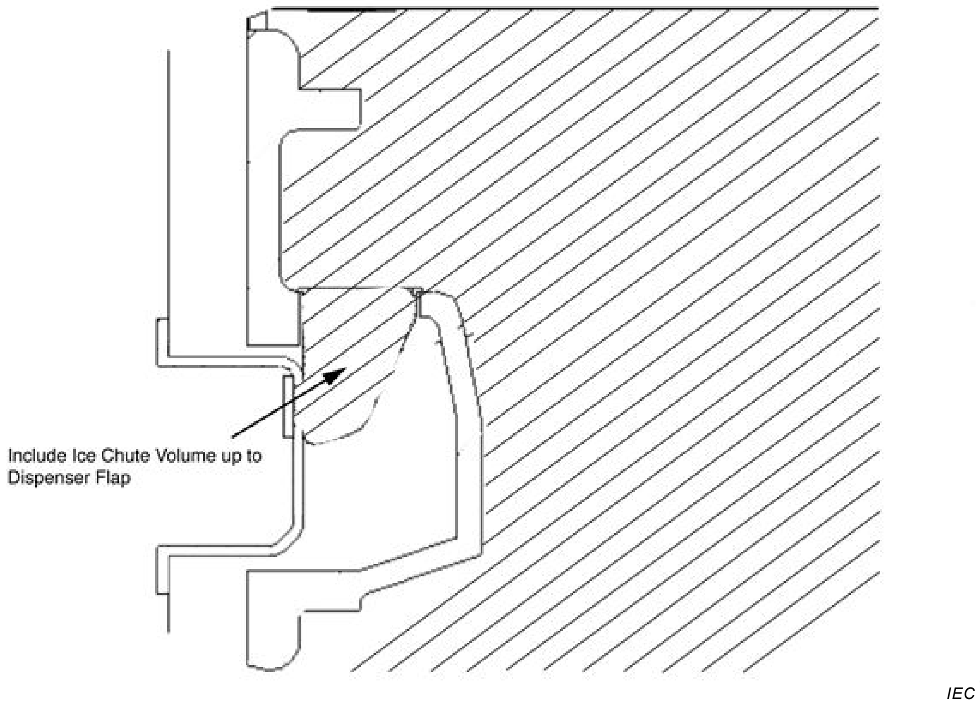


These figures graphically support procedures for determination of **volume** described in H.2.2 and H.2.3.



NOTE This diagram also applies to all side by side, bottom mounted **freezers** and separate single **compartment refrigerating appliances**. All deductions are the same. See the next figures for dispenser unit clarification.

Figure H.1 – Basic view of top mounted freezer appliance



NOTE For automatic ice-makers, plugs or covers over the chute (e.g. during shipping or periods of non-use) are removed for the determination of **volume**.

Figure H.2 – Automatic ice-maker dispenser and chute

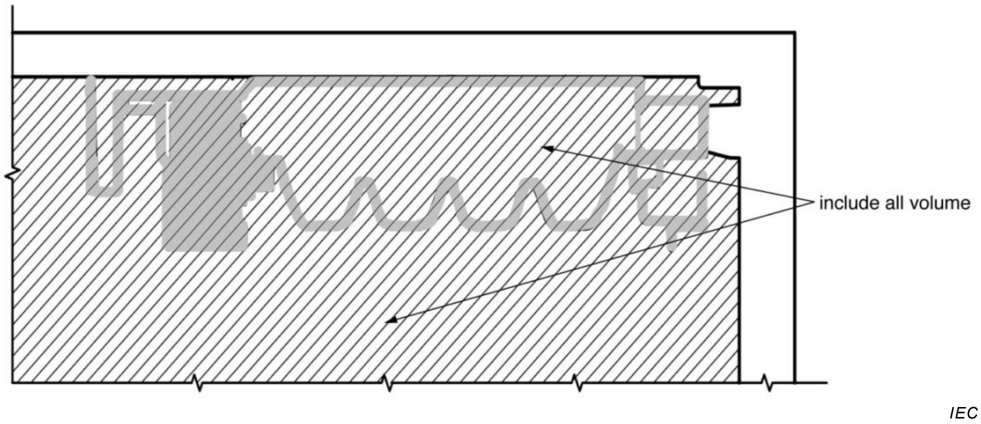


Figure H.3 – Automatic ice-making compartment

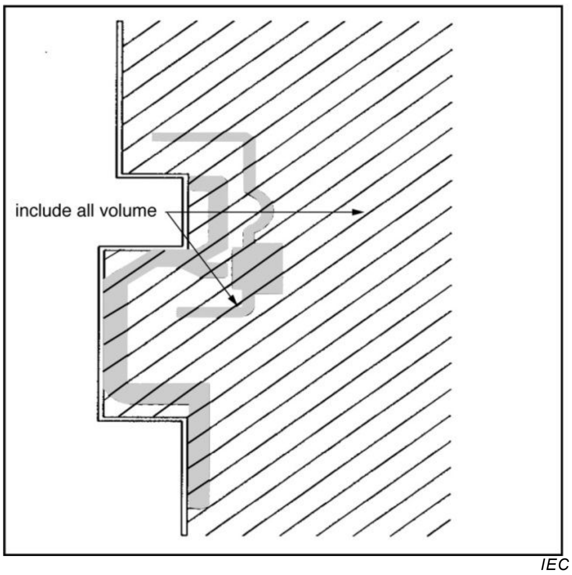
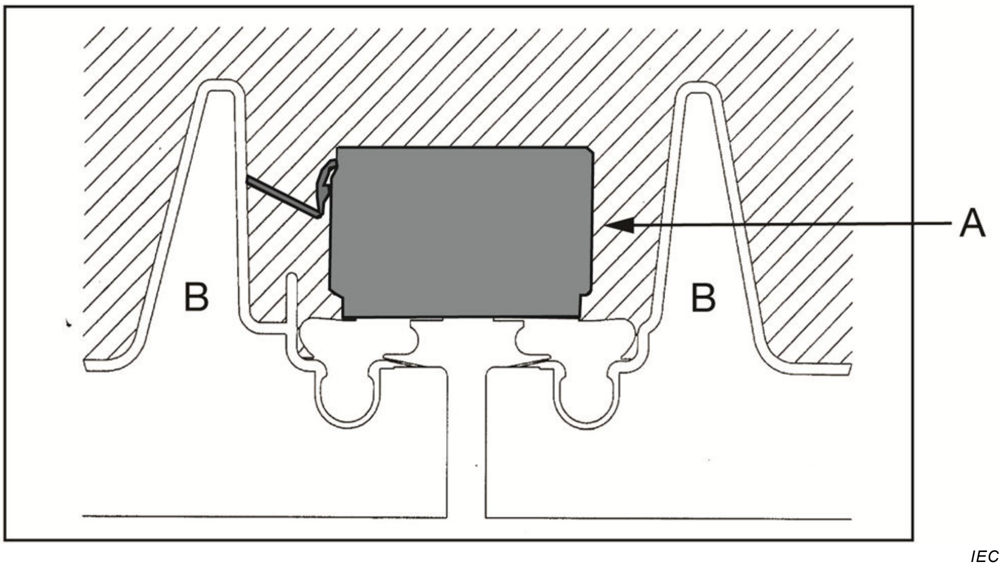


Figure H.4 – Rail of drawer type shelves or baskets



NOTE Rotary divider is calculated with the door closed. **Volume** of internal rotary divider (A) is not included. Protrusion from door liner (B) is not included.

Figure H.5 – Rotary divider of fresh food compartment for French Doors

Annex I
(informative)

Worked examples of energy consumption calculations

I.1 Example calculation of daily energy consumption

In accordance with 6.8.2, the daily **energy consumption** of a **refrigerating appliance** with a defrost system (with its own **defrost control cycle**) is given by:

$$E_{daily} = P \times 24 + \frac{\Delta E_{df} \times 24}{\Delta t_{df}} \quad (2)$$

The average temperature for each **compartment** for this **temperature control setting** is given by:

$$T_{average} = T_{ss} + \frac{\Delta Th_{df}}{\Delta t_{df}} \quad (3)$$

An **automatic defrost refrigerator-freezer** had the following test results at 32 °C:

Steady state power P_{32} (Annex B): 43,2 W

Steady state fresh food temperature T_{ff}: 3,6 °C

Steady state freezer temperature T_{fz}: –19,4 °C

Incremental defrost energy ΔE_{df32} (Annex C): 94,3 Wh

Accumulated temperature during defrost in fresh food ΔTh_{df32} (Annex C): +1,6 Kh

Accumulated temperature during defrost in **freezer** ΔTh_{df32} (Annex C): +8,5 Kh

Defrost interval Δt_{df32} (Annex D): 23,4 h

It also had the following test results at 16 °C:

Steady state power P_{16} (Annex B): 16,9 W

Steady state fresh food temperature: 2,9 °C

Steady state freezer temperature: –18,9 °C

Incremental defrost energy ΔE_{df16} (Annex C): 85,6 Wh

Accumulated temperature during defrost in fresh food ΔTh_{df16} (Annex C): +1,8 Kh

Accumulated temperature during defrost in **freezer** ΔTh_{df16} (Annex C): +8,1 Kh

Defrost interval Δt_{df16} (Annex D): 46,8 h

Daily energy and average **compartment** temperature at an ambient of 32 °C is:

$$E_{daily32} = 43{,}2 \times 24 + \frac{94{,}3 \times 24}{23{,}4} = 1\ 134 \text{ Wh/d}$$

$$T_{averageFF} = 3{,}6 + \frac{1{,}6}{23{,}4} = 3{,}67 \text{ °C}$$

$$T_{averageFZ} = -19{,}4 + \frac{8{,}5}{23{,}4} = -19{,}04 \text{ °C}$$

Daily energy and average **compartment** temperature at an ambient of 16 °C is:

$$E_{daily16} = 16{,}9 \times 24 + \frac{85{,}6 \times 24}{46{,}8} = 449 \text{ Wh/d}$$

$$T_{averageFF} = 2{,}9 + \frac{1{,}8}{46{,}8} = 2{,}94 \text{ °C}$$

$$T_{averageFZ} = -18{,}9 + \frac{8{,}1}{46{,}8} = -18{,}73 \text{ °C}$$

I.2 Variable defrost – calculation of defrost intervals

In Annex D, **variable defrost** controllers use a calculation approach to determine the **defrost interval** for determination of daily **energy consumption**.

The **defrost interval** for a **variable defrost** system is given by:

$$\Delta t_{df32} = \frac{\Delta t_{d-\max} \times \Delta t_{d-\min}}{[0{,}2 \times (\Delta t_{d-\max} - \Delta t_{d-\min}) + \Delta t_{d-\min}]} \tag{27}$$

where

Δt_{df32} is the **defrost interval** for the test **ambient temperature** of 32 °C

Δt_{d-max} is maximum possible **defrost interval** at an **ambient temperature** of 32 °C as specified by the manufacturer, in hours of elapsed time

Δt_{d-min} is minimum possible **defrost interval** at an **ambient temperature** of 32 °C as specified by the manufacturer, in hours of elapsed time

The following limits are placed on the input variable Δt_{d-max} and Δt_{d-min}, irrespective of the manufacturer's specification:

– Δt_{d-min} is normally greater than 6 h and shall not exceed 12 h at an **ambient temperature** of 32 °C (elapsed time).

– Δt_{d-max} shall not exceed 96 h at an **ambient temperature** of 32 °C (elapsed time).

– Δt_{d-max} shall be greater than Δt_{d-min} at an **ambient temperature** of 32 °C.

A manufacturer has a product where the elapsed time for relevant **defrost intervals** are:

- Δt_{d-min} is 6,5 h at an **ambient temperature** of 32 °C.
- Δt_{d-max} is 44 h at an **ambient temperature** of 32 °C.

- The condition that $\Delta t_{d\text{-}max}$ shall be greater than $\Delta t_{d\text{-}min}$ at an **ambient temperature** of 32 °C is satisfied.

At an **ambient temperature** of 32 °C the value of Δt_{df32} is:

$$\Delta t_{df32} = \frac{44 \times 6{,}5}{[0{,}2 \times (44 - 6{,}5) + 6{,}5]}$$

= 20,43 h (elapsed time)

= 20,4 h (rounded to the nearest 0,1)

According to D.4.2, the value of Δt_{df16} is twice the value of Δt_{df32} = 40,857 h (elapsed time)

= 40,9 h (rounded to the nearest 0,1).

I.3 Examples of Interpolation

I.3.1 General

This Clause I.3 provides examples for linear interpolation, triangulation and solutions using matrices. The examples provided are useful for checking that automated systems for analysis are calculating results correctly.

I.3.2 Linear interpolation

I.3.2.1 General

As set out in E.3.3 the equations used for linear interpolation are:

$$f_i = \frac{(T_{i-tar} - T_{i1})}{(T_{i2} - T_{i1})} \tag{28}$$

$$T_j = T_{j1} + f_i \times (T_{j2} - T_{j1}) \tag{29}$$

$$E_{i-tar} = E_1 + f_i \times (E_2 - E_1) \tag{30}$$

The following examples illustrate how these equations can be applied to test data.

I.3.2.2 Single compartment example

A separate **freezer** had the following test results at 32 °C in accordance with 6.8.2 as set out in Table I.1.

Table I.1 – Example of linear interpolation, single compartment

Parameter	Test 1	Test 2	Type	Target
Compartment A	T_{A1} = –19,6 °C	T_{A2} = –17,1 °C	**Freezer**	–18,0 °C
Energy	E_{Daily1} = 789 Wh/d	E_{Daily2} = 668 Wh/d		

Validity check: T_{A1} and T_{A2} shall not be more than 4 K apart. Result = OK.

As set out in Clause E.3, it is necessary to perform calculations for each **compartment** *i* from 1 to *n* **compartments**. Each of these iterations is referred to as a loop. There is only a single **compartment** so only 1 loop needs to be performed in this case.

Step 1: Calculate f_i = (–18,0 – (–19,6))/((–17,1) – (–19,6)) = 0,640. Verify that this is higher than 0 and lower than 1. Result = OK. (This is always the case if one test point lies above the **target temperature** and one below the **target temperature**).

Step 2: Calculate T_j = –19,6 + 0,640 × ((–17,1) – (–19,6)) = –18,0 (only needed for $j = 1$). As there is only one **compartment** this delivers the **target temperature** back for **compartment** i.

Step 3: Verify that for all T_j its value is equal or below target. In this case this is true. Then calculate E = 789 + 0,640 × (668 – 789) = 711,6 Wh/d.

Interpolation is on **Compartment** A and the slope S_i is given by:

$$S_i = \frac{(E_2 - E_1)}{(T_2 - T_1)} \tag{32}$$

$$S_i = \frac{(668 - 789)}{((-17{,}1) - (-19{,}6))} = -48{,}4 \text{ Wh/d/K}$$

I.3.2.3 Two compartments

First an example is given with two **compartments** with one point above and one point below the **target temperatures** for both **compartments** as shown in Table I.2.

Table I.2 – Example 1 of linear interpolation, two compartments

Parameter	Test 1	Test 2	Type	Target
Compartment A	T_{A1} = +4,9 °C	T_{A2} = +1,4 °C	Fresh food	+4,0 °C
Compartment B	T_{B1} = –16,5 °C	T_{B2} = –18,9 °C	**Freezer**	–18,0 °C
Energy	E_{Daily1} = 822,1 Wh/d	E_{Daily2} = 935,6 Wh/d		

Validity check: **Compartment** A temperatures of both points are within 4 K of each other as well as for **compartment** B, so linear interpolation can be used.

Loop 1 for i = A (**Compartment** A)

Step 1: Calculate f_i = (4,0 – 4,9)/(1,4 – 4,9) = 0,257. Verify that this is higher than 0 and lower than 1. Result is OK.

Step 2: Calculate T_j values:

T_A = 4,9 + 0,257 × (1,4 – 4,9) = 4,0 °C

T_B = –16,5 + 0,257 × (–18,9 – (–16,5)) = –17,12 °C

Step 3: T_A less than or equal to target of 4 °C? Result: true

T_B less than or equal to target of –18 °C ? Result: false

Not all interpolated temperature are below target so no **energy consumption** calculation: $E_{A\text{-}tar}$ = invalid.

End of loop for i = A

Loop 2 for i = B (**Compartment** B)

Step 1: Calculate f_i = (–18 – (–16,5))/(–18,9 – (–16,5)) = 0,625. Verify that this is higher than 0 and lower than 1. Result is OK.

Step 2: Calculate T_j values:

T_A = 4,9 + 0,625 × (1,4 – 4,9) = 2,71 °C

T_B = –16,5+0,625 × (–18,9 – (–16,5)) = –18,0 °C

Step 3: T_A less than or equal to target of 4 °C? Result: true

T_B less than or equal to target of –18 °C? Result: true

All interpolated temperature are below target so **energy consumption** interpolation: $E_{B\text{-}tar}$ = 822,1 + 0,625 × (935,6 – 822,1) = 893,0 Wh/d.

End of loop for i = B

The final interpolated **energy consumption** is E_{linear} = minimum valid value of $E_{A\text{-}tar}$ and $E_{B\text{-}tar}$ which means that E_{linear} = $E_{B\text{-}tar}$ = 893,0 Wh/d (noting that $E_{A\text{-}tar}$ is invalid in this case).

Interpolation is on **Compartment** B and the slope S_i is –47,292 Wh/d/K.

This example is illustrated in Figure I.1 and Figure I.2 which show that only interpolating on **compartment** B gives a valid result in this case.

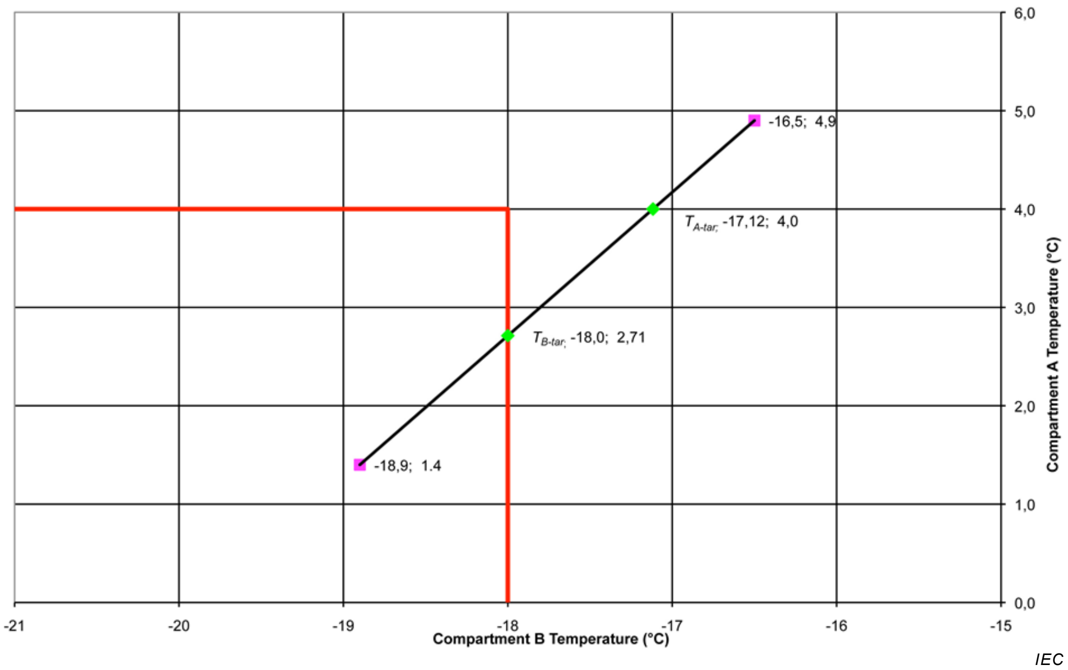


Figure I.1 – Example linear interpolation two compartments (Compartment B critical)

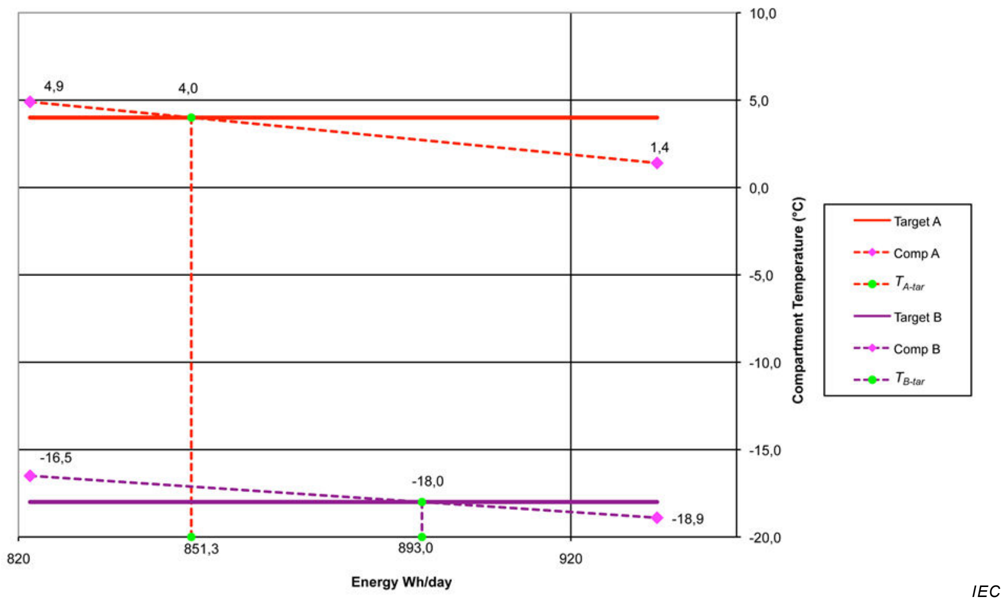


Figure I.2 – Example linear interpolation two compartments (Compartment B critical)

In the second example neither of the test points has both **compartments** below the **target temperatures** as shown in Table I.3. This can still lead to valid interpolation cases. If not valid, the algorithm will identify this.

