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# Railway applications — Heating, ventilation and air conditioning systems for rolling stock —

## Part 3:
## Energy efficiency

*Applications ferroviaires — Systèmes de chauffage, ventilation et climatisation pour le matériel roulant —*

*Partie 3: Efficacité énergétique*



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# Foreword

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The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular, the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights. Details of any patent rights identified during the development of the document will be in the Introduction and/or on the ISO list of patent declarations received (see www.iso.org/patents).

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For an explanation of the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT), see www.iso.org/iso/foreword.html.

This document was prepared by Technical Committee ISO/TC 269, *Railway applications, Subcommittee SC 2, Rolling Stock*.

A list of all parts in the ISO 19659 series can be found on the ISO website.

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

# Introduction

The world's energy resources are being consumed at a significant rate that will result in the depletion of non-renewable resources. It is imperative that energy be conserved. Conservation of energy in railway vehicles can result in a slowdown of non-renewable resource usage and consequently of the build-up of greenhouse gases.

The HVAC (heating, ventilation and air-conditioning) system is one of the main energy consumers on a train, and its energy efficiency is a key issue to reduce the environmental impact of public transport.

As most railway vehicles are designed to last for a long period (15 y to 40 y), lower energy consumption can also be considered a means of reducing the cost to railway operators and authorities.

The energy consumption of the HVAC systems is affected by multiple parameters therefore, a common guideline is essential for comparative assessment of energy efficiency between different systems.

This document offers methodologies to deliver comparable energy consumption values of the HVAC system without unnecessary lead times and costs by suggesting appropriate conditions for simulation or testing.

In general, this document describes the conditions that should be considered:

— train mode,

— principles such as measurements, climatic and operational boundary conditions,

— assessment methods such as simulation, calculation, verification and post-processing.

These can be used to assess the effectiveness of energy efficiency measures to evaluate different cars and/or HVAC concepts and to provide an indication of the annual HVAC energy consumption for the whole train (except driver's cab).

The specifications in this document are to be considered together with the national/regional standards, which take different preferences, local weather and operational conditions into account.

# Railway applications — Heating, ventilation and air conditioning systems for rolling stock —

# Part 3:
# Energy efficiency

## 1 Scope

This document is applicable to the calculation, measurement and/or verification of energy consumption of railway vehicle HVAC (heating, ventilation and air-conditioning) systems.

The HVAC system energy consumption is simulated, calculated, measured and validated in accordance with the requirements of thermal comfort defined in ISO 19659-2, considering the same category of passenger railway vehicles as detailed in ISO 19659-2, Clause 4:

— Category 1 (e.g. main line, intercity, long distance, high speed);

— Category 2 (e.g. suburban, commuter, regional);

— Category 3 (e.g. urban, LRV, tram, metro/subway).

This document only covers the passenger area HVAC systems. Driver's cab HVAC systems are excluded but could be treated in a similar way.

## 2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 19659-1, *Railway applications — Heating, ventilation and air conditioning systems for rolling stock — Part 1: Terms and definitions*

ISO 19659-2, *Railway applications — Heating, ventilation and air conditioning systems for rolling stock — Part 2: Thermal comfort*

## 3 Terms, definitions and abbreviated terms

### 3.1 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 19659-1 apply.

ISO and IEC maintain terminology databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at https://www.electropedia.org/

### 3.2 Abbreviated terms

For the purposes of this document, the following abbreviated terms apply.

TISM Train in-service mode

TRSM Train ready for service mode

PCM Pre-conditioning mode

PM Parking mode

# 4 Train mode

## 4.1 General

The following train modes, 4.2 to 4.5 are the different operating states of train and relate to the operating mode of the HVAC system.

## 4.2 Train in-service mode (TISM)

This mode covers the commercial operation of the train, including several passenger load cases. The train is moving or is stationary with the HVAC system running in its automatic mode.

## 4.3 Train ready for service mode (TRSM)

In this mode, the HVAC system is operational (same as for TISM) without passengers.

This situation occurs frequently, for example when the:

— train is waiting between two commercial runs;

— train is at a terminal station with the doors closed;

— train is in operation between a depot and a terminal station.

When the train is being cleaned at a terminal station, the time should be considered for this mode.

## 4.4 Pre-conditioning mode (PCM)

Pre-conditioning is the process which enables the interior temperature to be lowered or raised to a defined comfort level including pre-cooling and pre-heating. This mode will depend on the ambient temperature conditions at which the train is operating. During hot conditions pre-cooling is required and in cold conditions, pre-heating is required.

This mode of operation is without passengers on the train.

This mode is an option. If the customer requires this mode, the detailed requirements shall be specified in the technical specification.

## 4.5 Parking mode (PM)

Parking mode is used when the train is not in operation, and there are no staff or passengers on board. The HVAC system runs normally with different setpoints for temperature and airflow or alternatively, is shut down to conserve energy.

The purpose of parking mode includes frost protection and keeping the interior temperature at a reasonable level. Trains are normally shut down during the night to reduce noise and energy consumption.

This mode is an option. If the customer requires this mode, the detailed requirements shall be specified in the technical specification.