Table I.3 – Example 2 of linear interpolation, two compartments

Parameter	Test 1	Test 2	Type	Target
Compartment A	T_{A1} = +5,2 °C	T_{A2} = +2,2 °C	Fresh food	+4,0 °C
Compartment B	T_{B1} = –18,8 °C	T_{B2} = –17,3 °C	**Freezer**	–18,0 °C
Energy	E_{Daily1} = 853,9 Wh/d	E_{Daily2} = 828,6 Wh/d		

Validity check: **Compartment** A temperatures of both points are within 4 K of each other as well as for **compartment** B, so linear interpolation can be used.

NOTE In this example (and the following example) the temperature of **Compartment** A and **Compartment** B are moving in opposite directions. This would normally only be possible where there are two independent **user-adjustable temperature controls** and where **Compartment** A is set colder for test Point 2 and **Compartment** B is set warmer for test Point 2.

Loop 1 for i = A (**Compartment** A)

Step 1: Calculate f_i = (4,0 – 5,2)/(2,2 – 5,2) = 0,400. Verify that this is higher than 0 and lower than 1. Result is OK.

Step 2: Calculate T_j values:

T_A = 5,2 + 0,400 × (2,2–5,2) = 4,0 °C

T_B = –18,8 + 0,400 × (–17,3 – (–18,8)) = –18,20 °C

Step 3: T_A less than or equal to target of 4 °C? Result: true

T_B less than or equal to target of –18 °C? Result: true

All interpolated temperatures are below target so the interpolated **energy consumption** becomes: $E_{A\text{-}tar}$ = 853,9 + 0,400 × (828,6 – 853,9) = 843,8 Wh/d.

End of loop for i = A

Loop 2 for i = B (**Compartment** B)

Step 1: Calculate f_i = (–18,0 – (–18,8))/(–17,3 – (–18,8)) = 0,533. Verify that this is higher than 0 and lower than 1. Result is OK.

Step 2: Calculate T_j values:

T_A = 5,2 + 0,533 × (2,2–5,2) = 3,60 °C

T_B = –18,8 + 0,533 × (–17,3 – (–18,8)) = –18,0 °C

Step 3: T_A less than or equal to target of 4 °C? Result: true

T_B less than or equal to target of –18 °C? Result: true

All interpolated temperatures are below target so **energy consumption** interpolation: $E_{B\text{-}tar}$ = 853,9 + 0,533 × (828,6 – 853,9) = 840,4 Wh/d.

End of loop for i = B

The final interpolated **energy consumption** is E_{linear} = minimum value of $E_{A\text{-}tar}$ and $E_{B\text{-}tar}$ which means that E_{linear} = $E_{B\text{-}tar}$ = 840,4 Wh/d.

Interpolation is on **Compartment** B and the slope S_i is –16,87 Wh/d/K.

This example is illustrated in Figure I.3 and Figure I.4 which show that there are two valid interpolation points. The minimum consumption value is taken as this is closer to the optimal case where both **compartment** temperatures would be at their respective **target temperatures**.

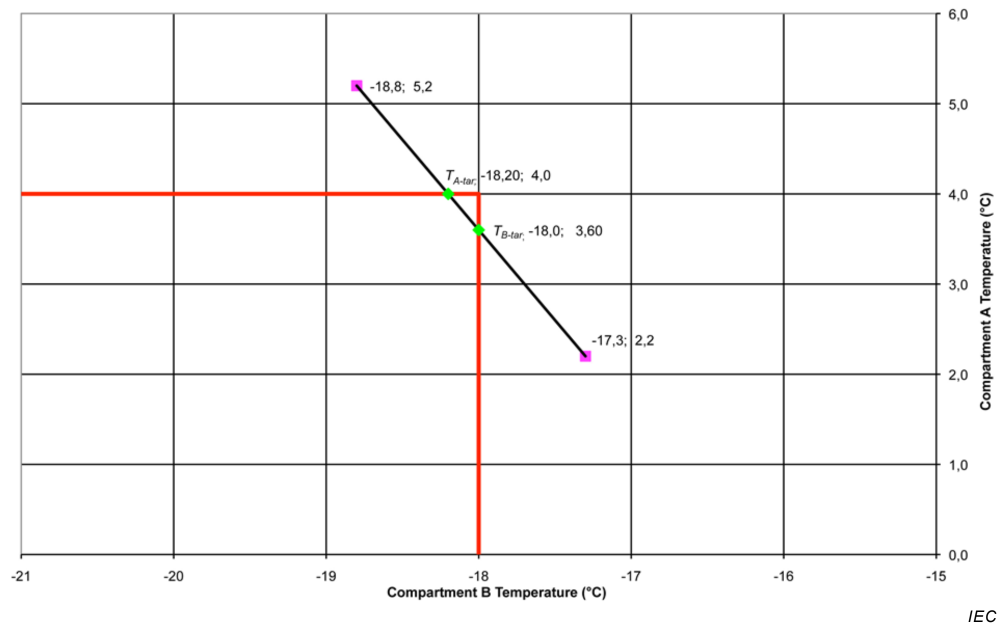


Figure I.3 – Example Interpolation where both test points have both compartments below target (two valid results)

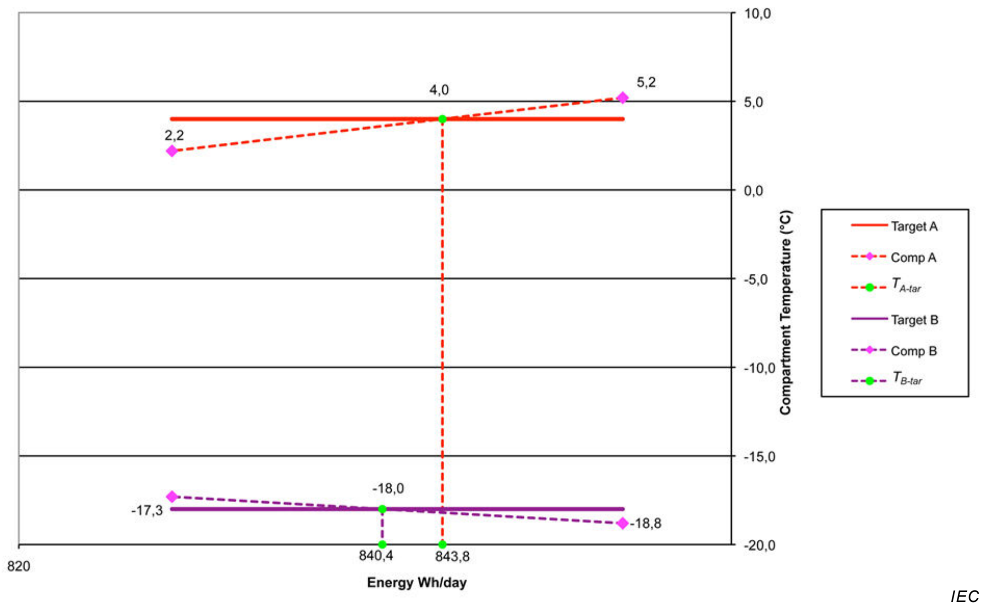


Figure I.4 – Example Interpolation where both test points have both compartments below target (two valid results)

The third example is to show what happens if there is no valid interpolation point possible. Example data is shown in Table I.4.

Table I.4 – Example 3 of linear interpolation, two compartments

Parameter	Test 1	Test 2	Type	Target
Compartment A	T_{A1} = +5,2 °C	T_{A2} = +2,3 °C	Fresh food	+4,0 °C
Compartment B	T_{B1} = –18,3 °C	T_{B2} = –16,8 °C	**Freezer**	–18,0 °C
Energy	E_{Daily1} = 853,9 Wh/d	E_{Daily2} = 828,6 Wh/d		

Validity check: **Compartment** A temperatures of both points are within 4 K of each other as well as for **compartment** B, so linear interpolation can be used.

Loop 1 for i = A (**compartment** A)

Step 1: Calculate f_i = (4,0 – 5,2)/(2,3 – 5,2) = 0,414. Verify that this is higher than 0 and lower than 1. Result is OK.

Step 2: Calculate T_j values:

T_A = 5,2 + 0,414 × (2,3 – 5,2) = 4,0 °C

T_B = –18,3 + 0,414 × (–16,8 – (–18,3)) = –17,68 °C

Step 3: T_A less than or equal to target of 4 °C? Result: true

T_B less than or equal to target of –18 °C? Result: false

Not all interpolated temperatures are below target so no interpolated **energy consumption** can be calculated: $E_{A\text{-}tar}$ = invalid.

End of loop for i = A

Loop 2 for i = B (**Compartment** B)

Step 1: Calculate f_i = (–18– (–18,3))/(–16,8 – (–18,3)) = 0,200. Verify that this is higher than 0 and lower than 1. Result is OK.

Step 2: Calculate T_j values:

T_A = 5,2 + 0,200 × (2,3 – 5,2) = 4,62 °C

T_B = –18,3 + 0,200 × (–16,8 – (–18,3)) = –18,0 °C

Step 3: T_A less than or equal to target of 4 °C? Result: false

T_B less than or equal to target of –18 °C? Result: true

Not all interpolated temperatures are below target so no interpolated **energy consumption** can be calculated: $E_{B\text{-}tar}$ = invalid.

End of loop for i = B

The final interpolated **energy consumption** cannot be derived as neither $E_{A\text{-}tar}$ nor $E_{B\text{-}tar}$ have valid values. This example is illustrated in Figure I.5 and Figure I.6. Another test point needs to be selected.

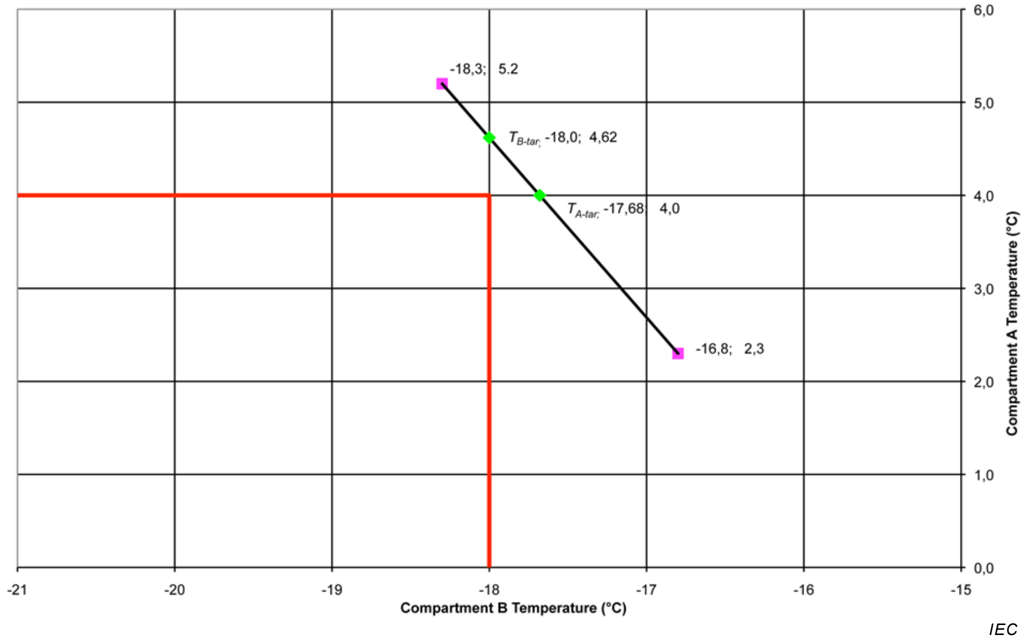


Figure I.5 – Example Interpolation where neither test point has both compartments below target (no valid results)

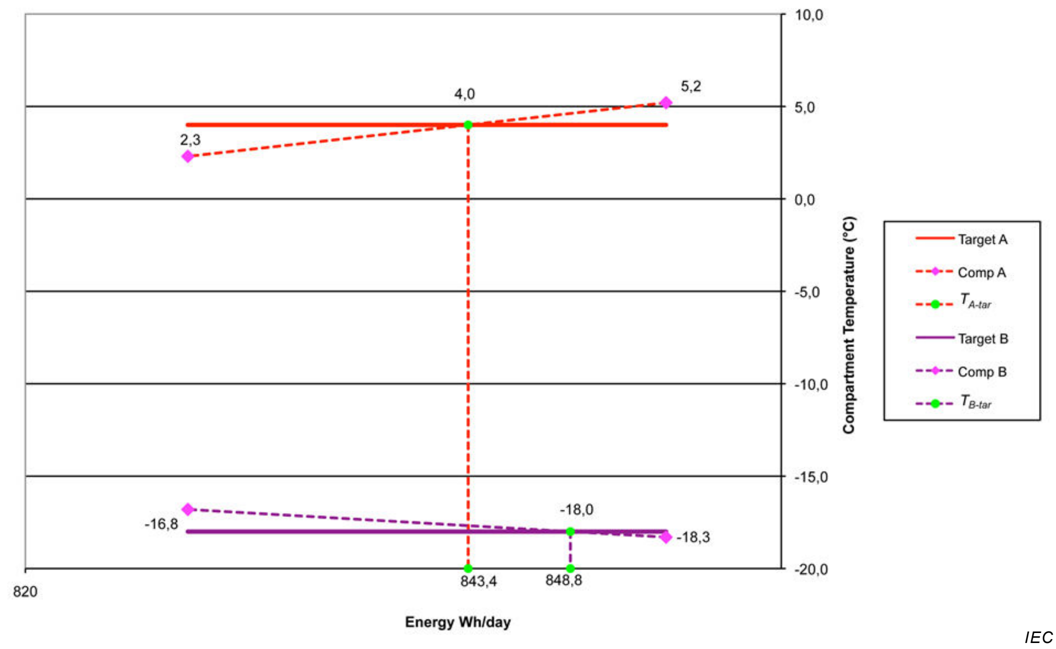


Figure I.6 – Example Interpolation where neither test point has both compartments below target (no valid results)

I.3.2.4 Multiple compartments

The next example deals with the case that two test point are available for a cabinet with 4 **compartments**. Example data is given in Table I.5.

Table I.5 – Example of linear interpolation, test data for four compartments

Parameter	Test 1	Test 2	**Compartment** Type	Target
Compartment A °C	+5,5	+2,4	**Fresh food**	+4,0
Compartment B °C	–16,5	–18,9	**Freezer** (Four-star)	–18,0
Compartment C °C	+1,3	–2,0	**Zero-star**	0,0
Compartment D °C	–10,7	–13,9	Frozen (**Two-star**)	–12,0
Energy Wh/d	822,1	935,6		
NOTE Green shading indicates interpolation at the **compartment target temperature**.				

Validity check: All **compartment** temperatures for both points lie within 4 K of each other, so linear interpolation can be used.

Loop 1 for i = A (**compartment** A)

Step 1: Calculate f_i = (4,0 – 5,5)/(2,4 – 5,5) = 0,484. Verify that this is higher than 0 and lower than 1. Result is OK.

Step 2: Calculate T_j values:

T_A = 5,5 + 0,484 × (2,4 – 5,5) = 4,0 °C

T_B = –16,5 + 0,484 × (–18,9 – (–16,5)) = –17,66 °C; loop can be stopped as > –18 °C: $E_{A\text{-}tar}$ = invalid.

As one of the **compartments** is above target for loop 1, calculations can be stopped (if done manually). In practice all values would be calculated simultaneously in a spreadsheet and validity of each point checked afterwards (see table below for an example).

End of loop for i = A

Loop 2 for i = B (**Compartment** B)

Step 1: Calculate f_i = (–18– (–16,5))/(–18,9 – (–16,5)) = 0,625. Verify that this is higher than 0 and lower than 1. Result is OK.

Step 2: Calculate T_j values:

T_A = 5,5 + 0,625 × (2,4 – 5,5) = 3,56 °C

T_B = –16,5 + 0,625 × (–18,9 – (–16,5)) = –18,0 °C

T_C = 1,3 + 0,625 × (–2,0 – 1,3) = –0,76 °C

T_D = –10,7 + 0,625 × (–13,9 – (–10,7)) = –12,7 °C

Step 3: T_A less than or equal to target of 4 °C? Result: true

T_B less than or equal to target of –18 °C? Result: true

T_C less than or equal to target of 0 °C? Result: true

T_D less than or equal to target of –12 °C? Result: true

All interpolated temperatures are below target so the interpolated **energy consumption** can be calculated: $E_{B\text{-}tar}$ = 822,1 + 0,625 × (935,6 – 822,1) = 893,0 Wh/d.

End of loop for i = B

Loop 3 for i = C (**compartment** C)

Step 1: Calculate f_i = (0,0 –1,3)/(–2,0 – 1,3) = 0,394. Verify that this is higher than 0 and lower than 1. Result is OK.

Step 2: Calculate T_j values:

T_A = 5,5 + 0,394 × (2,4 – 5,5) = 4,28 °C; loop can be stopped as > 4 °C: $E_{C\text{-}tar}$ = invalid.

End of loop for i = C

Loop 4 for i = D (**compartment** D)

Step 1: Calculate f_i = (–12,0 –(–10,7))/(–13,9 – (–10,7)) = 0,406. Verify that this is higher than 0 and lower than 1. Result is OK.

Step 2: Calculate T_j values:

T_A = 5,5 + 0,406 × (2,4 – 5,5) = 4,24 °C; loop can be stopped as >4 °C: $E_{D\text{-}tar}$ = invalid.

End of loop for i = D

The final interpolated **energy consumption** is E_{linear} = minimum value of $E_{A\text{-}tar}$ to $E_{D\text{-}tar}$. As only $E_{B\text{-}tar}$ has a valid value, this is by definition the E_{linear} value (893 Wh/d).

Interpolation is on **Compartment** B and the slope S_i is –47,29 Wh/d/K.

The calculations for this example are shown in Table I.6 and are illustrated in Figure I.7. Moving from coldest to warmest, **Compartment** B (with energy E_2) is the first to cross its **target temperature** (while all other **compartments** are less than **target temperature**). The data can also be laid out in a table, which is useful when calculating the results using a spreadsheet. Blue text is where **compartment** temperatures are at or below target, red text are temperatures above target. Only loop 2 (**Compartment** B at target) is valid (column 3, energy in green text) as all **compartments** are at or below **target temperature**.

Table I.6 – Example of linear interpolation, results for four compartments

Parameter	Interpolation **Compartment** A (loop 1)	Interpolation **Compartment** B (loop 2)	Interpolation **Compartment** C (loop 3)	Interpolation **Compartment** D (loop 4)
f_i	0,483 87	0,625	0,393 94	0,406 25
Compartment A °C	4,0	3,562 5	4,278 8	4,240 6
Compartment B °C	–17,661	–18,0	–17,445	–17,475
Compartment C °C	–0,296 77	–0,762 5	0,0	–0,0406 25
Compartment D °C	–12,248	–12,7	–11,961	–12,0
Energy Wh/d interpolated	877,02	893,04	866,81	868,21

NOTE
- Green shading indicates interpolation at the **compartment target temperature**.
- Red text indicates that the **compartment** temperature is above the **target temperature** (not valid).
- Blue text indicates that the **compartment** temperature is at or below **target temperature** (valid).
- Red text for energy indicates an invalid value as one or more **compartment** temperatures are above **target temperature** for that interpolation.
- Green text for energy indicates a valid value as all **compartment** temperatures are at or below target for that interpolation.

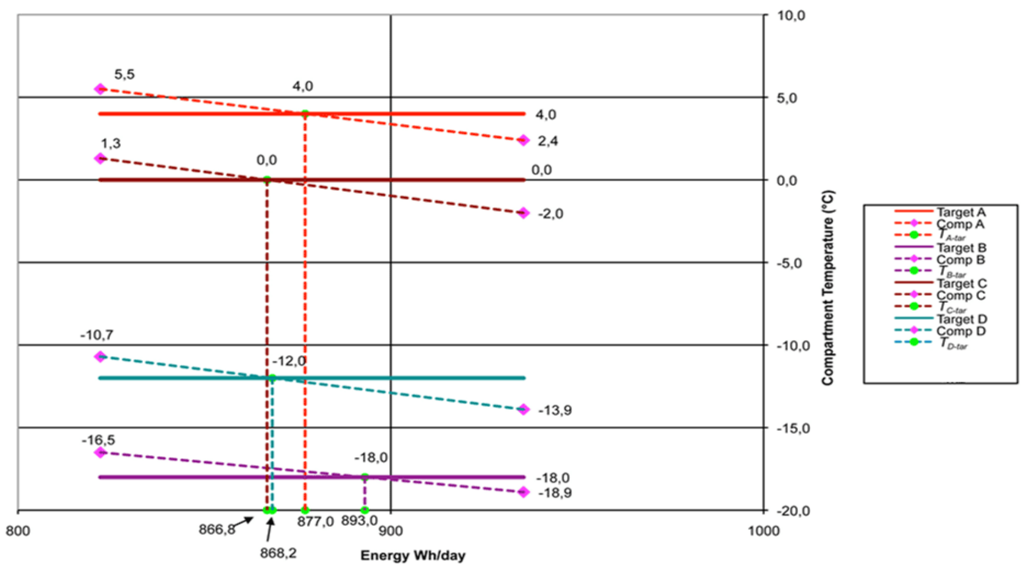


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Figure I.7 – Example Interpolation for 4 compartments

I.3.3 Two compartments – manual triangulation

For this example, we consider a **refrigerator-freezer** with two **compartments** used for triangulation. The test data for 3 points is given in Table I.7. This example provides a worked example of the equations in E.4.

Table I.7 – Example of triangulation, two compartments

Parameter	Test 1	Test 2	Test 3	Point 4 (calc)	Type	Target
Compartment A	–20,7	–17,5	–16,0	–18,435 8	**Freezer**	–18,0
Compartment B	+6,5	+0,8	+7,1	+6,789	**Fresh Food**	+4,0
Energy Wh/d	1 390	1 310	1 120	1 259,93		

All 3 test points lie within the ±4 K of the **target temperature** for each **compartment**, so the points are valid. The 3 test points surround the intersection of the **target temperatures** (as illustrated in Figure I.8, so triangulation can proceed.

Firstly check that Point Q lies inside the triangle formed by test points 1, 2 and 3. Calculate the following two parameters as set out in E.4.2.2:

$$Check1 = [(T_{B-tar} - T_{B1}) \times (T_{A2} - T_{A1}) - (T_{A-tar} - T_{A1}) \times (T_{B2} - T_{B1})] \times [(T_{B-tar} - T_{B2}) \times (T_{A3} - T_{A2}) - (T_{A-tar} - T_{A2}) \times (T_{B3} - T_{B2})]$$

$$Check2 = [(T_{B-tar} - T_{B2}) \times (T_{A3} - T_{A2}) - (T_{A-tar} - T_{A2}) \times (T_{B3} - T_{B2})] \times [(T_{B-tar} - T_{B3}) \times (T_{A1} - T_{A3}) - (T_{A-tar} - T_{A3}) \times (T_{B1} - T_{B3})]$$

Point Q lies within the triangle formed by Points 1, 2 and 3 if the following inequality is true:

IF {[$Check1 \geq 0$] AND [$Check2 \geq 0$]} = TRUE (33)

NOTE It is recommended that these equations be entered into a spreadsheet for regular use to avoid errors. A value of 0 for Check1 or Check2 indicates that the Point Q lies exactly on one of the triangle sides and that linear interpolation could yield the same result with less data.

In this case, $Check1$ and $Check2$ yield the following results:

$$Check1 = [(4 - 6{,}5) \times (-17{,}5 - (-20{,}7)) - (-18 - (-20{,}7)) \times (0{,}8 - 6{,}5)] \times [(4 - 0{,}8) \times (-16 - (-17{,}5)) - (-18 - (-17{,}5)) \times (7{,}1 - 0{,}8)]$$

$Check1$ = 58,750 5

$$Check2 = [(4 - 0{,}8) \times (-16 - (-17{,}5)) - (-18 - (-17{,}5)) \times (7{,}1 - 0{,}8)] \times [(4 - 7{,}1) \times (-20{,}7 - (-16)) - (-18 - (-16)) \times (6{,}5 - 7{,}1)]$$

$Check2$ = 106,291 5

As both $Check1$ and $Check2$ are greater than 0, Point Q lies inside the triangle formed by Points 1, 2 and 3, so triangulation using manual interpolation or matrices can proceed.

An alternative approach to check that Point Q lies inside the triangle (using the same principles) is set out in E.4.6. Calculate the Determinant of each of the following four matrices:

$$D_0 \text{ for } \begin{vmatrix} -20{,}7 & 6{,}5 & 1 \\ -17{,}5 & 0{,}8 & 1 \\ -16{,}0 & 7{,}1 & 1 \end{vmatrix} = 28{,}71$$

D_1 for $\begin{vmatrix} -18,0 & 4,0 & 1 \\ -17,5 & 0,8 & 1 \\ -16,0 & 7,1 & 1 \end{vmatrix} = 7,95$

D_2 for $\begin{vmatrix} -20,7 & 6,5 & 1 \\ -18,0 & 4,0 & 1 \\ -16,0 & 7,1 & 1 \end{vmatrix} = 13,37$

D_3 for $\begin{vmatrix} -20,7 & 6,5 & 1 \\ -17,5 & 0,8 & 1 \\ -18,0 & 4,0 & 1 \end{vmatrix} = 7,39$

As a check $D_0 = D_1 + D_2 + D_3$

28,71 = 7,95 +13,37 + 7,39 = correct

If D_1 and D_2 and D_3 are the same sign as D_0, then Point Q is inside of the triangle (correct).

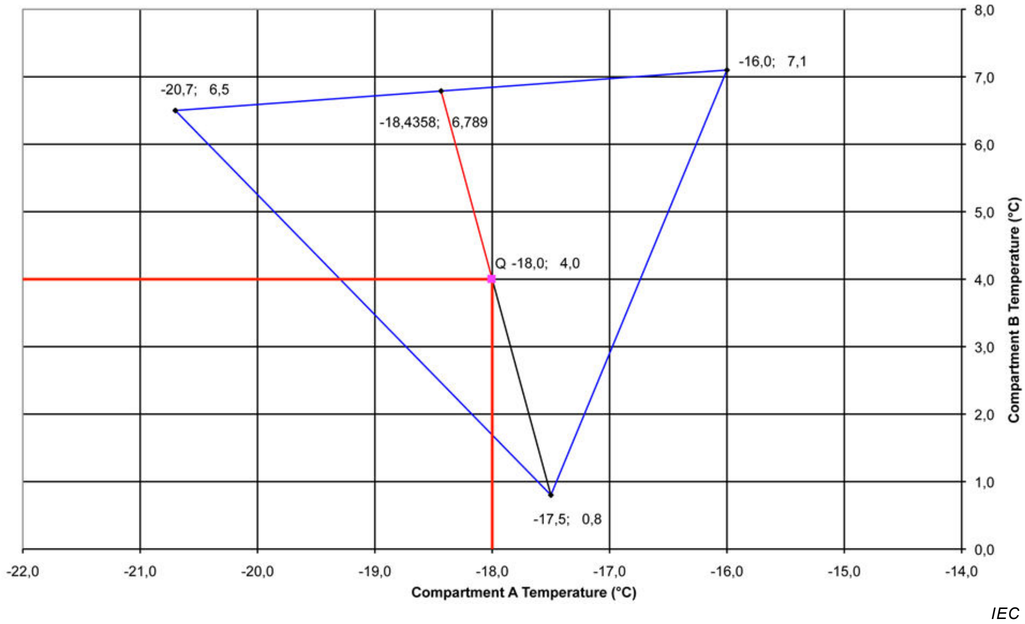


Figure I.8 – Example of triangulation (temperatures)

The equations to determine the values for manual interpolation are set out below.

Calculate the temperature in C**ompartment** A at Point 4, which is the intersection of a line through Point 2 and Point Q (target) and a line between Points 1 and 3.

$$T_{A4} = \frac{\left[T_{B-tar} - \dfrac{T_{A-tar} \times (T_{B2} - T_{B-tar})}{(T_{A2} - T_{A-tar})} - T_{B1} + \dfrac{T_{A1} \times (T_{B3} - T_{B1})}{(T_{A3} - T_{A1})} \right]}{\left[\dfrac{(T_{B3} - T_{B1})}{(T_{A3} - T_{A1})} - \dfrac{(T_{B2} - T_{B-tar})}{(T_{A2} - T_{A-tar})} \right]} \tag{34}$$

$$T_{A4} = \frac{\left[4 - \frac{(-18{,}0)\times(0{,}8-4{,}0)}{((-17{,}5)-(-18{,}0))} - 6{,}5 + \frac{(-20{,}7)\times(7{,}1-6{,}5)}{((-16{,}0)-(-20{,}7))}\right]}{\left[\frac{(7{,}1-6{,}5)}{((-16{,}0)-(-20{,}7))} - \frac{(0{,}8-4{,}0)}{((-17{,}5)-(-18{,}0))}\right]} = -18{,}435\ 8\ °\text{C}$$

Figure I.8 shows clearly that Point Q lies within the triangle of test Points 1 to 3. Formula (33) above also confirms that Point Q lies inside the triangle formed by Points 1 to 3. An additional check may be performed as follows:

$T_{A4} < T_{A\text{-}tar} < T_{A2}$ or

$T_{A4} > T_{A\text{-}tar} > T_{A2}$

and

$T_{A1} < T_{A4} < T_{A3}$ or

$T_{A1} > T_{A4} > T_{A3}$

In this example the first condition of each is met:

–18,435 8 °C < –18 °C < –17,5 °C and

–20,7 °C < –18,435 8 °C < –16,0 °C

Where is there any doubt whether the Point Q lies inside the triangle (e.g. close to one of the sides of the triangle), mathematical evaluation in accordance with Formula (33) shall be used to confirm validity.

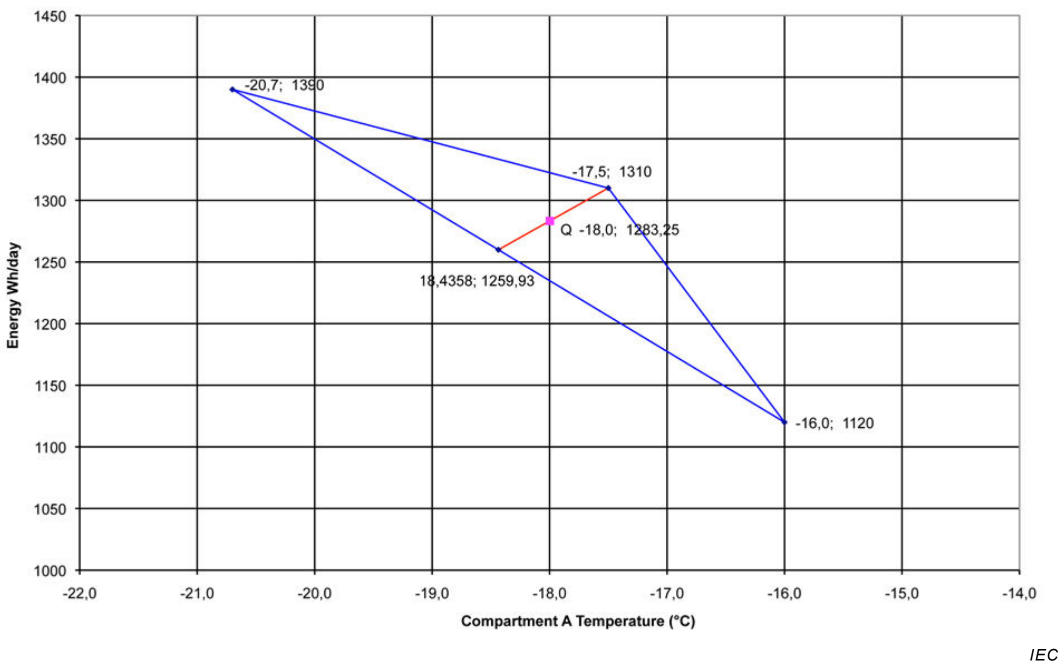


Figure I.9 – Example of triangulation (temperature and energy)

The interpolated **energy consumption** at the temperature for Point 4 between test Points 1 and 3 is determined as follows (**compartment** A temperatures are used):

$$E_4 = E_1 + (E_3 - E_1) \times \frac{(T_{A4} - T_{A1})}{(T_{A3} - T_{A1})} \tag{35}$$

$$E_4 = 1390 + (1120 - 1390) \times \frac{((-18{,}4358) - (-20{,}7))}{((-16{,}0) - (-20{,}7))} = 1\,259{,}93 \text{ Wh/d}$$

The calculated **energy consumption** at the **target temperature** (Point Q) using temperature and energy data for Point 4 above and test Point 2 is determined as follows (**compartment** A temperatures are used) is given by:

$$E_{AB-tar} = E_2 + (E_4 - E_2) \times \frac{(T_{A-tar} - T_{A2})}{(T_{A4} - T_{A2})} \tag{36}$$

$$E_{AB-tar} = 1310 + (1259{,}93 - 1310) \times \frac{((-18{,}0) - (-17{,}5))}{((-18{,}4358) - (-17{,}5))} = 1\,283{,}25 \text{ Wh/d}$$

E_{AB-tar} is the **energy consumption** determined using triangulation of **compartments** A and B. This is illustrated in Figure I.9. Note that the results above for T_{A4} , E_4 and E_{AB-tar} are normally calculated without rounding. Small differences will occur if the rounded values shown above are used in the equations in this standard. Unrounded values should be used for all calculations where possible. Calculations are normally undertaken in a spreadsheet or other mathematical tool.

I.3.4 Two compartments – triangulation using matrices

For this worked example, we consider the same **refrigerator-freezer** with two **compartments** used for triangulation in the previous example. The use of Formula (33) has already confirmed that the 3 test points surround Point Q. Note that it is not necessary to calculate a value for Point 4 when matrices are used.

The basic premise of the approach on two **compartments** using matrices is to assume that we have 3 simultaneous equations to describe the 3 test points as follows:

$E_0 + A \times T_{A1} + B \times T_{B1} = E_1$

$E_0 + A \times T_{A2} + B \times T_{B2} = E_2$

$E_0 + A \times T_{A3} + B \times T_{B3} = E_3$

In this example, the equations are:

$E_0 + A \times (-20{,}7) + B \times 6{,}5 = 1\,390$

$E_0 + A \times (-17{,}5) + B \times 0{,}8 = 1\,310$

$E_0 + A \times (-16{,}0) + B \times 7{,}1 = 1\,120$

The value of E_0 is conceptually the **energy consumption** of the **refrigerating appliance** at the given ambient test temperature when the temperature of both **compartments** is 0 °C (which will not be possible to achieve in practice).

These three equations can be organised into a matrices as follows:

$$[M_{33}] \times [C_{31}] = [E_{31}] \tag{37}$$

Where:

$[M_{33}]$ is a 3 × 3 matrix of 1 (constant), T_A and T_B for each test point

$[C_{31}]$ is a 3 × 1 matrix of E_0, A and B (constants to be solved)

$[E_{31}]$ is a 3 × 1 matrix of E_1, E_2 and E_3

$$\begin{bmatrix} 1 & -20,7 & 6,5 \\ 1 & -17,5 & 0,8 \\ 1 & -16,0 & 7,1 \end{bmatrix} \times \begin{bmatrix} E_0 \\ A \\ B \end{bmatrix} = \begin{bmatrix} 1390 \\ 1310 \\ 1120 \end{bmatrix}$$

To solve for the unknown constants matrix $[C_{31}]$, find the solution to the matrix multiplication $[M_{33}]^{-1} \times [E_{31}]$

In this example, $[M_{33}]^{-1}$ is equal to:

$$\begin{bmatrix} -3,88192 & +1,49669 & +3,38523 \\ -0,21944 & +0,02090 & +0,19854 \\ +0,05225 & -0,16371 & +0,11146 \end{bmatrix}$$

The matrix multiplication $[M_{33}]^{-1} \times [E_{31}]$ yields the following matrix for E_0, A and B

$$[C_{31}] = \begin{bmatrix} 356,2522 \\ -55,2769 \\ -16,9976 \end{bmatrix}$$

Using the solved constants from matrix $[C_{31}]$, the **energy consumption** at any combination of **compartment** temperatures can be accurately estimated by the equation:

$$E_{AB} = 356,2522 - 55,276\,9 \times T_A - 16,9976 \times T_B$$

The **energy consumption** at the **target temperature** for **Compartment** A = –18,0 and **Compartment** B = +4,0 is given by:

$$E_{AB\text{-}tar} = 356,2522 - 55,2769 \times (-18,0) - 16,9976 \times 4,0 = 1\,283,246 \text{ Wh/d}$$

NOTE The result using matrices gives exactly the same result as manual interpolation as set out in the previous subclause. In the examples documented in this subclause and the previous subclause, some errors in the last significant figure may occur due to rounding. This would not occur if spreadsheets are used to calculate the results without rounding.

The energy impact of a change in **compartment** temperatures can be readily calculated from these parameters.

For **Compartment** A (**freezer**), the change in energy resulting from a 1 K warmer **compartment** temperature is given by:

$$\frac{A}{E_{t\arg et}} = \frac{-55,2769}{1283,246} = -4,31\ \%$$

i.e. 1 K warmer **freezer** temperature will result in a 4,31 % decrease in **energy consumption** (for a constant fresh food temperature).

Similarly, for **Compartment** B (fresh food), the change in energy resulting from a 1 K warmer **compartment** temperature is given by:

$$\frac{B}{E_{target}} = \frac{-16{,}997}{1283{,}246} = -1{,}32\ \%$$

i.e. 1 K warmer fresh food temperature will result in a 1,32 % decrease in **energy consumption** (for a constant **freezer** temperature).

I.3.5 Three compartments – triangulation using matrices

For this worked example, we consider a **refrigerator-freezer** with three **compartments** and four points used for triangulation, as shown in Table I.8.

Table I.8 – Example of triangulation, three compartments

Parameter	Test 1	Test 2	Test 3	Test 4	Type	Target
Compartment A	–20,1	–18,8	–16,0	–17,4	**Freezer**	–18,0
Compartment B	+4,3	+1,3	+6,4	+2,4	**Fresh Food**	+4,0
Compartment C	–14,2	–12,5	–10,5	–10,5	**Two-star**	–12,0
Energy Wh/d	1 250	1 220	1 080	1 150		

Firstly we check that the Point Q lies inside the tetrahedron formed by the four test points. Calculate the Determinant of the following five matrices:

$$D_0 \text{ for } \begin{vmatrix} -20{,}1 & 4{,}3 & -14{,}2 & 1 \\ -18{,}8 & 1{,}3 & -12{,}5 & 1 \\ -16{,}0 & 6{,}4 & -10{,}5 & 1 \\ -17{,}4 & 2{,}4 & -10{,}5 & 1 \end{vmatrix} = -11{,}898$$

$$D_1 \text{ for } \begin{vmatrix} -18{,}0 & 4{,}0 & -12{,}0 & 1 \\ -18{,}8 & 1{,}3 & -12{,}5 & 1 \\ -16{,}0 & 6{,}4 & -10{,}5 & 1 \\ -17{,}4 & 2{,}4 & -10{,}5 & 1 \end{vmatrix} = -3{,}190$$

$$D_2 \text{ for } \begin{vmatrix} -20{,}1 & 4{,}3 & -14{,}2 & 1 \\ -18{,}0 & 4{,}0 & -12{,}0 & 1 \\ -16{,}0 & 6{,}4 & -10{,}5 & 1 \\ -17{,}4 & 2{,}4 & -10{,}5 & 1 \end{vmatrix} = -3{,}022$$

$$D_3 \text{ for } \begin{vmatrix} -20{,}1 & 4{,}3 & -14{,}2 & 1 \\ -18{,}8 & 1{,}3 & -12{,}5 & 1 \\ -18{,}0 & 4{,}0 & -12{,}0 & 1 \\ -17{,}4 & 2{,}4 & -10{,}5 & 1 \end{vmatrix} = -4{,}075$$

$$D_4 \text{ for } \begin{vmatrix} -20{,}1 & 4{,}3 & -14{,}2 & 1 \\ -18{,}8 & 1{,}3 & -12{,}5 & 1 \\ -16{,}0 & 6{,}4 & -10{,}5 & 1 \\ -18{,}0 & 4{,}0 & -12{,}0 & 1 \end{vmatrix} = -1{,}611$$

As a check $D_0 = D_1 + D_2 + D_3 + D_4$

–11,898 = –3,190 – 3,022 – 4,075 – 1,611 = correct

If D_1 and D_2 and D_3 and D_4 are the same sign as D_0, then Point Q is inside of the tetrahedron (correct).

As per the previous example, the data can be organised into a matrices as follows:

$$[M_{44}] \times [C_{41}] = [E_{41}] \tag{39}$$

$[M_{44}]$ is a 4 × 4 matrix of 1 (constant), T_A, T_B and T_C for each test point

$[C_{41}]$ is a 4 × 1 matrix of E_0, A, B and C (constants to be solved)

$[E_{41}]$ is a 4 × 1 matrix of E_1, E_2, E_3 and E_4.

$$\begin{bmatrix} -20{,}1 & +4{,}3 & -14{,}2 & 1 \\ -18{,}8 & +1{,}3 & -12{,}5 & 1 \\ -16{,}0 & +6{,}4 & -10{,}5 & 1 \\ -17{,}4 & +2{,}4 & -10{,}5 & 1 \end{bmatrix} \times \begin{bmatrix} E_0 \\ A \\ B \\ C \end{bmatrix} = \begin{bmatrix} 1\,250 \\ 1\,220 \\ 1\,080 \\ 1\,150 \end{bmatrix}$$

To solve for the unknown constants matrix $[C_{41}]$, find the solution to the matrix multiplication $[M_{44}]^{-1} \times [E_{41}]$

In this example, $[M_{44}]^{-1}$ is equal to:

$$\begin{bmatrix} -8{,}68129 & +10{,}81039 & +6{,}49647 & -7{,}62557 \\ -0{,}67238 & +1{,}24391 & +0{,}66146 & -1{,}23298 \\ +0{,}23533 & -0{,}43537 & +0{,}01849 & +0{,}18154 \\ +0{,}34123 & -1{,}13128 & -0{,}47319 & +1{,}26324 \end{bmatrix}$$

The matrix multiplication $[M_{44}]^{-1} \times [E_{41}]$ yields the following matrix for E_0, A, B and C

$$[C_{41}] = \begin{bmatrix} 583{,}8452 \\ -26{,}4666 \\ -8{,}23668 \\ -11{,}9432 \end{bmatrix}$$

Using the solved constants from matrix $[C_{41}]$, the **energy consumption** at any combination of **compartment** temperatures can be accurately estimated by the equation:

$$E_{ABC} = 583{,}8452 - 26{,}4666 \times T_A - 8{,}23668 \times T_B - 11{,}9432 \times T_C$$

The **energy consumption** at the **target temperature** for **Compartment** A = –18,0 and **Compartment** B = +4,0 and **Compartment** C = –12,0 is given by:

$$E_{ABC\text{-}tar} = = 583{,}8452 - 26{,}4666 \times (-18) - 8{,}23668 \times (+4) - 11{,}9432 \times (-12) \text{ Wh/d}$$

= 1 170,616 Wh/d

The energy impact of a change in **compartment** temperatures can be readily calculated from these parameters.

For **compartment** A, a 1 K warmer **compartment** temperature will result in a 26,4666 Wh/d decrease in energy consumption (equivalent to 1,10 W decrease or a 2,26 % energy decrease per K warmer).

For **compartment** B, a 1 K warmer **compartment** temperature will result in a 8,236 68 Wh/d decrease in energy consumption (equivalent to 0,343 W decrease or a 0,70 % energy decrease per K warmer).

For **compartment** C, a 1 K warmer **compartment** temperature will result in a 11,9432 Wh/d decrease in energy consumption (equivalent to 0,498 W decrease or a 1,02 % energy decrease per K warmer).

I.4 Calculating the energy impact of internal temperature changes

I.4.1 General

It is often useful to calculate the energy impact of internal **compartment** temperature changes which result from changes in user adjustments to **temperature control settings**. Calculation of these values can give a good indication of the user-related impact of changes in **temperature control settings** that may occur from user to user and can assist with analysis of field data.

Analysis of a range of **refrigerator-freezers** tested at an ambient of 32 °C showed that the impact of **freezer** temperature was typically an increase in energy of 2 % to 5 % per degree K **compartment** decrease and for the fresh food temperature was typically an increase in energy of 1 % to 3 % per degree K decrease. These values vary by model.

While such calculations are of interest and are recommended, they are not required as part of this standard.

NOTE When calculating the energy impact of internal temperature changes, great care is required in cases where the base of the triangle is less than 2 K and the height of the triangle is less than 1 K. Small or flat shaped triangles may not provide an accurate estimate of the impact in either **compartment** for products with 2 **user-adjustable temperature controls**.

I.4.2 One compartment

Where two point interpolation using a single control is used to calculate the energy for a **refrigerating appliance** with only one **compartment**, the energy impact per degree K change can be readily calculated.

$$E_{target} = E_1 + (E_2 - E_1) \times \frac{(T_{tar} - T_1)}{(T_2 - T_1)}$$

and

$$\Delta E = \frac{(E_2 - E_1)}{(T_2 - T_1) \times E_{target}}$$

where

E_{target} is the **energy consumption** at the **target temperature** determined by linear interpolation from test Points 1 & 2

E_1 is the measured **energy consumption** at test Point 1 for **temperature control setting** 1

E_2 is the measured **energy consumption** at test Point 2 for **temperature control setting** 2

T_1 is the measured temperature at test Point 1 for **temperature control setting** 1

T_2 is the measured temperature at test Point 2 for **temperature control setting** 2

T_{tar} is the **target temperature** for the **compartment** type as set out in Table 1

ΔE is the energy change in % of the target **energy consumption** per change in degree K for the **compartment**

NOTE The value of ΔE is usually negative in that an increase in temperature will result in a decrease in energy.

Using the example for a single **compartment** from I.3.2.2

E_{Daily1} = 789 Wh/d

T_1 = –19,6 °C

E_{Daily2} = 668 Wh/d

T_2 = –17,1 °C

Target temperature for **freezer**: –18,0 °C

$$E_n = 789 + (668 - 789) \times \frac{(-18{,}0 - (-19{,}6))}{(-17{,}1 - (-19{,}6))} = 711{,}56 \text{ Wh/d}$$

therefore:

$$\Delta E = \frac{(668 - 789)}{(-17{,}1 - (-19{,}6)) \times 711{,}56}$$

ΔE = –0,068 per K

or a 6,8 % energy increase per degree K decrease in internal temperature.

Where the temperatures in two **compartments** are affected by a single control, the calculation for ΔE is performed for each **compartment** using the target **energy consumption** for the critical **compartment** as specified in E.3. Because it may not be possible to independently vary the **compartment** temperatures, values for both **compartments** should be reported together.

Where there are two independent **user-adjustable temperature controls** that are both adjusted (or only one is adjusted) to get two test points, the resulting calculations will not give a valid representation of the temperature energy impact in both **compartments**. This can only be done using triangulation (3 test points for 2 **compartments**).

I.4.3 Triangulation

Where triangulation is undertaken in accordance with E.4, the test points can be used to derive another useful characteristic of the **refrigerating appliance**, which is the energy change per degree temperature change for each **compartment** (where there are two **compartments** and two controls changed). This is most reliably done when the triangle surrounding Point Q are well spread in both **compartments** (e.g. close to an equilateral triangle, rather than a flat triangle).

To calculate these parameters, exactly the same equations in E.4 are used but with an adjusted **target temperature** for each **compartment** applied separately. For the purposes of this analysis, it is not critical whether the adjusted **target temperature** Point Q strictly lies inside the triangle of test points or not if the data are not used as the basis of a primary claim.

If matrices are used to interpolate (as set out in E.4.4), then the derived coefficients A and B are in fact the ΔE_A and ΔE_B parameters for **Compartments** A and B (i.e. energy change per degree change in each **compartment**) as set out in the examples in I.3.3. This is the easiest approach. Alternatively, the impacts can be manually determined as set out below.

For a **refrigerator-freezer** with 2 **user-adjustable temperature controls**, the recommended approach is:

– Determine the **energy consumption** at Point Q for the specified **target temperatures** of +4 °C and –18 °C ($E_{4,-18}$);
– Determine the **energy consumption** at the temperatures of +4 °C and –19 °C ($E_{4,-19}$);
– Determine the **energy consumption** at the temperatures of +3 °C and –18 °C ($E_{3,-18}$).

NOTE 1 These calculations can be done for any two **compartments** A and B. The **fresh food** and **freezer** is used as an illustrative example.

The temperature response to changes in internal temperatures can then be calculated as:

$$\Delta E_{freezer} = \frac{E_{4,-18} - E_{4,-19}}{E_{4,-18}}$$

where

$\Delta E_{freezer}$ is the change in **energy consumption** per degree K warmer in **freezer** temperature as a % of the target **energy consumption** at Point Q

$E_{4,-18}$ is the **energy consumption** by interpolation at +4 °C and –18 °C

$E_{4,-19}$ is the **energy consumption** by interpolation at +4 °C and –19 °C.

The temperature response to changes in internal temperatures can then be calculated as:

$$\Delta E_{freshfood} = \frac{E_{4,-18} - E_{3,-18}}{E_{4,-18}}$$

where

$\Delta E_{freshfood}$ is the change in **energy consumption** per degree K warmer in fresh food temperature as a % of the target **energy consumption** at Point Q

$E_{4,-18}$ is the **energy consumption** by interpolation at +4 °C and –18 °C

$E_{3,-18}$ is the **energy consumption** by interpolation at +3 °C and –18 °C.

NOTE 2 The value of ΔE is usually negative in that a warmer temperature will result in a decrease in energy.

The energy response to internal temperature changes (away from the **target temperature**) can be calculated in a similar way for all relevant **compartments** with separate **user-adjustable temperature controls**.

I.5 Automatically controlled anti-condensation heater(s)

A labelling jurisdiction has decided on only 3 temperatures 16 °C, 22 °C, and 32 °C for this procedure. Calculations shall be based on an indoor **ambient temperature** of 16 °C for 30 % of the time, on 22 °C for 60 % of the time, and on 32 °C for 10 % of the time. The regional probability of various indoor relative humidity levels in that jurisdiction shall be as in the three “Probability constant” columns in Table I.9.

A **refrigerator-freezer** has automatically controlled anti-condensation heaters. For this particular model (at **compartment target temperatures**) at the various relative humidity levels and the three **ambient temperatures**, the average wattage of the heaters is as in the "Average heater wattage" columns in Table I.9.

Table I.9 – Example of population-weighted humidity probabilities and heater wattages at 16 °C, 22 °C and 32 °C

RH band mid-point	Regional Probability, R_i (AS/NZS conditions)			Average heater power P_{Hi} (in W) (from manufacturer)			Probability times power at each ambient temperature		
	16 °C	22 °C	32 °C	16 °C	22 °C	32 °C	16 °C	22 °C	32 °C
5 %	0,00 %	0,00 %	0,03 %	0	0	0	0,0000	0,0000	0,0000
15 %	0,06 %	0,06 %	0,33 %	0	0	1	0,0000	0,0000	0,0033
25 %	0,60 %	1,62 %	2,35 %	0	1	2	0,0000	0,0162	0,0470
35 %	2,76 %	9,24 %	2,56 %	0	2	3	0,0000	0,1848	0,0768
45 %	6,93 %	12,72 %	3,57 %	1	2	4	0,0693	0,2544	0,1428
55 %	8,01 %	11,70 %	1,11 %	1	3	5	0,0801	0,3510	0,0555
65 %	5,55 %	11,40 %	0,05 %	1	3	6	0,0555	0,3420	0,0030
75 %	3,30 %	7,92 %	0,00 %	2	4	7	0,0660	0,3168	0,0000
85 %	1,80 %	3,48 %	0,00 %	2	5	8	0,0360	0,1740	0,0000
95 %	0,99 %	1,86 %	0,00 %	3	6	9	0,0297	0,1116	0,0000
Total	**30 %**	**60 %**	**10 %**						

NOTE The example in this table is based on Australia and New Zealand standard conditions for a hypothetical **refrigerating appliance**.

For each ambient,

$$W_{heaters} = \left[\sum_{i=1}^{k} (R_i \times P_{H\,i}) \right] \times 1{,}3 \qquad (40)$$

Note these values are weighted by the assumed time at each condition: 30 % of the time assumed to be at 16 °C, 60 % at 22 °C and 10 % at 32 °C.

Weighted average annual power, $W_{heaters}$ = 2,4158 × 1,3 W

= 3,14054 W

The system loss factor (1,3) is to allow for the extra energy used to remove heater energy that leaks into the **refrigerating appliance**.

The annual energy from this auxiliary can be calculated as:

E_{aux} = 3,14054 W × 24 h/d × 365 d/year × 0,001 kW/W = 27,511 kWh/year

This value would add to the annual energy value if the heater was not operating when tested for **energy consumption**.

NOTE The values for **energy consumption** are initially calculated on a daily basis in 6.8.2, so care is required to ensure consistent units when adding energy values.

I.6 Calculation of load processing efficiency

A product has been tested for **load processing efficiency** in accordance with Annex G of this standard

The appliance attributes were as follows:

- Fresh food **volume**: 300 l, therefore the water load = 3 600 g (12 g/l)
- **Freezer volume**: 120 l, therefore the water load = 480 g (4 g/l)

An unfrozen load of 3 600 g is made up of 6 PET bottles of 500 g and 2 bottles of 300 g. These are placed:

- 1 000 g at the level of TMP_1,
- 1 300 g at the level of TMP_2,
- 1 300 g at the level of TMP_3.

A frozen load of 480 g is made up of one **ice cube tray** of 200 g and two **ice cube trays** of 140 g.

The water load is left in the test room for 20 h prior to the test. The average test room temperature in the 6 h prior to the start of the test is 32,1 °C.

The following data was collected during the test:

- **Steady state** prior to load insertion: +3,7 °C, –18,5 °C, 45,2 W (3 blocks as per B.3)
- **Steady state** at completion of load processing: +3,5 °C, –18,4 °C, 46,3 W (3 blocks as per B.3). The fresh food temperatures are T_1 = +4,8 °C, T_2 = +3,4 °C, T_3 = +2,3 °C measured at sensor positions TMP_1, TMP_2 and TMP_3 respectively.

Comparing **steady state** conditions before and after the **load processing efficiency** test, the spread of temperature is less than 1 K in both **compartments** (0,2 K and 0,1 K respectively) and the spread of power is less than 2 W and 5 % (1,1 W and 2,4 % respectively), so the data is acceptable (refer G.4.4). Both **compartment** temperatures are within 1 K of the relevant **target temperature**.

The equations to calculation the input energy are specified in Annex G.

$$E_{unfrozen-test} = \frac{\left[M_1 \times (T_{amb} - T_1) + M_2 \times (T_{amb} - T_2) + M_3 \times (T_{amb} - T_3)\right] \times 4{,}186}{3{,}6} \quad (48)$$

For this example, the data is:

$$E_{unfrozen-test} = \frac{\left[1{,}0 \times (32{,}1 - 4{,}8) + 1{,}3 \times (32{,}1 - 3{,}4) + 1{,}3 \times (32{,}1 - 2{,}3)\right] \times 4{,}186}{3{,}6}$$

= 120,17 Wh

$$E_{frozen-test} = \frac{\left[M_{tot-fz} \times (4{,}186 \times T_{amb} + 333{,}6 - T_{fz-av} \times 2{,}05)\right]}{3{,}6} \quad (49)$$

For this example, the data is:

$$E_{frozen-test} = \frac{[0,48 \times (4,186 \times 32,1 + 333,6 - (-18,4) \times 2,05)]}{3,6}$$

= 67,43 Wh

$$E_{input\text{-}test} = E_{unfrozen\text{-}test} + E_{frozen\text{-}test} \tag{50}$$

$E_{input\text{-}test}$ = 120,17 + 67,43 = 187,60 Wh

The following data were recorded during the test:

- E_{start} 403,8 Wh
- E_{end} 1 910,5 Wh
- P_{after} 46,3 W
- t_{start} 46,2 h
- t_{end} 72,1 h
- z = 1 defrost occurred during the test period
- ΔE_{df} 135,2 Wh (determined from Annex C)

Calculate the $\Delta E_{additional\text{-}test}$ during the test as given in Annex G:

$$\Delta E_{additional-test} = (E_{end} - E_{start}) - P_{after} \times (t_{end} - t_{start}) - z \times \Delta E_{df} \tag{51}$$

$$\Delta E_{additional-test} = (1910,5 - 403,8) - 46,3 \times (72,1 - 46,2) - 1 \times 135,2$$

= 172,33 Wh

$$Efficiency_{load,ambient} = \frac{E_{input-test}}{\Delta E_{additional-test}} \tag{52}$$

$$Efficiency_{load,32C} = \frac{187,60}{172,33}$$

= 1,089

The nominal load added for the **load processing efficiency** test $E_{input\text{-}nominal}$ is then calculated:

$$E_{unfrozen-nominal} = \frac{[M_{tot-unfz} \times (T_{amb-tar} - T_{unfz-tar})] \times 4,186}{3,6} \tag{53}$$

$$E_{unfrozen-nominal} = \frac{[3,6 \times (32 - 4)] \times 4,186}{3,6}$$

$E_{unfrozen\text{-}nominal}$ = 117,21 Wh

$$E_{frozen-nominal} = \frac{[M_{tot-fz} \times (4,186 \times T_{amb-tar} + 333,6 - T_{fz-tar} \times 2,05)]}{3,6} \tag{54}$$

$$E_{frozen-nominal} = \frac{[0{,}48 \times (4{,}186 \times 32 + 333{,}6 - (-18) \times 2{,}05)]}{3{,}6}$$

$E_{frozen-\ nominal}$ = 67,26 Wh

$$E_{input\text{-}nominal} = E_{unfrozen-\ nominal} + E_{frozen-\ nominal} \qquad (55)$$

$E_{input\text{-}nominal}$ = 117,21 + 67,26 = 184,47 Wh at an ambient of 32 °C.

The daily energy impact of a known daily **processing load** of 155 Wh at an **ambient temperature** of 32 °C could be calculated as follows:

$$\Delta E_{processing} = \frac{E_{user}}{Efficiency_{load,ambient}} \qquad (56)$$

$$\Delta E_{processing} = \frac{155}{1{,}089} = 142{,}3 \text{ Wh/d}$$

The value of 155 Wh/d in this example is a regional factor intended to represent user related heat loads and could be fixed for all **refrigerating appliances** or it could be a function of size and type of product.

Alternatively, the nominal daily energy impact specified in the **load processing efficiency** test could be scaled to an equivalent **ambient temperature** of 32 °C as follows:

$$\Delta E_{processing} = \frac{E_{input-nominal}}{Efficiency_{load,ambient}} \times a \qquad (57)$$

$$\Delta E_{processing} = \frac{184{,}47}{1{,}089} \times 0{,}9 = 152{,}45 \text{ Wh/d}$$

The value of a = 0,9 in this example is a regional factor that reflects user related heat loads. It would normally be fixed for all **refrigerating appliances** of a similar type (as the $E_{input\text{-}nominal}$ is a function of appliance **volume**), but it may vary by product type (e.g. **freezers** may be expected to have less user interaction and **processing load** than **refrigerator-freezers**).

I.7 Determination of annual energy consumption

A product has been tested for **energy consumption** in accordance with this standard. Daily **energy consumption** at 16 °C and 32 °C has been determined.

A number of possible approaches to determine annual **energy consumption** can be used. One possible approach is to use the results from both test **ambient temperatures** with a regional factor for the equivalent number of days in each ambient condition in a year to give a representative annual **energy consumption**. The example below illustrates how the components in this standard could be assembled in this way to make a regionally relevant estimate of **energy consumption**. It is one possible example – many other local approaches could be developed and applied.

Consider the following **refrigerating appliance**:

E_{16C} = 597 Wh/d at **target temperature** (triangulation)

E_{32C} = 1 230 Wh/d at **target temperature** (triangulation)

The product has an ambient controlled anti-condensation as set out in the previous Clause (I.5), with an annual **energy consumption** of 27,511 kWh/year.

The measured **load processing efficiency** at an **ambient temperature** of 16 °C is 1,47 Wh/Wh.

The measured **load processing efficiency** at an **ambient temperature** of 32 °C is 1,15 Wh/Wh.

The daily regional **processing load** for cooler conditions is 135 Wh/d (**ambient temperature** of 16 °C).

The daily regional **processing load** for warmer conditions is 390 Wh/d (**ambient temperature** of 32 °C).

The regional equivalent operating factors for a **refrigerating appliance** are:

Annual days operating at an **ambient temperature** of 16 °C equivalent is 170 d (Day_{16}).

Annual days operating at an **ambient temperature** of 32 °C equivalent is 195 d (Day_{32}).

$Day_{16} + Day_{32}$ = 365

A regional function of the annual energy at 16 °C and 32 °C is expressed as follows:

$$E_{total} = f\{E_{daily16C}, E_{daily32C}\} + E_{aux} + \Delta E_{processing\text{-}annual} \tag{59}$$

$$E_{total} = (Day_{16} \times E_{Daily16C}) + (Day_{32} \times E_{Daily32C}) + (E_{aux}) + (\Delta E_{processing\text{-}annual})$$

E_{total} = (170 × 597/1 000) + (195 × 1 230/1 000) + (27,511) + (170 × 135/1,47/1 000 + 195 × 390/1,15/1 000)

E_{total} = 101,49 + 239,85 + 27,511 + 15,6122 + 66,1304

E_{total} = 450,594 kWh/year

NOTE The factor of 1 000 in this equation converts the units of Wh/d to kWh/d. Care is required to make sure all units are consistent.

I.8 Examples of determination of power and temperature from raw data

I.8.1 Manual review of data

Figure I.10 shows an example of test data for a **refrigerator-freezer** that has been tested for **energy consumption**. The figure illustrates data for power and temperature in the **fresh food** and **frozen compartments** that is collected every minute. The product operates in a **steady state** condition and then undertakes a **defrost and recovery period** as marked. The follow steps outline how this data is analysed using approach SS1 in Annex B to determine the key characteristics of the product in accordance with this standard. Later examples for approach SS2 and for the calculation of defrost and recovery energy and temperature change are included using the same data set.

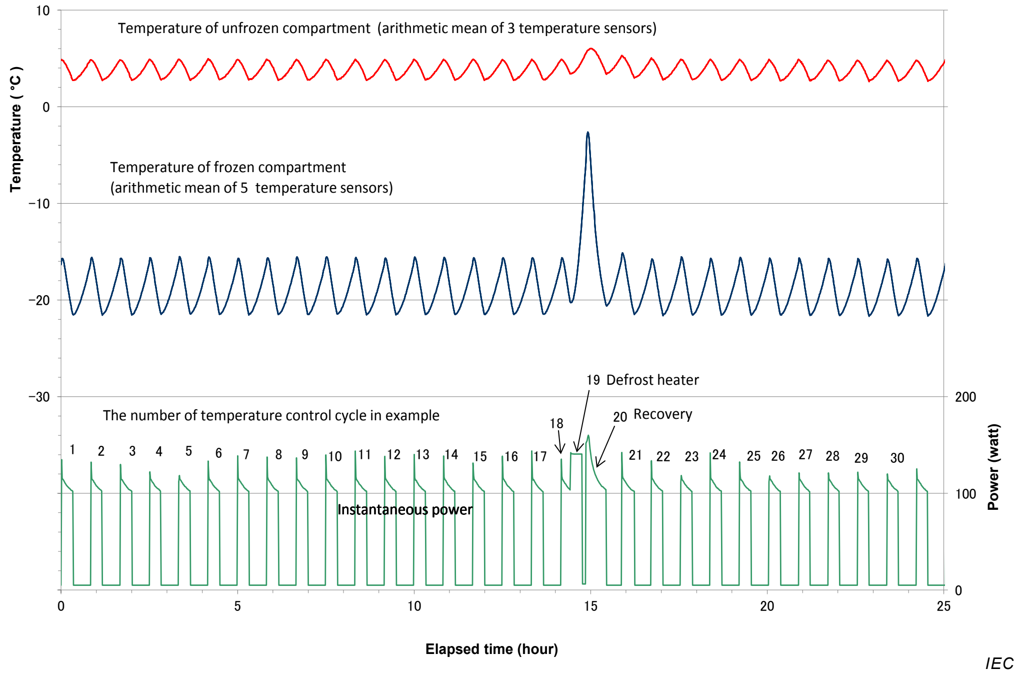


Figure I.10 – An example of power and temperature data

Step 1: Select **temperature control cycles** from the raw data (not provided in this example). In this example, each **temperature control cycle** is selected from the operation of compressor "on" to the subsequent compressor "on" (the product is relatively simple and this provides the most reliable and stable **temperature control cycles**). In this example, **temperature control cycle** 18 is a short compressor run before the defrost heater operates (**temperature control cycle** 19). The recovery period is **temperature control cycle** 20.

Step 2: Calculate the average temperature in each **compartment**, the energy consumed and the average power for each **temperature control cycle** (TCC) from the raw data. The raw data that is illustrated in Figure I.10 has been used to determine the values for each TCC that are set out in table format in Table I.10. This data for each TCC is used as the basis for subsequent sample calculations in this example.

Step 3: Select the number of **temperature control cycles** per block to be examined. (See B.3.1). In this example, 3 **temperature control cycles** in each block (A, B, C) have been selected as the first example because each **temperature control cycle** is just under 1 h in length and the minimum permitted block size of the test data is no less than 2 h in duration for each block (i.e. a block size smaller than three TCC would yield no valid data). The sample data for each possible block (1 to 56) is illustrated in Table I.11.

Step 4: Possible test periods, made up of consecutive blocks of data, are then constructed from these blocks. An example of all possible test periods using a block size of 3 **temperature control cycles** is illustrated in Table I.12. The first test period consists of Block A (block 1 using TCC 1 to 3), Block B (block 4 using TCC 4 to 6) and Block C (block 7 using TCC 7 to 9). The second test period consists of Block A (block 2 using TCC 2 to 4), Block B (block 5 using TCC 5 to 7) and Block C (block 8 using TCC 8 to 10). A total of 36 possible test periods are listed in Table I.12 using this approach. It is then possible to calculate the characteristics for each of the selected test periods and check the validity requirements across the blocks of data (spread of temperature, slope of temperature, spread of power and slope of power from Block A to Block C) as set out in B.3.1.

Table I.10 – An example of calculation of energy, power and temperature for each temperature control cycle (TCC)

Number of TCC	Time length of TCC	Cumulative time at start TCC	Energy consumption during TCC	Average Power	Average Unfrozen Temp.	Average Frozen Temp.	Remark
	hh:mm:ss	h	Wh	W	°C	°C	
1	0:50:00	0,000	38,625	46,350	3,741	–18,956	
2	0:50:00	0,833	38,250	45,900	3,765	–18,920	
3	0:50:00	1,667	39,000	46,800	3,760	–18,919	
4	0:49:00	2,500	36,250	44,388	3,766	–18,932	
5	0:50:00	3,317	38,375	46,050	3,793	–18,876	
6	0:50:00	4,150	38,750	46,500	3,805	–18,900	
7	0:50:00	4,983	38,250	45,900	3,775	–18,940	
8	0:50:00	5,817	38,250	45,900	3,772	–18,894	
9	0:50:00	6,650	37,875	45,450	3,747	–18,900	
10	0:50:00	7,483	38,125	45,750	3,767	–18,902	
11	0:50:00	8,317	38,375	46,050	3,759	–18,931	
12	0:50:00	9,150	38,000	45,600	3,750	–18,941	
13	0:50:00	9,983	38,000	45,600	3,755	–18,928	
14	0:50:00	10,817	38,000	45,600	3,775	–18,927	
15	0:50:00	11,650	38,375	46,050	3,773	–18,912	
16	0:50:00	12,483	38,000	45,600	3,744	–18,922	
17	0:50:00	13,317	38,000	45,600	3,771	–18,924	
18	0:16:00	14,150	29,625	111,094	4,288	–17,509	Pre-cool
19	0:26:00	14,417	47,500	109.615	4.179	–15,294	Defrost
20	1:01:00	14,850	74,750	73.525	4.757	–14,996	Recovery
21	0:50:00	15,867	41,000	49,200	4,019	–18,817	
22	0:50:00	16,700	38,750	46,500	3,819	–18,973	
23	0:50:00	17,533	38,875	46,650	3,784	–18,977	
24	0:50:00	18,367	38,000	45,600	3,755	–18,970	
25	0:50:00	19,200	38,250	45,900	3,739	–18,956	
26	0:51:00	20,033	40,250	47,353	3,724	–18,954	
27	0:50:00	20,883	38,250	45,900	3,709	–18,995	
28	0:50:00	21,717	38,250	45,900	3,699	–19,006	
29	0:50:00	22,550	38,625	46,350	3,693	–19,034	
30	0:50:00	23,383	38,000	45,600	3,681	–19,049	
31	0:50:00	24,217	38,500	46,200	3,705	–19,016	
32	0:50:00	25,050	38,375	46,050	3,703	–19,041	
33	0:50:00	25,883	38,750	46,500	3,717	–19,041	
34	0:50:00	26,717	38,500	46,200	3,723	–19,033	
35	0:50:00	27,550	38,500	46,200	3,730	–19,006	
36	0:49:00	28,383	36,500	44,694	3,704	–19,057	
37	0:51:00	29,200	40,250	47,353	3,760	–18,931	
38	0:50:00	30,050	38,375	46,050	3,730	–19,031	
39	0:50:00	30,883	38,500	46,200	3,719	–19,079	

Number of TCC	Time length of TCC	Cumulative time at start TCC	Energy consumptio n during TCC	Average Power	Average Unfrozen Temp.	Average Frozen Temp.	Remark
40	0:50:00	31,717	38,500	46,200	3,706	–19,061	
41	0:50:00	32,550	38,500	46,200	3,703	–19,069	
42	0:50:00	33,383	38,750	46,500	3,703	–19,067	
43	0:50:00	34,217	38,125	45,750	3,682	–19,084	
44	0:50:00	35,050	38,375	46,050	3,690	–19,062	
45	0:50:00	35,883	38,000	45,600	3,685	–19,096	
46	0:50:00	36,717	38,250	45,900	3,691	–19,110	
47	0:50:00	37,550	38,000	45,600	3,668	–19,138	
48	0:50:00	38,383	38,000	45,600	3,693	–19,073	
49	0:51:00	39,217	40,375	47,500	3,708	–19,039	
50	0:50:00	40,067	38,000	45,600	3,683	–19,095	
51	0:16:00	40,900	29,625	111,094	4,142	–17,758	Pre-cool
52	0:27:00	41,167	50,500	112,222	4,232	–14,685	Defrost
53	1:02:00	41,617	76,000	73,548	4,767	–15,220	Recovery
54	0:50:00	42,650	42,125	50,550	4,001	–18,885	
55	0:49:00	43,483	37,875	46,378	3,735	–19,146	
56	0:50:00	44,300	39,250	47,100	3,673	–19,108	
57	0:49:00	45,133	37,250	45,612	3,639	–19,162	
58	0:50:00	45,950	39,500	47,400	3,661	–19,116	

Table I.11 – An example of calculation of energy, power and temperature for all possible blocks (size = 3 TCC)

Block	Start TCC	End TCC	Time length of Block	Energy consumption during Block	Average Power	Average Unfrozen Temp.	Average Frozen Temp.
			hh:mm:ss	Wh	W	°C	°C
1	1	3	2:30:00	115,875	46,350	3,756	–18,932
2	2	4	2:29:00	113,500	45,705	3,764	–18,924
3	3	5	2:29:00	113,625	45,755	3,773	–18,909
4	4	6	2:29:00	113,375	45,654	3,788	–18,903
5	5	7	2:30:00	115,375	46,150	3,791	–18,905
6	6	8	2:30:00	115,250	46,100	3,784	–18,911
7	7	9	2:30:00	114,375	45,750	3,765	–18,911
8	8	10	2:30:00	114,250	45,700	3,762	–18,899
9	9	11	2:30:00	114,375	45,750	3,758	–18,911
10	10	12	2:30:00	114,500	45,800	3,759	–18,925
11	11	13	2:30:00	114,375	45,750	3,754	–18,933
12	12	14	2:30:00	114,000	45,600	3,760	–18,932
13	13	15	2:30:00	114,375	45,750	3,767	–18,922
14	14	16	2:30:00	114,375	45,750	3,764	–18,920
15	15	17	2:30:00	114,375	45,750	3,762	–18,919
16	16	18	1:56:00	105,625	54,634	3,830	–18,728
17	17	19	1:32:00	115,125	75,082	3,976	–17,652
18	18	20	1:43:00	151,875	88,471	4,538	–15,462
19	19	21	2:17:00	163,250	71,496	4,378	–16,447
20	20	22	2:41:00	154,500	57,578	4,236	–17,418
21	21	23	2:30:00	118,625	47,450	3,874	–18,923
22	22	24	2:30:00	115,625	46,250	3,786	–18,973
23	23	25	2:30:00	115,125	46,050	3,759	–18,968
24	24	26	2:31:00	116,500	46,291	3,739	–18,960
25	25	27	2:31:00	116,750	46,391	3,724	–18,968
26	26	28	2:31:00	116,750	46,391	3,711	–18,985
27	27	29	2:30:00	115,125	46,050	3,700	–19,011
28	28	30	2:30:00	114,875	45,950	3,691	–19,030
29	29	31	2:30:00	115,125	46,050	3,693	–19,033
30	30	32	2:30:00	114,875	45,950	3,696	–19,036
31	31	33	2:30:00	115,625	46,250	3,708	–19,033
32	32	34	2:30:00	115,625	46,250	3,714	–19,038
33	33	35	2:30:00	115,750	46,300	3,724	–19,027
34	34	36	2:29:00	113,500	45,705	3,719	–19,032
35	35	37	2:30:00	115,250	46,100	3,732	–18,997
36	36	38	2:30:00	115,125	46,050	3,732	–19,005
37	37	39	2:31:00	117,125	46,540	3,737	–19,013
38	38	40	2:30:00	115,375	46,150	3,718	–19,057
39	39	41	2:30:00	115,500	46,200	3,709	–19,070
40	40	42	2:30:00	115,750	46,300	3,704	–19,066

Block	Start TCC	End TCC	Time length of Block	Energy consumption during Block	Average Power	Average Unfrozen Temp.	Average Frozen Temp.
			hh:mm:ss	Wh	W	°C	°C
41	41	43	2:30:00	115,375	46,150	3,696	–19,073
42	42	44	2:30:00	115,250	46,100	3,692	–19,071
43	43	45	2:30:00	114,500	45,800	3,686	–19,081
44	44	46	2:30:00	114,625	45,850	3,689	–19,089
45	45	47	2:30:00	114,250	45,700	3,681	–19,115
46	46	48	2:30:00	114,250	45,700	3,684	–19,107
47	47	49	2:31:00	116,375	46,242	3,690	–19,083
48	48	50	2:31:00	116,375	46,242	3,695	–19,069
49	49	51	1:57:00	108,000	55,385	3,756	–18,888
50	50	52	1:33:00	118,125	76,210	3,921	–17,585
51	51	53	1:45:00	156,125	89,214	4,534	–15,469
52	52	54	2:19:00	168,625	72,788	4,387	–16,435
53	53	55	2:41:00	156,000	58,137	4,215	–17,553
54	54	56	2:29:00	119,250	48,020	3,804	–19,046
55	55	57	2:28:00	114,375	46,368	3,683	–19,139
56	56	58	2:29:00	116,000	46,711	3,658	–19,128

NOTE The values in Table I.11 can be derived from the data in Table I.10. Great care is required to ensure that time weighted averages of power and temperature are derived for each block.

Table I.12 – An example of calculation of energy, power and temperature for all possible test periods (3 blocks each of 3 TCC)

Block A	Block B	Block C	Test Period Unfrozen	Test Period Frozen	Test Period Power	Test Period (A-B-C)	Ambient Temp. (A-B-C)	Spread Unfrozen (A-B-C)	Spread Frozen (A-B-C)	Spread Power (A-B-C)	Slope Unfrozen (A-C)	Slope Frozen (A-C)	Slope Power (A- C)	Permitted Power Spread	IEC Criteria Annex B	Test Period Valid
TCCs	TCCs	TCCs	°C	°C	W	h	°C	K	K	%	K/h	K/h	%/h	%		
1 to 3	4 to 6	7 to 9	3,769	–18,915	45,919	7,483	32,035	0,0326	0,0292	1,51 %	0,0018	0,0041	0,262 %	1,0 %	FALSE	INVALID
2 to 4	5 to 7	8 to 10	3,772	–18,909	45,852	7,483	32,034	0,0291	0,0252	0,98 %	0,0004	0,0051	0,002 %	1,0 %	TRUE	INVALID
3 to 5	6 to 8	9 to 11	3,772	–18,910	45,869	7,483	32,034	0,0264	0,0023	0,76 %	0,0031	0,0004	0,002 %	1,0 %	TRUE	INVALID
4 to 6	7 to 9	10 to 12	3,770	–18,913	45,735	7,483	32,035	0,0295	0,0222	0,32 %	0,0059	0,0045	0,064 %	1,0 %	TRUE	VALID
5 to 7	8 to 10	11 to 13	3,769	–18,912	45,867	7,500	32,035	0,0367	0,0348	0,98 %	0,0073	0,0056	0,174 %	1,0 %	TRUE	VALID
6 to 8	9 to 11	12 to 14	3,767	–18,918	45,817	7,500	32,036	0,0264	0,0208	1,09 %	0,0048	0,0041	0,218 %	1,0 %	FALSE	INVALID
7 to 9	10 to 12	13 to 15	3,764	–18,919	45,767	7,500	32,036	0,0087	0,0137	0,11 %	0,0005	0,0022	0,000 %	1,0 %	TRUE	INVALID
8 to 10	11 to 13	14 to 16	3,760	–18,917	45,733	7,500	32,036	0,0093	0,0348	0,11 %	0,0004	0,0043	0,022 %	1,0 %	TRUE	INVALID
9 to 11	12 to 14	15 to 17	3,760	–18,921	45,700	7,500	32,036	0,0049	0,0208	0,33 %	0,0010	0,0017	0,000 %	1,0 %	TRUE	VALID
10 to 12	13 to 15	16 to 18	3,782	–18,869	48,245	6,933	32,037	0,0718	0,1969	18,41 %	0,0152	0,0417	3,882 %	1,0 %	FALSE	INVALID
11 to 13	14 to 16	17 to 19	3,810	–18,628	52,634	6,533	32,037	0,2216	1,2812	55,73 %	0,0491	0,2837	12,338 %	1,0 %	FALSE	INVALID
12 to 14	15 to 17	18 to 20	3,960	–18,040	56,613	6,717	32,037	0,7784	3,4703	75,73 %	0,1689	0,7531	16,432 %	1,0 %	FALSE	INVALID
13 to 15	16 to 18	19 to 21	3,993	–18,025	57,060	6,717	32,036	0,6108	2,4751	45,12 %	0,1412	0,5723	10,433 %	1,0 %	FALSE	INVALID
14 to 16	17 to 19	20 to 22	4,001	–18,031	57,171	6,717	32,037	0,4727	1,5022	51,30 %	0,1146	0,3642	5,015 %	1,0 %	FALSE	INVALID
15 to 17	18 to 20	21 to 23	4,002	–18,037	57,301	6,717	32,037	0,7757	3,4610	74,55 %	0,0265	0,0008	0,704 %	1,0 %	FALSE	INVALID
16 to 18	19 to 21	22 to 24	4,000	–18,044	57,246	6,717	32,037	0,5921	2,5263	44,10 %	0,0099	0,0546	3,254 %	1,0 %	FALSE	INVALID
17 to 19	20 to 22	23 to 25	3,999	–18,048	57,283	6,717	32,037	0,4771	1,5497	50,68 %	0,0461	0,2799	10,783 %	1,0 %	FALSE	INVALID
18 to 20	21 to 23	24 to 26	3,993	–18,054	57,475	6,733	32,038	0,7989	3,4982	73,39 %	0,1730	0,7577	15,896 %	1,0 %	FALSE	INVALID
19 to 21	22 to 24	25 to 27	3,950	–18,181	54,195	7,300	32,038	0,6540	2,5263	46,58 %	0,1335	0,5144	9,454 %	1,0 %	FALSE	INVALID
20 to 22	23 to 25	26 to 28	3,910	–18,433	50,179	7,700	32,038	0,5254	1,5666	22,97 %	0,1030	0,3072	4,371 %	1,0 %	FALSE	INVALID
21 to 23	24 to 26	27 to 29	3,771	–18,965	46,596	7,517	32,037	0,1736	0,0889	3,00 %	0,0346	0,0177	0,599 %	1,0 %	FALSE	INVALID
22 to 24	25 to 27	28 to 30	3,734	–18,990	46,197	7,517	32,038	0,0951	0,0617	0,95 %	0,0190	0,0112	0,129 %	1,0 %	TRUE	INVALID
23 to 25	26 to 28	29 to 31	3,721	–18,995	46,164	7,517	32,038	0,0664	0,0656	0,74 %	0,0132	0,0131	0,000 %	1,0 %	TRUE	INVALID

Block A	Block B	Block C	Test Period Unfrozen	Test Period Frozen	Test Period Power	Test Period (A-B-C)	Ambient Temp. (A-B-C)	Spread Unfrozen (A-B-C)	Spread Frozen (A-B-C)	Spread Power (A-B-C)	Slope Unfrozen (A-C)	Slope Frozen (A-C)	Slope Power (A- C)	Permitted Power Spread	IEC Criteria Annex B	Test Period Valid
TCCs	TCCs	TCCs	°C	°C	W	h	°C	K	K	%	K/h	K/h	%/h	%		
24 to 26	27 to 29	30 to 32	3,712	–19,002	46,098	7,517	32,037	0,0431	0,0759	0,74 %	0,0086	0,0151	0,148 %	1,0 %	TRUE	VALID
25 to 27	28 to 30	31 to 33	3,708	–19,010	46,197	7,517	32,037	0,0332	0,0650	0,95 %	0,0031	0,0130	0,061 %	1,0 %	TRUE	VALID
26 to 28	29 to 31	32 to 34	3,706	–19,019	46,231	7,517	32,036	0,0216	0,0539	0,74 %	0,0007	0,0108	0,061 %	1,0 %	TRUE	VALID
27 to 29	30 to 32	33 to 35	3,707	–19,025	46,100	7,500	32,035	0,0273	0,0241	0,76 %	0,0046	0,0030	0,108 %	1,0 %	TRUE	VALID
28 to 30	31 to 33	34 to 36	3,706	–19,031	45,969	7,483	32,034	0,0284	0,0033	1,19 %	0,0057	0,0004	0,107 %	1,0 %	FALSE	INVALID
29 to 31	32 to 34	35 to 37	3,713	–19,023	46,133	7,500	32,034	0,0389	0,0415	0,43 %	0,0078	0,0073	0,022 %	1,0 %	TRUE	INVALID
30 to 32	33 to 35	36 to 38	3,717	–19,023	46,100	7,500	32,035	0,0356	0,0301	0,76 %	0,0071	0,0060	0,043 %	1,0 %	TRUE	INVALID
31 to 33	34 to 36	37 to 39	3,721	–19,026	46,167	7,500	32,033	0,0282	0,0198	1,81 %	0,0056	0,0040	0,126 %	1,0 %	FALSE	INVALID
32 to 34	35 to 37	38 to 40	3,722	–19,031	46,167	7,500	32,033	0,0173	0,0601	0,32 %	0,0008	0,0037	0,043 %	1,0 %	TRUE	INVALID
33 to 35	36 to 38	39 to 41	3,722	–19,034	46,183	7,500	32,034	0,0224	0,0643	0,54 %	0,0028	0,0086	0,043 %	1,0 %	TRUE	INVALID
34 to 36	37 to 39	40 to 42	3,720	–19,037	46,183	7,500	32,034	0,0329	0,0526	1,81 %	0,0031	0,0068	0,257 %	1,0 %	FALSE	INVALID
35 to 37	38 to 40	41 to 43	3,715	–19,042	46,133	7,500	32,034	0,0360	0,0765	0,11 %	0,0072	0,0153	0,022 %	1,0 %	TRUE	INVALID
36 to 38	39 to 41	42 to 44	3,711	–19,049	46,117	7,500	32,034	0,0402	0,0656	0,33 %	0,0080	0,0131	0,022 %	1,0 %	TRUE	INVALID

NOTE

– Orange shading indicates that the selected test parameter does not comply with the specific validity requirements of Annex B.

– Green shading in the last two columns indicates that the relevant criteria is TRUE or VALID.

– Light blue shading indicates the test period that has been selected as optimal for this range of data and the selected block size.

Step 5: Once each of the validity characteristics across the blocks has been calculated, these can be evaluated against the validity criteria in B.3.2. In this example for a block size of 3 **temperature control cycles**, there are several possible test periods that meet the specified validity criteria in B.3.2 (a total of 7 test periods, noted as VALID in the last column in Table I.12). Note that the test periods that start with **temperature control cycles** in the range 10 to 24 (in Table I.12) do not comply with the validity criteria because of the effects of the **defrost and recovery period** that occur at **temperature control cycle** 19 (see Figure I.10 and Table I.10). Where there are a number of possible test periods that meet all of the validity criteria in B.3.2 for the selected block size, the test period with the minimum spread of power should be selected. In this example, the test period before the defrost that has the lowest power spread across blocks A, B and C is test period starting with **temperature control cycle** number 10 (the test period from TCC 4 to TCC 12 inclusive). The lowest power spread in this case is 0,32 % and is marked in green in Table I.12. Note that this is the third consecutive test period for this block size where all validity criteria are met (each one incremented by one TCC) as set out in B.3.2. There are several valid test periods after the defrost at TCC 19. The one with the lowest power spread across blocks A, B and C is test period starting with **temperature control cycle** number 26 (coloured in green – the test period from TCC 26 to TCC 34 inclusive). The lowest power spread in this case is 0,74 % and is also marked in green in Table I.12. Note that the power and the temperatures after the defrost are slightly different to those before the defrost.

In this example (Table I.11 and Table I.12), the relatively small block size (3 TCC) means that the power spread is larger and this occasionally exceeds the permitted level of 1 % spread (for a test period of around 7,5 h). While the IEC standard does allow very short test periods for very stable products (as short as 6 h), a 1 % power spread (for test periods less than 12 h) is quite onerous and even this quite stable product does not always meet the requirements for such a short duration.

Where there is a longer period of data available, more robust results can be obtained by selecting longer test periods, which are constructed from blocks that contain a larger number of TCCs. The following tables (Table I.13 to Table I.14) illustrate the same source data set out in Figure I.10 and Table I.10 with test periods made up of 3 blocks with a block size of 5 TCC (test periods made up of 15 TCC) and a block size of 9 TCC (test periods made up of 27 TCC). These give a test period length of around 11,7 h and 21,7 h respectively for this particular product. Only valid data after the first defrost can be found for the larger block size of 9 TCC (as the period before the first defrost is too short to establish stability).

Note that values for P_{SS1} are corrected for deviations in the measured **ambient temperature** during the test period according to Formula (15) (not shown in this example).

The examples set out in these tables can be used to check that laboratory software for undertaking **steady state** analysis in accordance with approach SS1 in Annex B is operating correctly.

Table I.13 – An example of calculation of energy, power and temperature for all possible blocks (size = 5 TCC)

Block	Start TCC	End TCC	Time length of Block	Energy consumption during Block	Average Power	Average Unfrozen Temp.	Average Frozen Temp.
			hh:mm:ss	Wh	W	°C	°C
1	1	5	04:09:00	190,500	45,904	3,765	–18,921
2	2	6	04:09:00	190,625	45,934	3,778	–18,909
3	3	7	04:09:00	190,625	45,934	3,780	–18,913
4	4	8	04:09:00	189,875	45,753	3,782	–18,908
5	5	9	04:10:00	191,500	45,960	3,778	–18,902
6	6	10	04:10:00	191,250	45,900	3,773	–18,907
7	7	11	04:10:00	190,875	45,810	3,764	–18,913
8	8	12	04:10:00	190,625	45,750	3,759	–18,914
9	9	13	04:10:00	190,375	45,690	3,755	–18,920
10	10	14	04:10:00	190,500	45,720	3,761	–18,926
11	11	15	04:10:00	190,750	45,780	3,762	–18,928
12	12	16	04:10:00	190,375	45,690	3,759	–18,926
13	13	17	04:10:00	190,375	45,690	3,763	–18,923
14	14	18	03:36:00	182,000	50,556	3,804	–18,817
15	15	19	03:12:00	191,500	59,844	3,863	–18,311
16	16	20	03:23:00	227,875	67,352	4,154	–17,167
17	17	21	03:23:00	230,875	68,239	4,221	–17,141
18	18	22	03:23:00	231,625	68,461	4,233	–17,153
19	19	23	03:57:00	240,875	60,981	4,135	–17,514
20	20	24	04:21:00	231,375	53,190	4,058	–18,014
21	21	25	04:10:00	194,875	46,770	3,823	–18,939
22	22	26	04:11:00	194,125	46,404	3,764	–18,966
23	23	27	04:11:00	193,625	46,285	3,742	–18,970
24	24	28	04:11:00	193,000	46,135	3,725	–18,976
25	25	29	04:11:00	193,625	46,285	3,713	–18,989
26	26	30	04:11:00	193,375	46,225	3,701	–19,007
27	27	31	04:10:00	191,625	45,990	3,697	–19,020
28	28	32	04:10:00	191,750	46,020	3,696	–19,029
29	29	33	04:10:00	192,250	46,140	3,700	–19,036
30	30	34	04:10:00	192,125	46,110	3,706	–19,036
31	31	35	04:10:00	192,625	46,230	3,716	–19,027
32	32	36	04:09:00	190,625	45,934	3,716	–19,036
33	33	37	04:10:00	192,500	46,200	3,727	–19,013
34	34	38	04:10:00	192,125	46,110	3,730	–19,011
35	35	39	04:10:00	192,125	46,110	3,729	–19,020
36	36	40	04:10:00	192,125	46,110	3,724	–19,031
37	37	41	04:11:00	194,125	46,404	3,724	–19,034
38	38	42	04:10:00	192,625	46,230	3,712	–19,062
39	39	43	04:10:00	192,375	46,170	3,703	–19,072
40	40	44	04:10:00	192,250	46,140	3,697	–19,069

Block	Start TCC	End TCC	Time length of Block	Energy consumption during Block	Average Power	Average Unfrozen Temp.	Average Frozen Temp.
			hh:mm:ss	Wh	W	°C	°C
41	41	45	04:10:00	191,750	46,020	3,692	–19,076
42	42	46	04:10:00	191,500	45,960	3,690	–19,084
43	43	47	04:10:00	190,750	45,780	3,683	–19,098
44	44	48	04:10:00	190,625	45,750	3,685	–19,096
45	45	49	04:11:00	192,625	46,046	3,689	–19,091
46	46	50	04:11:00	192,625	46,046	3,689	–19,091
47	47	51	03:37:00	184,000	50,876	3,722	–18,988
48	48	52	03:14:00	196,500	60,773	3,806	–18,351
49	49	53	03:26:00	234,500	68,301	4,123	–17,233
50	50	54	03:25:00	236,250	69,146	4,196	–17,187
51	51	55	03:24:00	236,125	69,449	4,211	–17,190
52	52	56	03:58:00	245,750	61,954	4,103	–17,554
53	53	57	04:20:00	232,500	53,654	4,002	–18,155
54	54	58	04:08:00	196,000	47,419	3,742	–19,083

NOTE The values in Table I.13 can be derived from the data in Table I.10. Great care is required to ensure that time weighted averages of power and temperature are derived.

Table I.14 – An example of calculation of energy, power and temperature for all possible blocks (size = 9 TCC)

Block	Start TCC	End TCC	Time length of Block	Energy consumption during Block	Average Power	Average Unfrozen Temp.	Average Frozen Temp.
			hh:mm:ss	Wh	W	°C	°C
1	1	9	07:29:00	343,625	45,919	3,769	–18,915
2	2	10	07:29:00	343,125	45,852	3,772	–18,909
3	3	11	07:29:00	343,250	45,869	3,772	–18,910
4	4	12	07:29:00	342,250	45,735	3,770	–18,913
5	5	13	07:30:00	344,000	45,867	3,769	–18,912
6	6	14	07:30:00	343,625	45,817	3,767	–18,918
7	7	15	07:30:00	343,250	45,767	3,764	–18,919
8	8	16	07:30:00	343,000	45,733	3,760	–18,917
9	9	17	07:30:00	342,750	45,700	3,760	–18,921
10	10	18	06:56:00	334,500	48,245	3,782	–18,869
11	11	19	06:32:00	343,875	52,634	3,810	–18,628
12	12	20	06:43:00	380,250	56,613	3,960	–18,040
13	13	21	06:43:00	383,250	57,060	3,993	–18,025
14	14	22	06:43:00	384,000	57,171	4,001	–18,031
15	15	23	06:43:00	384,875	57,301	4,002	–18,037
16	16	24	06:43:00	384,500	57,246	4,000	–18,044
17	17	25	06:43:00	384,750	57,283	3,999	–18,048
18	18	26	06:44:00	387,000	57,475	3,993	–18,054
19	19	27	07:18:00	395,625	54,195	3,950	–18,181
20	20	28	07:42:00	386,375	50,179	3,910	–18,433
21	21	29	07:31:00	350,250	46,596	3,771	–18,965
22	22	30	07:31:00	347,250	46,197	3,734	–18,990
23	23	31	07:31:00	347,000	46,164	3,721	–18,995
24	24	32	07:31:00	346,500	46,098	3,712	–19,002
25	25	33	07:31:00	347,250	46,197	3,708	–19,010
26	26	34	07:31:00	347,500	46,231	3,706	–19,019
27	27	35	07:30:00	345,750	46,100	3,707	–19,025
28	28	36	07:29:00	344,000	45,969	3,706	–19,031
29	29	37	07:30:00	346,000	46,133	3,713	–19,023
30	30	38	07:30:00	345,750	46,100	3,717	–19,023
31	31	39	07:30:00	346,250	46,167	3,721	–19,026
32	32	40	07:30:00	346,250	46,167	3,722	–19,031
33	33	41	07:30:00	346,375	46,183	3,722	–19,034
34	34	42	07:30:00	346,375	46,183	3,720	–19,037
35	35	43	07:30:00	346,000	46,133	3,715	–19,042
36	36	44	07:30:00	345,875	46,117	3,711	–19,049
37	37	45	07:31:00	347,375	46,214	3,709	–19,053
38	38	46	07:30:00	345,375	46,050	3,701	–19,073
39	39	47	07:30:00	345,000	46,000	3,694	–19,085
40	40	48	07:30:00	344,500	45,933	3,691	–19,085

Block	Start TCC	End TCC	Time length of Block	Energy consumption during Block	Average Power	Average Unfrozen Temp.	Average Frozen Temp.
			hh:mm:ss	Wh	W	°C	°C
41	41	49	07:31:00	346,375	46,081	3,691	–19,082
42	42	50	07:31:00	345,875	46,014	3,689	–19,085
43	43	51	06:57:00	336,750	48,453	3,705	–19,036
44	44	52	06:34:00	349,125	53,166	3,744	–18,732
45	45	53	06:46:00	386,750	57,155	3,907	–18,155
46	46	54	06:46:00	390,875	57,765	3,946	–18,129
47	47	55	06:45:00	390,500	57,852	3,952	–18,131
48	48	56	06:45:00	391,750	58,037	3,952	–18,127
49	49	57	06:44:00	391,000	58,069	3,946	–18,135
50	50	58	06:43:00	390,125	58,083	3,941	–18,143

NOTE The values in Table I.14 can be derived from the data in Table I.10. Great care is required to ensure that time weighted averages of power and temperature are derived.

Table I.15 – An example of calculation of energy, power and temperature for all possible test periods (3 blocks each of 5 TCC)

Block A	Block B	Block C	Test Period Unfrozen	Test Period Frozen	Test Period Power	Test Period (A-B-C)	Ambient Temp. (A-B-C)	Spread Unfrozen (A-B-C)	Spread Frozen (A-B-C)	Spread Power (A-B-C)	Slope Unfrozen (A-C)	Slope Frozen (A-C)	Slope Power (A- C)	Permitted Power Spread	IEC Criteria Annex B	Test Period Valid
TCCs	TCCs	TCCs	°C	°C	W	h	°C	K	K	%	K/h	K/h	%/h	%		
1 to 5	6 to 10	11 to 15	3,767	–18,919	45,861	12,483	32,035	0,0111	0,0206	0,27 %	0,0004	0,0009	0,032 %	1,040 %	TRUE	INVALID
2 to 6	7 to 11	12 to 16	3,767	–18,916	45,811	12,483	32,035	0,0187	0,0164	0,53 %	0,0022	0,0020	0,064 %	1,040 %	TRUE	INVALID
3 to 7	8 to 12	13 to 17	3,767	–18,916	45,791	12,483	32,035	0,0210	0,0092	0,53 %	0,0020	0,0011	0,064 %	1,040 %	TRUE	VALID
4 to 8	9 to 13	14 to 18	3,780	–18,885	47,182	11,917	32,036	0,0487	0,1038	10,31 %	0,0027	0,0114	1,266 %	1,000 %	FALSE	INVALID
5 to 9	10 to 14	15 to 19	3,796	–18,747	49,725	11,533	32,036	0,1016	0,6150	28,40 %	0,0107	0,0753	3,557 %	1,000 %	FALSE	INVALID
6 to 10	11 to 15	16 to 20	3,879	–18,412	52,052	11,717	32,036	0,3914	1,7611	41,44 %	0,0479	0,2192	5,189 %	1,000 %	FALSE	INVALID
7 to 11	12 to 16	17 to 21	3,894	–18,406	52,244	11,717	32,036	0,4621	1,7849	43,16 %	0,0576	0,2232	5,406 %	1,000 %	FALSE	INVALID
8 to 12	13 to 17	18 to 22	3,897	–18,408	52,287	11,717	32,037	0,4742	1,7696	43,55 %	0,0597	0,2217	5,469 %	1,000 %	FALSE	INVALID
9 to 13	14 to 18	19 to 23	3,898	–18,414	52,340	11,717	32,037	0,3793	1,4066	29,21 %	0,0495	0,1837	3,815 %	1,000 %	FALSE	INVALID
10 to 14	15 to 19	20 to 24	3,899	–18,419	52,351	11,717	32,037	0,2965	0,9119	26,98 %	0,0398	0,1223	1,913 %	1,000 %	FALSE	INVALID
11 to 15	16 to 20	21 to 25	3,897	–18,423	52,361	11,717	32,037	0,3914	1,7719	41,20 %	0,0081	0,0014	0,250 %	1,000 %	FALSE	INVALID
12 to 16	17 to 21	22 to 26	3,894	–18,425	52,447	11,733	32,038	0,4621	1,8249	42,99 %	0,0006	0,0053	0,180 %	1,000 %	FALSE	INVALID
13 to 17	18 to 22	23 to 27	3,891	–18,429	52,468	11,733	32,037	0,4909	1,8172	43,40 %	0,0028	0,0063	0,150 %	1,000 %	FALSE	INVALID
14 to 18	19 to 23	24 to 28	3,887	–18,435	52,489	11,733	32,038	0,4094	1,4620	28,28 %	0,0100	0,0203	1,074 %	1,000 %	FALSE	INVALID
15 to 19	20 to 24	25 to 29	3,882	–18,442	52,543	11,733	32,037	0,3447	0,9747	25,81 %	0,0186	0,0843	3,209 %	1,000 %	FALSE	INVALID
16 to 20	21 to 25	26 to 30	3,875	–18,452	52,511	11,733	32,037	0,4522	1,8406	40,23 %	0,0569	0,2315	5,061 %	1,000 %	FALSE	INVALID
17 to 21	22 to 26	27 to 31	3,872	–18,459	52,553	11,733	32,038	0,5239	1,8790	42,34 %	0,0658	0,2361	5,320 %	1,000 %	FALSE	INVALID
18 to 22	23 to 27	28 to 32	3,867	–18,467	52,585	11,733	32,037	0,5370	1,8763	42,67 %	0,0675	0,2358	5,362 %	1,000 %	FALSE	INVALID
19 to 23	24 to 28	29 to 33	3,848	–18,527	50,904	12,300	32,037	0,4350	1,5226	29,16 %	0,0528	0,1847	3,537 %	1,025 %	FALSE	INVALID
20 to 24	25 to 29	30 to 34	3,829	–18,670	48,593	12,700	32,037	0,3517	1,0222	14,57 %	0,0417	0,1211	1,726 %	1,058 %	FALSE	INVALID
21 to 25	26 to 30	31 to 35	3,747	–18,991	46,408	12,517	32,036	0,1219	0,0888	1,17 %	0,0129	0,0106	0,139 %	1,043 %	FALSE	INVALID
22 to 26	27 to 31	32 to 36	3,726	–19,007	46,110	12,500	32,036	0,0665	0,0696	1,02 %	0,0058	0,0084	0,122 %	1,042 %	TRUE	INVALID
23 to 27	28 to 32	33 to 37	3,722	–19,004	46,168	12,517	32,036	0,0461	0,0591	0,57 %	0,0018	0,0051	0,022 %	1,043 %	TRUE	INVALID

Block A	Block B	Block C	Test Period Unfrozen	Test Period Frozen	Test Period Power	Test Period (A-B-C)	Ambient Temp. (A-B-C)	Spread Unfrozen (A-B-C)	Spread Frozen (A-B-C)	Spread Power (A-B-C)	Slope Unfrozen (A-C)	Slope Frozen (A-C)	Slope Power (A- C)	Permitted Power Spread	IEC Criteria Annex B	Test Period Valid
24 to 28	29 to 33	34 to 38	3,718	–19,008	46,128	12,517	32,036	0,0300	0,0605	0,07 %	0,0005	0,0042	0,007 %	1,043 %	TRUE	VALID
25 to 29	30 to 34	35 to 39	3,716	–19,015	46,168	12,517	32,035	0,0231	0,0476	0,38 %	0,0019	0,0038	0,045 %	1,043 %	TRUE	VALID
26 to 30	31 to 35	36 to 40	3,714	–19,022	46,188	12,517	32,035	0,0228	0,0240	0,26 %	0,0027	0,0029	0,030 %	1,043 %	TRUE	VALID
27 to 31	32 to 36	37 to 41	3,712	–19,030	46,110	12,500	32,035	0,0263	0,0155	1,02 %	0,0032	0,0017	0,108 %	1,042 %	TRUE	VALID
28 to 32	33 to 37	38 to 42	3,712	–19,035	46,150	12,500	32,035	0,0311	0,0486	0,46 %	0,0019	0,0039	0,055 %	1,042 %	TRUE	VALID
29 to 33	34 to 38	39 to 43	3,711	–19,040	46,140	12,500	32,034	0,0300	0,0611	0,13 %	0,0003	0,0043	0,008 %	1,042 %	TRUE	VALID
30 to 34	35 to 39	40 to 44	3,710	–19,042	46,120	12,500	32,035	0,0323	0,0484	0,07 %	0,0011	0,0039	0,008 %	1,042 %	TRUE	VALID
31 to 35	36 to 40	41 to 45	3,711	–19,045	46,120	12,500	32,034	0,0317	0,0483	0,46 %	0,0028	0,0058	0,055 %	1,042 %	TRUE	VALID
32 to 36	37 to 41	42 to 46	3,710	–19,051	46,100	12,500	32,034	0,0336	0,0501	1,02 %	0,0030	0,0058	0,007 %	1,042 %	TRUE	VALID
33 to 37	38 to 42	43 to 47	3,708	–19,058	46,070	12,500	32,034	0,0440	0,0851	0,98 %	0,0053	0,0102	0,109 %	1,042 %	TRUE	VALID
34 to 38	39 to 43	44 to 48	3,706	–19,060	46,010	12,500	32,035	0,0443	0,0850	0,91 %	0,0053	0,0102	0,094 %	1,042 %	TRUE	VALID
35 to 39	40 to 44	45 to 49	3,705	–19,060	46,099	12,517	32,036	0,0398	0,0708	0,20 %	0,0048	0,0085	0,017 %	1,043 %	TRUE	VALID
36 to 40	41 to 45	46 to 50	3,702	–19,066	46,059	12,517	32,036	0,0354	0,0595	0,20 %	0,0042	0,0071	0,017 %	1,043 %	TRUE	VALID

NOTE

– Orange shading indicates that the selected test parameter does not comply with the specific validity requirements of Annex B.

– Green shading in the last two columns indicates that the relevant criteria is TRUE or VALID.

– Light blue shading indicates the test period that has been selected as optimal for this range of data and the selected block size.

Table I.16 – An example of calculation of energy, power and temperature for all possible test periods (3 blocks each of 9 TCC)

Block A	Block B	Block C	Test Period Unfrozen	Test Period Frozen	Test Period Power	Test Period (A-B-C)	Ambient Temp. (A-B-C)	Spread Unfrozen (A-B-C)	Spread Frozen (A-B-C)	Spread Power (A-B-C)	Slope Unfrozen (A-C)	Slope Frozen (A-C)	Slope Power (A- C)	Permitted Power Spread	IEC Criteria Annex B	Test Period Valid
TCCs	TCCs	TCCs	°C	°C	W	h	℃	K	K	%	K/h	K/h	%/h	%		
1 to 9	10 to 18	19 to 27	3,834	–18,654	49,444	21,717	32,036	0,1804	0,7338	16,74 %	0,0126	0,0512	1,169 %	1,810 %	FALSE	INVALID
2 to 10	11 to 19	20 to 28	3,832	–18,656	49,426	21,717	32,036	0,1375	0,4761	13,72 %	0,0097	0,0337	0,620 %	1,810 %	FALSE	INVALID
3 to 11	12 to 20	21 to 29	3,830	–18,660	49,444	21,717	32,036	0,1885	0,9243	21,73 %	0,0000	0,0038	0,104 %	1,810 %	FALSE	INVALID
4 to 12	13 to 21	22 to 30	3,827	–18,665	49,398	21,717	32,037	0,2595	0,9654	22,93 %	0,0026	0,0054	0,066 %	1,810 %	FALSE	INVALID
5 to 13	14 to 22	23 to 31	3,824	–18,668	49,463	21,733	32,037	0,2800	0,9646	22,85 %	0,0034	0,0058	0,042 %	1,811 %	FALSE	INVALID
6 to 14	15 to 23	24 to 32	3,821	–18,675	49,463	21,733	32,037	0,2902	0,9654	23,22 %	0,0039	0,0059	0,040 %	1,811 %	FALSE	INVALID
7 to 15	16 to 24	25 to 33	3,817	–18,680	49,463	21,733	32,037	0,2922	0,9661	23,21 %	0,0039	0,0064	0,061 %	1,811 %	FALSE	INVALID
8 to 16	17 to 25	26 to 34	3,815	–18,684	49,475	21,733	32,036	0,2933	0,9704	23,34 %	0,0038	0,0071	0,071 %	1,811 %	FALSE	INVALID
9 to 17	18 to 26	27 to 35	3,814	–18,688	49,486	21,733	32,036	0,2862	0,9705	23,80 %	0,0037	0,0073	0,057 %	1,811 %	FALSE	INVALID
10 to 18	19 to 27	28 to 36	3,812	–18,694	49,461	21,717	32,036	0,2437	0,8500	16,63 %	0,0052	0,0112	0,317 %	1,810 %	FALSE	INVALID
11 to 19	20 to 28	29 to 37	3,812	–18,695	49,521	21,733	32,036	0,1968	0,5898	13,13 %	0,0066	0,0269	0,892 %	1,811 %	FALSE	INVALID
12 to 20	21 to 29	30 to 38	3,811	–18,699	49,521	21,733	32,036	0,2425	0,9823	21,23 %	0,0166	0,0672	1,452 %	1,811 %	FALSE	INVALID
13 to 21	22 to 30	31 to 39	3,810	–18,704	49,544	21,733	32,036	0,2717	1,0010	21,99 %	0,0186	0,0684	1,503 %	1,811 %	FALSE	INVALID
14 to 22	23 to 31	32 to 40	3,808	–18,709	49,567	21,733	32,036	0,2800	1,0003	22,21 %	0,0191	0,0684	1,518 %	1,811 %	FALSE	INVALID
15 to 23	24 to 32	33 to 41	3,805	–18,715	49,590	21,733	32,036	0,2902	0,9971	22,59 %	0,0192	0,0682	1,533 %	1,811 %	FALSE	INVALID
16 to 24	25 to 33	34 to 42	3,802	–18,721	49,607	21,733	32,036	0,2922	0,9928	22,30 %	0,0192	0,0679	1,525 %	1,811 %	FALSE	INVALID
17 to 25	26 to 34	35 to 43	3,800	–18,727	49,613	21,733	32,036	0,2933	0,9943	22,47 %	0,0194	0,0680	1,537 %	1,811 %	FALSE	INVALID
18 to 26	27 to 35	36 to 44	3,797	–18,732	49,630	21,733	32,036	0,2862	0,9947	22,92 %	0,0193	0,0681	1,566 %	1,811 %	FALSE	INVALID
19 to 27	28 to 36	37 to 45	3,787	–18,760	48,744	22,300	32,036	0,2437	0,8718	16,88 %	0,0162	0,0585	1,100 %	1,858 %	FALSE	INVALID
20 to 28	29 to 37	38 to 46	3,776	–18,839	47,478	22,700	32,036	0,2088	0,6403	8,70 %	0,0138	0,0424	0,576 %	1,892 %	FALSE	INVALID
21 to 29	30 to 38	39 to 47	3,728	–19,024	46,232	22,517	32,036	0,0771	0,1206	1,29 %	0,0051	0,0080	0,086 %	1,876 %	TRUE	INVALID
22 to 30	31 to 39	40 to 48	3,715	–19,034	46,099	22,517	32,036	0,0424	0,0942	0,57 %	0,0028	0,0063	0,038 %	1,876 %	TRUE	INVALID
23 to 31	32 to 40	41 to 49	3,711	–19,036	46,137	22,533	32,036	0,0301	0,0869	0,19 %	0,0020	0,0058	0,012 %	1,878 %	TRUE	VALID
24 to 32	33 to 41	42 to 50	3,708	–19,040	46,098	22,533	32,036	0,0323	0,0827	0,37 %	0,0015	0,0055	0,012 %	1,878 %	TRUE	VALID

Block A	Block B	Block C	Test Period Unfrozen	Test Period Frozen	Test Period Power	Test Period (A-B-C)	Ambient Temp. (A-B-C)	Spread Unfrozen (A-B-C)	Spread Frozen (A-B-C)	Spread Power (A-B-C)	Slope Unfrozen (A-C)	Slope Frozen (A-C)	Slope Power (A- C)	Permitted Power Spread	IEC Criteria Annex B	Test Period Valid
TCCs	TCCs	TCCs	°C	°C	W	h	°C	K	K	%	K/h	K/h	%/h	%		
25 to 33	34 to 42	43 to 51	3,711	–19,027	46,906	21,967	32,036	0,0150	0,0267	4,84 %	0,0002	0,0018	0,326 %	1,831 %	FALSE	INVALID
26 to 34	35 to 43	44 to 52	3,721	–18,940	48,307	21,583	32,036	0,0379	0,3107	14,56 %	0,0026	0,0197	0,987 %	1,799 %	FALSE	INVALID
27 to 35	36 to 44	45 to 53	3,770	–18,763	49,542	21,767	32,036	0,2001	0,8939	22,31 %	0,0137	0,0594	1,525 %	1,814 %	FALSE	INVALID
28 to 36	37 to 45	46 to 54	3,782	–18,758	49,721	21,767	32,036	0,2396	0,9243	23,72 %	0,0164	0,0616	1,620 %	1,814 %	FALSE	INVALID
29 to 37	38 to 46	47 to 55	3,783	–18,763	49,741	21,750	32,036	0,2507	0,9426	23,73 %	0,0163	0,0610	1,611 %	1,813 %	FALSE	INVALID
30 to 38	39 to 47	48 to 56	3,782	–18,766	49,770	21,750	32,036	0,2583	0,9581	24,19 %	0,0161	0,0612	1,640 %	1,813 %	FALSE	INVALID
31 to 39	40 to 48	49 to 57	3,781	–18,770	49,774	21,733	32,036	0,2553	0,9490	24,38 %	0,0154	0,0609	1,636 %	1,811 %	FALSE	INVALID
32 to 40	41 to 49	50 to 58	3,779	–18,774	49,820	21,733	32,036	0,2498	0,9392	24,09 %	0,0150	0,0607	1,635 %	1,811 %	FALSE	INVALID

NOTE

– Orange shading indicates that the selected test parameter does not comply with the specific validity requirements of Annex B.

– Green shading in the last two columns indicates that the relevant criteria is TRUE or VALID.

– Light blue shading indicates the test period that has been selected as optimal for this range of data and the selected block size.

The next set of calculations to be performed in this example is to determine the incremental energy and temperature change associated with a defrost and recovery event in accordance with Annex C. The defrost to be examined in the sample data is the one that occurs at TCC 19.

Firstly, a period of no less than 3 TCC and 3 h in length is selected before and after the defrost event to be analysed (Periods D and F respectively). Period D is before the defrost and ends no less than 3 h before the nominal centre of the defrost (which is 2 h after the defrost heater operation at TCC 19). Period F is after the defrost and ends no less than 3 h after the nominal centre of the defrost.

The defrost heater starts at a cumulative test time of 14,417 h. The nominal centre of the **defrost and recovery period** according to C.3 is 2 h after the start of the defrost heater, which is 16,417 h. The end of Period D must be before 13,417 h and the start of Period F must be after 19,417 h. Note that the cumulative hours at the end of a TCC is exactly the same time as the start of the next TCC. In this case TCC 16 ends at 13,317 h (start of TCC 17) so this defines the end of Period D. Similarly, TCC 26 starts at 20,033 h so this defines the start of Period F.

In this example Period D is made up of 4 TCC (TCC 13 to TCC 16 inclusive) and is a total of 3 h and 20 min in duration. Period F is made up of 4 TCC (TCC 26 to TCC 29 inclusive) and is a total of 3 h and 21 min in duration.

A series of checks are conducted on Periods D and F to ensure that they meet the requirements for DF1 as set out in C.3.2. These are set out in Table I.17.

Table I.17 – Determination of defrost validity DF1

Parameter	Period D	Period F	Spread/Criteria	Validity and Notes
Length (time)	03:20:00	03:21:00	Ratio 0,995	OK (0,8 to 1,25, ≥3 h, both ≥3TCC, equal number of TCC in D and F)
Power W	45,7125	46,3806	1,45 % and 0,668 W	OK (either <2 % or <1 W)
Fresh food °C	3,7615	3,7065	0,0550	OK (<0,5K)
Freezer °C	–18,9221	–18,9968	0,0747	OK (<0,5K)

If the validity of the original periods D and F are not met, the standard allows for the size of D and F to be incremented by one TCC steps to see if any complying periods are present. Similarly, if no complying periods are found, the size of D1 (from the end of Period D to the nominal centre of the defrost and recovery) and F1 (from the nominal centre of the defrost and recovery to the start of Period F) can be increased in 30 min steps. The position of the nominal centre of the **defrost and recovery period** can also be adjusted if required. For these data, none of the above adjustments are needed.

From the data for each TCC given in Table I.10 the following values can be determined:

Total energy from start Period D to end of Period F = 692,5 Wh (TCC 13 to 29 inclusive)

Total time from start Period D to end of Period F = 13 h 24 min (= 13,4 h)

Average power for Period D and Period F = 46,04655 W (note that this is not time weighted)

From Formula (19):

$$\Delta E_{dfj} = (E_{end-F} - E_{start-D}) - \frac{(P_{SS-D} + P_{SS-F})}{2} \times (t_{end-F} - t_{start-D})$$

For the selected defrost:

$$\Delta E_{df} = (692{,}5) - 46{,}04655 \times 13{,}4$$

ΔE_{df} = 75,4762 Wh

The next step is to determine the temperature variation during the selected defrost and recovery event.

From the data for each TCC given in Table I.10 the following values can be determined:

Average **fresh food** temperature from start Period D to end of Period F = 3,8670 °C (TCC 13 to 29 inclusive) (time weighted average)

Average **freezer** temperature from start Period D to end of Period F = –18,5027 °C (TCC 13 to 29 inclusive) (time weighted average)

Average **fresh food** temperature for Period D and Period F = 3,7340 °C (note that this is not time weighted)

Average **freezer** temperature for Period D and Period F = –18,95945 °C (note that this is not time weighted)

From Formula (20):

$$\Delta Th_{dfj-i} = (t_{end-F} - t_{start-D}) \times \left[(T_{av-startD-endF-i}) - \frac{(T_{av-D-i} + T_{av-F-i})}{2} \right]$$

For the selected defrost:

$$\Delta Th_{df-freshfood} = (13{,}4) \times [(3{,}8670) - (3{,}7340)]$$

$\Delta Th_{df\text{-}freshfood}$ = 1,7822 Kh

$$\Delta Th_{df-freezer} = (13{,}4) \times [(-18{,}5027) - (-18{,}95945)]$$

$\Delta Th_{df\text{-}freezer}$ = 6,1204 Kh

As an alternative to approach SS1 (which uses 3 blocks of **steady state** data to assess validity), the following calculation sets out an example using approach SS2 to determine the **steady state** power between defrosts as set out in B.4 using the same data set illustrated in Figure I.10 and Table I.10. The previous calculations have shown that the defrost at TCC 19 is valid according to DF1 in Annex C, so the SS2 approach can be used on this data set.

Firstly, a period of no less than 4 TCC and 4 h is selected before each defrost event. Period X is before the defrost heater operation at TCC 19 and Period Y is before the defrost heater operation at TCC 52 (see Figure I.10 and Table I.10). In this example Period X is made up of 5 TCC (TCC 13 to TCC 17 inclusive) and is a total of 4 h and 10 min in duration. Period Y is made up of 5 TCC (TCC 46 to TCC 50 inclusive) and is a total of 4 h and 11 min in duration.

A series of checks are conducted on Periods X and Y to ensure that they meet the requirements for SS2 as set out in B.4.2.

Table I.18 – Determination of steady state values using SS2

Parameter	Period X	Period Y	Spread/Criteria	Validity and Notes
Length (time)	04:10:00 (5 TCC)	04:11:00 (5 TCC)	Ratio 0,996	OK (0,8 to 1,25, ≥4 h, both ≥4 TCC, equal number of TCC in X and Y)
Power W	45,6900	46,0458	0,78 % and 0,356 W	OK (either <2 % or <1 W)
Fresh food °C	3,7633	3,6887	0,0746	OK (<0,5 K)
Freezer °C	–18,9226	–19,0908	0,1682	OK (<0,5 K)

From the data for each TCC given in Table I.10 the following values can be determined:

Total energy from end of Period X to end of Period Y = 1309,25 Wh (TCC 18 to 50 inclusive)

Total time from end of Period X to end of Period Y = 26 h 45 min (= 26,75 h)

The incremental energy of the defrost at the start of the period ΔE_{df} = 75,4762 Wh

From Formula (12):

$$P_{SS2} = \frac{(E_{end-Y} - E_{end-X}) - \Delta E_{df}}{(t_{end-Y} - t_{end-X})}$$

$$P_{SS2} = \frac{(1309{,}25) - 75{,}4762}{(26{,}75)}$$

P_{SS2} = 46,1224 W

This compares well with the value for P_{SS1} determined in Table I.16 for TCC 23 to TCC 49 of 46,137 W, which is a comparable test period.

Note that P_{SS1} and P_{SS2} must be corrected for the measured **ambient temperature** during the test period according to Formula (15) in Annex B in order to get a value for P_{SS} to be used in subsequent calculations and analysis. In this case, the measured **ambient temperature** is very close to the target **ambient temperature** of 32 °C so the adjustment is very small.

Similar calculations are also done to determine the **steady state** temperatures in each **compartment** using the approach SS2.

Average **fresh food** temperature from end of Period X to end of Period Y = 3,7764 °C (TCC 18 to 50 inclusive) (time weighted average)

Average **freezer** temperature from end of Period X to end of Period Y = –18,7796 °C (TCC 18 to 50 inclusive) (time weighted average)

From Formula (13):

$$T_{SS2-i} = (T_{av-endX-endY-i}) - \left[\frac{\Delta Th_{df-i}}{(t_{end-Y} - t_{end-X})} \right]$$

$$T_{SS2-freshfood} = (3{,}7764) - \left[\frac{1{,}7822}{(26{,}75)} \right]$$

$T_{SS2\text{-}freshfood}$ = 3,7096

$$T_{SS2-freezer} = (-18{,}7796) - \left[\frac{6{,}1204}{(26{,}75)} \right]$$

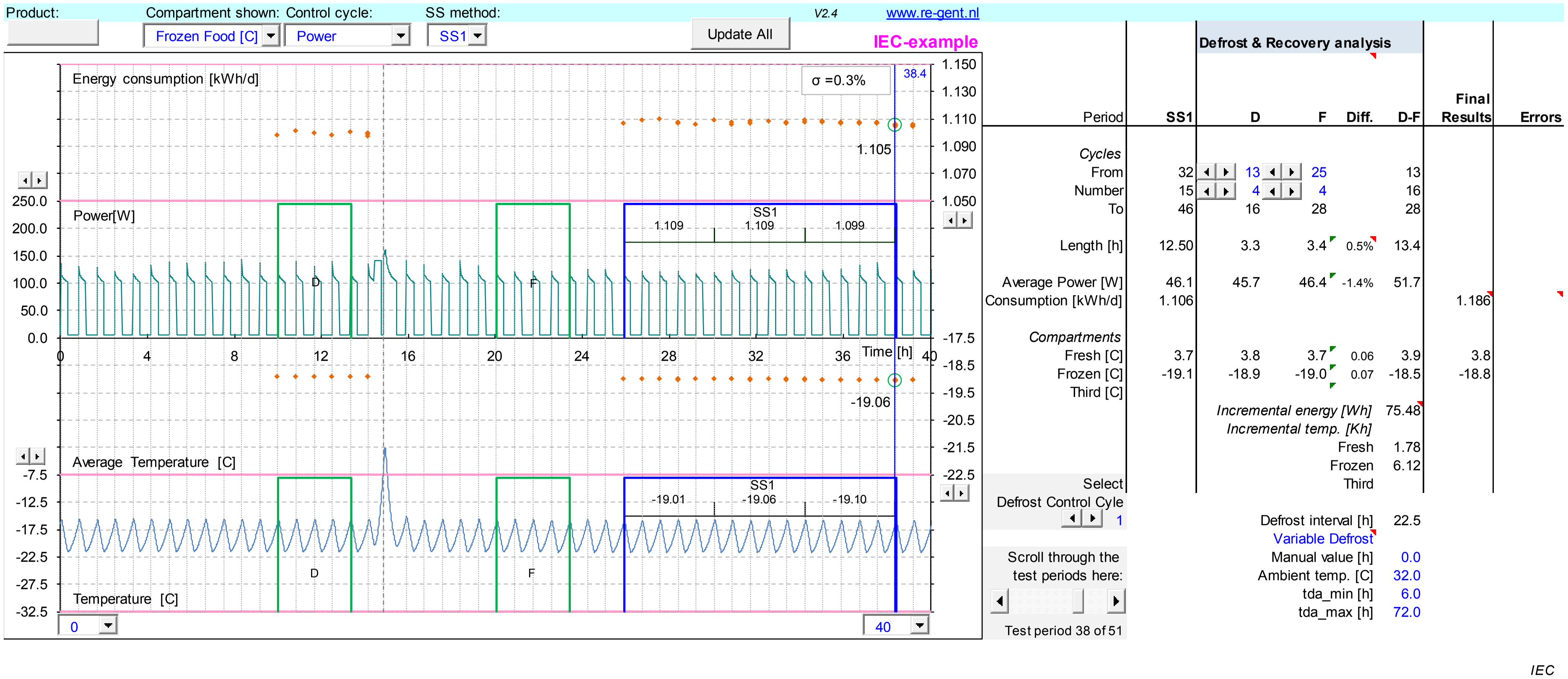
$T_{SS2\text{-}freezer}$ = –19,0084

These values compare well with the values for P_{SS1} determined in Table I.16 for TCC 23 to TCC 49 of 3,711 °C for **fresh food** and –19,036 °C for **freezer**, which is a comparable test period. Because the exact test periods selected for P_{SS1} and P_{SS2} are slightly different, small differences in the results for each parameter are expected. The examples set out above can be used to check that laboratory software for undertaking **steady state** analysis in accordance with approach SS2 in Annex B and DF1 in Annex C is operating correctly.

I.8.2 Review of data and selection of minimum spread using bespoke software

Figure I.11 shows an example of locating a possible test period at a given moment in time. Here the situation is illustrated at 38,4 h after start of data collection for the test of a **refrigerator-freezer**. The power signal is plotted in the middle panel (the diagram contains 5 panels stacked on each other). From this point it is possible to define a number of trial test periods, all consisting of three blocks and reaching backwards in time. For each of these trial periods the **energy consumption** is plotted in the second panel. For each of these trial periods the spread in power within the test period (which is the difference between the maximum and minimum average power observed between block A, B and C) is plotted in the bottom panel. The minimum possible value of this spread is then looked up and in the diagram an arrow is drawn here. This identifies the best possible stable test periods from all the trial periods possible. In this example the length of this test period is 12,5 h.

The **energy consumption** measured over this best possible test period is plotted in panel number 4 while the spread at this test period is plotted in the top panel. The other markers in these two panels illustrate the results of the best test periods at other moments in time. Combining these markers one can see that the **energy consumption** measured converges over time and that the spread gradually reduces. This effect is caused by a continuous increase in the length of the best test period found.



NOTE The selected SS1 test period above is equivalent to the test period from TCC 33 to TCC 47 inclusive shown in Table I.15. The defrost and recovery selected is the same as shown in the worked example in I.8.1.

Figure I.11 – Example of finding a test period with minimum spread in power

Annex J
(informative)

Development of the IEC global test method for refrigerating appliances

J.1 Purpose

This Annex sets out the background to the development of this international test procedure and outlines the broad objectives of a global approach to energy testing.

J.2 Overview

Household **refrigerating appliances** are complex thermo-dynamic products and a wide number of factors can have an effect on their measured **energy consumption**. Detailed investigations have shown that the most important factors (not necessarily in order of importance) that can impact on the **energy consumption** during **normal use** are:

Operating conditions:

- **Ambient temperature** and humidity in which the product operates during **normal use** (indoor or outdoor, whether the space is conditioned or not);
- The **temperature control setting** selected by the user;
- User interactions with the appliance during **normal use** (air exchange resulting from door openings, addition of warm food, drinks and humidity);
- Installation of the appliance (clearances, airflow).

Product design and how the product responds to operating conditions:

- The **defrost and recovery** characteristics of the product;
- The **defrost interval** during **normal use**;
- The **load processing efficiency** of the refrigeration system to remove heat load equivalents that arise from **normal use** and through normal heat gain;
- The quality and level of thermal insulation in doors, walls and gaskets etc.;
- Operation of certain auxiliaries that may be affected by ambient conditions and usage;
- The size, configuration and proportions (dimensions) of the product.

While there are a number of other factors that can also affect **energy consumption**, in general terms these are generally minor and of secondary importance.

J.3 Test method objective

The objective of this test method is to quantify as many as possible of the key components of **energy consumption** in a generic manner to allow them to be aggregated in a way that can reflect operating conditions and usage patterns of household refrigeration products in different climates and regions around the world. Regions and countries can select those test elements that are most important and combine them in a way that is most relevant to them.

The purpose of any test procedure is to provide accurate, quantitative data which can be used as the basis for comparing products that operate under comparable conditions when performing comparable tasks. While it is recognised that every single household **refrigerating appliance** in the world will have different actual operating conditions and different usage patterns, the dis-aggregation of energy into its key components allows typical operating and usage conditions to be applied to products for comparative purposes. It also provides a sound basis for understanding variations in actual **energy consumption** in individual products during **normal use** in a home on a case by case basis, where this is of interest.

The advantage of this global approach to energy determination is that manufacturers (ultimately) need only undertake a suite of standard tests to meet the requirements of all major regions. Regional differences can be achieved by applying different factors to the standardised test results. This will help manufacturers avoid expensive retesting of models that are sold into different regions.

J.4 Description of key components of energy consumption

The most common technology used in household **refrigerating appliances** is the vapour compression cycle, which is effectively a heat pump that removes energy from the refrigerated space (inside **compartments**) to the surrounding ambient air in the room. Some other technologies are used to perform this heat pump function (eg some absorption or thermoelectric (Peltier effect) systems) but these are usually less efficient and are generally used only in niche applications.

Under conditions of no user interaction, the heat flow into the internal **compartments** depends on the effective insulation of the cabinet. This is largely dictated by the wall thickness and insulation value of the wall materials, but there are many other factors that can also affect heat flows such as the design of gaskets and seals and the presence of penetrations through the walls (for services, wiring and ducts). There may also be internal electronic controls, heaters or other devices which consume energy (or put heat into the **compartments**) and that are required to maintain normal operation in the refrigeration appliance. The operation of some of these devices may vary with ambient conditions.

The **energy consumption** under this standard is determined under no use (**steady state**) conditions at an **ambient temperature** of 32 °C and an **ambient temperature** of 16 °C. This provides a good basis for determining the temperature-energy response of the **refrigerating appliance**. Most previous test procedures test **energy consumption** at a single **ambient temperature** only. This provides no information on the energy impacts of the different operating temperatures commonly encountered during **normal use**.

It is well understood that user selected **temperature control settings** on **refrigerating appliances** affect internal operating temperatures, which in turn affect the **energy consumption**. Under this standard (and most other test procedures), techniques are applied to energy measurements conducted at different **temperature control settings** in order to estimate the **energy consumption** at standard internal temperatures. They are called "**target temperatures** for **energy consumption**" in this standard. Single tests used as the basis for declaration of **energy consumption** are required to have their internal temperatures at or below the relevant **target temperature** for the **compartment** type or be based on estimates of the **energy consumption** at the **target temperature**. Additional tests may be conducted at a range of **temperature control settings** in order to determine the optimum (lowest possible) **energy consumption** at the relevant **target temperatures** at each **ambient temperature** condition.

In this standard, the **target temperature** for a **fresh food compartment** is 4 °C while the **target temperature** for a **freezer compartment** is –18 °C. Note that to increase speed of testing and to improve overall repeatability, for all **frozen compartment** types, temperatures are based on average air temperatures – test packages are no longer used for energy tests.

For products that include a defrost system (with its own **defrost control cycle**), there is usually additional energy associated with the **automatic defrost**. Some systems, where the **evaporator** operates close to freezing, can effectively defrost by extending the period without compressor operation – these use little additional energy (in fact they may use less energy during defrost as the **compartment** warms). Some products defrost on every compressor cycle (usually only **evaporators** that operate close to freezing) – these are called **cyclic defrost** (and do not have a **defrost control cycle**) and any defrosting energy is built into the normal operating schedule. Where applicable, the additional (or reduced) energy required to perform an **automatic defrost** and to recover back to a **steady state** condition is determined for a number of representative **defrost and recovery periods**. The frequency of defrosting also affects the total **energy consumption**. To determine the expected **defrost interval**, the test method includes a number of different methods appropriate to the different types of control used.

A significant part of the heat load inside a **refrigerating appliance** during **normal use** results from user related aspects such as door openings and insertion and removal of **foodstuff**. These heat loads are fairly complex and occur due to the exchange of air during door openings (warm air and moisture) and the addition of heat in the form of warm food and drinks. Sometimes moisture is released from **foodstuff** as well. The geometry of the **compartment** (e.g. open versus drawers and bins) and the speed and frequency of door openings can affect the air exchange. The temperature and humidity of the ambient air can also have an effect.

Attempting to replicate actual use through door openings and addition of food loads is difficult for laboratories to undertake and can be difficult to reproduce consistent results. It also requires tight control of test-room humidity in order to have any chance of consistent results. Calculating the resulting heat load from door openings is highly complex and the internal geometry can have an impact from product to product.

To minimise these problems, a new test has been devised for this standard which measures the **load processing efficiency** of the household **refrigerating appliance**. A precise mass of water at a known temperature (and of known enthalpy) is placed inside the **refrigerating appliance** and the product is operated until it returns to a **steady state** condition. The incremental energy used to “process” this load is determined from the test data and the difference between the initial and final energy of the water is used to determine the **load processing efficiency**. Processing of a single known heat load (in the form of warm water) provides a sound basis to determine the equivalent energy impact of user related interactions that could arise during **normal use**. It also allows the quantification of actual heat load equivalents to be determined when data from real homes is analysed.

Some auxiliaries are known to be affected by ambient conditions. Under this standard, the incremental **energy consumption** of specified auxiliaries under specified conditions is declared. These values can be added onto the standardised **energy consumption** for the product where applicable.

This standard does not provide a single global **energy consumption** number. Rather it provides detailed documentation of a number of key energy components which can be assembled to provide an estimate of **energy consumption** under a range of possible operating and usage conditions. Not all regions will use all test components. Regions are expected to use many of the standard components in a way that is most relevant to their regional requirements. Dis-aggregation of the energy components in this manner is an attempt to ultimately eliminate the need for regional test methods for household **refrigerating appliances**.

Annex K
(normative)

Analysis of a refrigerating appliance without steady state between defrosts

K.1 Purpose

This Annex illustrates the approach to be used for the analysis of test data for a **refrigerating appliance** without **steady state** conditions between defrosts.

K.2 Products with regular characteristics but without steady state operation

K.2.1 General

In addition to the routine use of Case SS2 to determine **steady state** power illustrated in Figure B.3, there is one special case that is theoretically envisaged where all data between successive **defrost and recovery periods** using Case SS2 may not be able to establish stability for the initial defrost in accordance with Annex C (DF1). In this case the incremental defrost and recovery energy for the initial defrost has to be determined using an approach called DF2, which is outlined in this Annex.

In this case, the **refrigerating appliance** exhibits a regular and stable pattern of operation but the power between defrosts is not constant (usually increasing or decreasing power). This example would apply to a **refrigerating appliance** that has relatively short **defrost intervals** and over-cools or under-cools after a defrost and then takes some time to reach steady conditions just prior to the next defrost. An example is illustrated in Figure K.1.

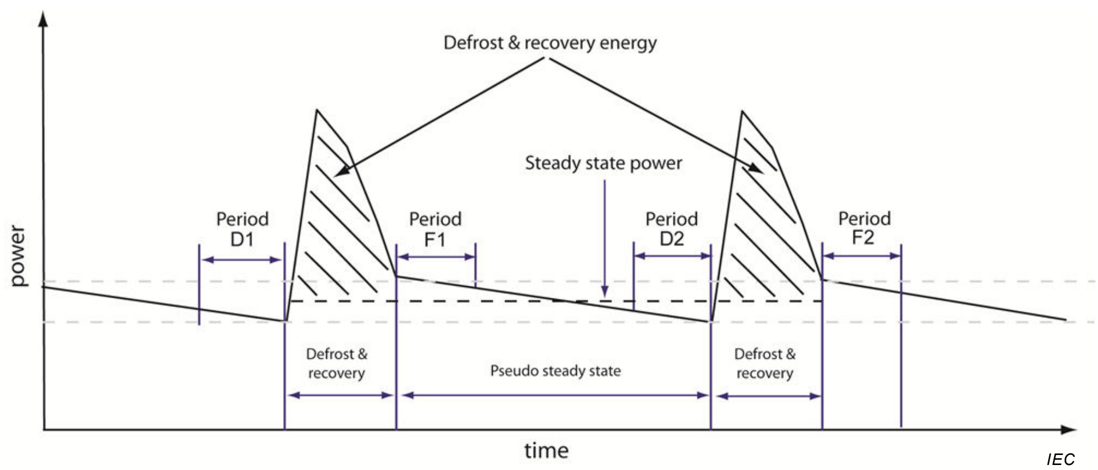


Figure K.1 – Special Case SS2 – where steady state operation is never reached between defrost and recovery periods and Annex C stability may not be established

K.2.2 Special case DF2 approach

Case DF2 is only used where the **refrigerating appliance** does not reach **steady state** operation between **defrost and recovery periods** and establishment of incremental **defrost and recovery** energy using DF1 (C.3) is not possible. In this case the **refrigerating appliance** usually exhibits a regular stable pattern of operation but may not establish **steady state** operation between **defrost and recovery periods**. Comparable parts of successive **defrost and recovery periods** are examined. This usually applies to **refrigerating appliances** that have shorter **defrost intervals**.

A period (called Period D1), ending at the start of a **defrost and recovery period** and made up of no less than 2 whole **temperature control cycles** (where **temperature control cycles** are present) and no less than 2 h in length, is selected. A second period (called Period D2), ending at the start of the next **defrost and recovery period** and made up no less than 2 whole **temperature control cycles** (where **temperature control cycles** are present) and no less than 2 h in length, is selected.

A period (called Period F1), starting after the first **defrost and recovery period** and made up of no less than 2 whole **temperature control cycles** (where **temperature control cycles** are present) and no less than 2 h in length, is selected. A second period (called Period F2), starting after the next **defrost and recovery period** and made up of no less than 2 whole **temperature control cycles** (where **temperature control cycles** are present) and no less than 2 h in length, is selected.

Periods D1, D2, F1 and F2 shall all contain an equal number of **temperature control cycles**, or they shall be the same length where there are no **temperature control cycles** present.

NOTE As guidance, the pseudo **steady state** can be safely identified where the power change per **temperature control cycle** is consistently less than 5 %. A significant change in the duration of the **temperature control cycle** is also a good indicator of the start of a **defrost and recovery period**.

K.2.3 Case DF2 acceptance criteria

For the two **defrost and recovery periods** to be valid, the following criteria shall be met:

- The spread of temperature for the Periods D1 and D2 shall be less than 0,5 K for each **compartment**;
- The spread of temperature for the Periods F1 and F2 shall be less than 0,5 K for each **compartment**;
- The spread of power for the Periods D1 and D2 shall be less than 2 % of the average power of Periods D1 and D2 or less than 1W, whichever is the greater value.
- The spread of power for the Periods F1 and F2 shall be less than 2 % of the average power of Periods F1 and F2 or less than 1W, whichever is the greater value.

NOTE Care is required to ensure that period pairs D1/D2 and F1/F2 are from comparable parts of the **defrost control cycle**. Where all of the above criteria are met, this data can provide **steady state** power for a single **temperature control setting** and energy/temperature data for two **defrost and recovery periods**. For some **refrigerating appliances** (especially those that use mechanical timers) the **temperature control cycle** immediately prior to the operation of the defrost heater can be random in length, so care is required to avoid these when comparing comparable parts of the cycle.

Where there are more than two **compartments**, assessment of temperature stability as set out above is required for:

- The largest **unfrozen compartment** and largest **frozen compartment** (where applicable), or
- The largest two **compartments** (where all **compartments** are **frozen** or **unfrozen**).

K.2.4 Case DF2 calculation of values

Where the acceptance criteria in K.2.3 have been met, the determination of additional energy associated with the first **defrost and recovery period** is calculated as follows:

$$\Delta E_{df} = (E_{end-D2} - E_{end-D1}) - P_{F1-D2} \times (t_{end-D2} - t_{end-D1}) \quad (60)$$

where

ΔE_{df} is the additional energy consumed by the **refrigerating appliance** for a valid **defrost and recovery period** in Wh

$E_{end\text{-}D1}$ is the accumulated energy reading at the end of Period D1 just before the first **defrost and recovery period** in Wh

$E_{end\text{-}D2}$ is the accumulated energy reading at the end of Period D2 just before the second **defrost and recovery period** in Wh

$P_{F1\text{-}D2}$ is the pseudo **steady state** power consumption that occurs from the start of Period F1 to the end of Period D2 inclusive between successive **defrost and recovery periods** in W and meets the acceptance criteria in K.2.3, see Formula (61)

$t_{end\text{-}D1}$ is the test time at the end of Period D1 just before the first **defrost and recovery period** in hours

$t_{end\text{-}D2}$ is the test time at the end of Period D2 just before the second **defrost and recovery period** in hours.

NOTE This calculation gives the **defrost and recovery** energy for the first **defrost and recovery period** (bounded by Periods D1 and F1). A similar calculation using values for Periods D2 and F2 can be performed to determine the **energy consumption** of the second **defrost and recovery period**.

$$P_{F1-D2} = \frac{(E_{end-D2} - E_{start-F1})}{(t_{end-D2} - t_{start-F1})} \quad (61)$$

where

$E_{start\text{-}F1}$ is the accumulated energy reading at the start of Period F1 just after the first **defrost and recovery period** in Wh

$t_{start\text{-}F1}$ is the test time at the start of Period F1 just after the first **defrost and recovery period** in h.

The determination of the temperature change in each **compartment** *i* associated with the **defrost and recovery period** is calculated as follows:

$$\Delta Th_{df-i} = (T_{av-endD1-endD2-i} - T_{F1-D2-i}) \times (t_{endD2} - t_{endD1}) \quad (62)$$

where

$\Delta Th_{df\text{-}i}$ is the accumulated temperature difference over time in **compartment** i (for **compartments** 1 to n) associated with a **defrost and recovery period** in Kh

$T_{av\text{-}endD1\text{-}endD2\text{-}i}$ is the average temperature in **compartment** i (for **compartments** 1 to n) over the period from the end of Period D1 just before the first **defrost and recovery period** to the end of Period D2 just before the second **defrost and recovery period** in ° C

$T_{F1\text{-}D2\text{-}i}$ is the pseudo **steady state** temperature in **compartment** i (for **compartments** 1 to n) that occurs from the start of Period F1 to the end of Period D2 between successive **defrost and recovery periods** in ° C and meets the acceptance criteria in K.2.3

$t_{end\text{-}D1}$ is the test time at the end of Period D1 just before the first **defrost and recovery period** in hours

$t_{end\text{-}D2}$ is the test time at the end of Period D2 just before the second **defrost and recovery period** in hours.

The additional compressor run-time associated with a **defrost and recovery period** (over and above the **steady state** run time) (in hours) shall also be calculated as set out in C.3.3.

Annex L
(informative)

Derivation of ambient temperature correction formula

L.1 Purpose

Ambient temperature has a very important influence on **energy consumption** and even within the permitted range of ambient test temperatures specified in IEC 62552-1:2015 (nominally ±0,5 K). The expected impact is significant, which has the potential to reduce repeatability and reproducibility of the measured values. A correction for **ambient temperature** has been included to normalize the impact of actual variations in **ambient temperature** that occur in the laboratory during the test. The values have been checked against a large number of **refrigerating appliances** of different configurations across a wide range of operating conditions and the results have been found to be in line with observed values. This Annex provides some of the theoretical and practical background to the **ambient temperature** correction included in B.5 to improve understanding and confidence in the use of the formula. More detail is included in a technical report prepared for IEC SC59M.

L.2 Background

The **steady state** power of **refrigerating appliances** generally exhibit a strong response to changes in **ambient temperature**. The following equation sets out the main factors that drive energy for a single **compartment refrigerator** or **freezer**:

$$P = \frac{U \times A \times (T_a - T_i)}{COP}$$

where

P is the (expected) **steady state** power consumption

U is the overall average U value (insulation) of the cabinet walls

A is the surface area of the cabinet walls

T_a is the average **ambient temperature** around the **refrigerating appliance**

T_i is the internal average temperature of the **refrigerating appliance**

COP is the operating coefficient of performance (efficiency) of the refrigeration system.

The value of insulation (U) and the total surface area (A) of the appliance remain constant once the **refrigerator** has been constructed (but every **refrigerator** is different). The internal temperature also (should) remain fairly constant for a given **compartment** type. So the **steady state** power is a function of **ambient temperature** divided by COP. The change in COP of real compressors tends to be fairly linear with changes in **ambient temperature** (which determines the condensing temperature). The power response to changes in **ambient temperature** are non linear because a linear change in the denominator results in a non-linear quotient.

There are many smaller factors that affect the **energy consumption** of a particular **refrigerating appliance** (such as heaters and other auxiliaries (internal and external fans), compressor operating losses, compressor start-up losses and variable speed drives and throat or gasket losses), but the compressor efficiency and heat gain into the **compartment**(s) are the most significant factors and are the ones directly addressed in the correction formula.

During a test, a value of **steady state** power P is measured. For an **ambient temperature** correction, an estimate of the slope or change in **steady state** power is required for a change in **ambient temperature**. The final correction equation needs to invert this effect so that the power consumption is estimated at the target **ambient temperature**. For example, an increase in test room **ambient temperature** above the nominal test room temperature will increase the measured **steady state** power. The correction formula will decrease the measured power consumption value back to the value that would be expected at the nominal test room temperature.

The impact of small differences in ambient test temperature is significant. Typically, the impact per degree of **ambient temperature** change could be expected to be 6 % to 8 % at 16 °C and around 4 % to 5 % at 32 °C (depending on the product). Given that test laboratories are required to hold **ambient temperatures** within ±0,5 K of the nominal test temperature, the measured values could vary between labs by 4 % to 8 % due to permitted **ambient temperature** variations alone. So this ambient correction is an important inclusion in this standard.

L.3 Approach

The following equation should provide an estimate of the total heat gain into a **refrigerating appliance**:

$$Q = U_1 \times A_1 \times (T_a - T_1) + U_2 \times A_2 \times (T_a - T_2) + ... + U_i \times A_i \times (T_a - T_i)$$

where

Q is the total heat gain into the **compartment**

U is the U value (insulation) of each **compartment** for i = 1 to n **compartments**

A is the surface area of each **compartment** for i = 1 to n **compartments** (excluding common partitions between **compartments**)

T_a is the average **ambient temperature** around the **refrigerating appliance**

T_i is the internal average temperature of each **compartment** for i = 1 to n **compartments**.

This equation is a simplification as it ignores heat gain through door seals (which can be factored into the **compartment** overall U value) and energy consumed by auxiliaries.

For a change in **ambient temperature**, the change in heat gain can be estimated by differentiating the equation above, so the change in heat gain per change in ambient is simply:

$$\frac{dQ}{dT_a} = U_1 \times A_1 + U_2 \times A_2 + ... + U_i \times A_i$$

This equation shows that the change in heat gain for a change in **ambient temperature** is constant, no matter what the **ambient temperature**, as it is a function of the U and A values for each **compartment**.

However, in terms of a correction for inclusion into the IEC standard, we are interested in a relative correction. So the value we need to calculate is the change in heat gain over the total heat gain at a given **ambient temperature**:

IEC heat gain correction (%) = $\dfrac{\left[\dfrac{dQ}{dT_a}\right]}{Q}$

This means that the relative correction for heat gain becomes smaller as the **ambient temperature** increases (because total heat gain Q becomes larger and the numerator is constant). This matches well with modelling and physical test data.

We do not know the actual insulation factor U for each **refrigerating appliance** and each **compartment** – to obtain this would be quite onerous. In order to calculate a change in heat gain above we only need an estimate of the relative insulation factor for each **compartment** and the relative surface area of each **compartment**. It should then be possible to make a reasonable estimate of the relative heat gain of **freezers** versus **fresh food compartments** (or indeed any **compartment** operating at any temperature).

The surface area can also be difficult to estimate accurately and it requires a different set of measurements from those already available. In the context of a correction for this standard, it has been found that **volume** data for each **compartment** provides a reasonable proxy for surface area for the purposes of a **steady state** power correction to be included in the IEC standard. The impact of surface area and insulation is only important for products with two or more **compartments** operating at different temperatures. For single **compartment** product operating at a single temperature, these values can be ignored (they will cancel out in the equation below where n = 1).

$$P_{ss} = P_{ssm} \times \left(1 + \frac{\left[T_{at} - T_{am}\right] \times \left[U_1 \times V_1 + \ldots + U_i \times V_i\right]}{\left[U_1 \times V_1 \times (T_{am} - T_1) + \ldots + U_i \times V_i \times (T_{am} - T_i)\right]} \right) \times \frac{1}{\left[1 + (T_{at} - T_{am}) \times \Delta COP\right]}$$

where

V_i is the nominal **volume** of **compartment** i (for n **compartments**)

U_i is relative U value of **compartment** i (for n **compartments**)

T_{am} is the measured **ambient temperature** during the test

T_{at} is the target (nominal) **ambient temperature** (correcting back to this temperature)

T_i is the measured **compartment** temperature during the test

ΔCOP is the expected COP impact for the product type and test condition

P_{SSM} is the measured **steady state** power during the test in accordance with Annex B

P_{SS} is the corrected **steady state** power that is expected at the nominal ambient test temperature in Annex B.

Conceptually, the components of the formula are:

- ($T_{at} - T_{am}$) is the deviation from the target **ambient temperature** in K
- $U \times V$ terms on the numerator estimate the slope of the heat gain for all **compartments**
- The denominator is total heat gain at the **ambient temperature**
- The last term is an overall correction for the expected change in COP for a change in ambient.

Note that the heat gain slope and heat gain in the above equation are based on relative U values and **rated volume** for each **compartment** (not surface area) and so will not be an accurate estimate in watt.

The value of U_i is estimated from the nominal temperature of operation of the **compartment**. This has been derived on the expectation that **compartments** that operate at colder temperatures tend to have better overall insulation (and therefore lower U values). An empirical fit of real data showed that the following values provided a reasonable estimate of the relative insulation in products with two **compartments**.

Table L.1 – Assumed relative insulation value for multi-compartment products

Compartment Target Temp °C	Relative Insulation Effectiveness	Relative Insulation Factor U_{rel}
–18	1,250	0,800
–12	1,182	0,846
–6	1,114	0,898
0	1,045	0,957
2	1,023	0,978
4	1,000	1,000
12	0,909	1,100
17	0,852	1,173

The overall correction equation can be further simplified by building in the above values from Table L.1 for relative insulation into the equation itself by using constants as follows:

$$P_{ss} = P_{ssm} \times \left(1 + \left[T_{at} - T_{am} \right] \times \frac{\sum \left[(c_1 \times (18 + T_{it}) + c_2) \times V_i \right]}{\sum \left[(c_1 \times (18 + T_{it}) + c_2) \times V_i) \times (T_{am} - T_{im}) \right]} \right) \times \frac{1}{\left[1 + (T_{at} - T_{am}) \times \Delta COP \right]}$$

The COP corrections included in the correction formula in Annex B (Table B.1) were adjusted to optimise the fit to actual data. Nominally, the COP impact is expected to be about –1,2 %/K at an **ambient temperature** of 16 °C and –1,7 %/K at an **ambient temperature** of 32 °C with an **evaporator** temperature of –25 °C. The actual values used vary from these because:

- An adjustment for multi-**compartment** products helps to partly compensate for the use of **volume** in lieu of surface area, hence the lower than expected COP values.
- Compressor start losses at low **ambient temperatures** become significant and to some extent these counterbalance the increase in COP as **ambient temperatures** fall (at low **ambient temperatures**) hence the lower than expected COP values.
- Single **compartment** products appear to be able to better optimise their operation (less starts, warmer **evaporator** for all **refrigerating appliance** with only **unfrozen compartments**).