### 4.6 Operating timetable, hours for each mode and category

Operating timetables and the number of hours for each train mode and category shall be specified in the technical specification. If values are not available in the technical specification, the values can be selected from Table 1.

**Table 1 — Train mode (timetable and operating hours)**

| Train mode | Category 1 | | Category 2 and Category 3 | |
|---|---|---|---|---|
| | Timetable | Operating hours | Timetable | Operating hours |
| TISM | 5:00 to 24:00 | 12 h/day | 5:00 to 24:00 | 14 h/day |
| TRSM | 5:00 to 24:00<br>excluding peak<br>time<br>7:00 to 9:00<br>17:00 to 19:00 | 4 h/day | 5:00 to 24:00<br>excluding peak<br>time<br>7:00 to 9:00<br>17:00 to 19:00 | 2 h/day |
| [**Option**]<br>PCM | 5:00 to 24:00<br>excluding peak<br>time<br>7:00 to 9:00<br>17:00 to 19:00 | 0,5 h/day | 5:00 to 24:00<br>excluding peak<br>time shown above<br>7:00 to 9:00<br>17:00 to 19:00 | 0,5 h/day |
| [**Option**]<br>PM | 1) 0:00 to 5:00<br>2) 5:00 to 24:00<br>rest of the time<br>excluding the<br>three modes<br>shown above | 1) 5 h/day<br>2) 2,5 h/day<br>addition of all<br>parking mode<br>periods 7,5 h/day<br>includes switch on<br>and switch off | 1) 0:00 to 5:00<br>2) 5:00 to 24:00<br>rest of the time<br>excluding the<br>three modes<br>shown above | 1) 5 h/day<br>2) 2,5 h/day<br>addition of all<br>parking mode<br>periods 7,5 h/day<br>includes switch on<br>and switch off |
| Total | | 24 h | | 24 h |

## 5 Principles

### 5.1 General

The energy consumption of a HVAC system could be measured on an in-service train for a certain period. Cycles for the HVAC system energy consumption would have to include annual cycles, or at least daily cycles for several days during a year, covering seasonal influences. This method is very time consuming and expensive with poor repeatability regarding the results. Furthermore, simulation of energy consumption for transient conditions in the HVAC system is difficult and not state of the art in view of a precise prediction of energy consumption.

Therefore, a different method shall be applied for the energy consumption of the HVAC system.

A matrix of steady-state operational points is defined to represent the annual climatic and operational conditions. It might be necessary to define different operational points depending on the respective region where the train is operating.

Each operational point is defined by the exterior temperature, corresponding relative humidity, passenger load and equivalent solar load. All operational points are defined at zero train speed.

Weather data to represent the local weather is collected and classified to prepare the data subset for each train mode and category.

Annual operating hours and weighting factors for each operational point are calculated based on the collected weather data to estimate the total annual energy consumption of the HVAC system.

The energy consumption of the operational points shall be calculated and later be verified by either:

— measurements in a climatic facility (Method I); or

— measurements on a train placed on a track in an outdoor environment, for example in a depot or siding at zero train speed of the vehicle (Method II).

One of these two methods shall be chosen prior to the calculation and validation.



## 5.2 Methods

### 5.2.1 General

Operational points shall be chosen in accordance with local climatic conditions and shall be selected following procedure described in 5.3.2.

The passenger load shall be applied using people or simulated by heat and humidity sources as described in ISO 19659-2, 10.4.

### 5.2.2 Method I [with climatic facility / ISO 19659-2]

The energy consumption is measured in a climatic facility in accordance with ISO 19659-2, Clause 10.

### 5.2.3 Method II [without climatic facility]

The energy consumption is measured on a train placed on a track in an outdoor environment, for example in a depot or siding at zero train speed. Since the environmental conditions cannot be influenced in a similar way as in a climatic facility, the environmental conditions are to remain within the tolerance as defined in 6.3.2.

## 5.3 Climatic and operational boundary conditions

### 5.3.1 General

Climatic and operational boundary conditions shall be representative of the local area to estimate energy consumption appropriately.

In this subclause the procedure for decision of operational point matrix, collection and analysis of weather data, calculation of annual operating hours and weighting factor are introduced with some examples.

The information is applicable for simulation, calculation and verification of energy consumption in 6.2 and 6.3.

### 5.3.2 Operational point matrix

A matrix of steady-state operational points for each train mode is defined to represent the annual climatic and operational conditions for the local area.

Table 2 gives typical operational points for cold, mild and hot areas in case of TISM and TRSM. This table contains values for $T_{em1}$, $T_{em3}$, $T_{em4}$, $T_{em5}$, $T_{em7}$ in Table 1, Table 2, Table 9, Table 11 of ISO 19659-2. In order to cover the complete temperature range for calculation of annual energy consumption, exterior temperatures 10 °C and 15 °C are added. The train is considered to be at zero train speed for all points.

Operational points can be selected from Table 2.

In order to ensure an optimal balance between calculation/test effort and the demand for accuracy, 6 to 8 operational points is reasonable for the calculation of annual energy consumption for TISM and TRSM.

Exterior temperature, 10 °C, 15 °C, 22 °C and 28 °C are reasonable conditions as specified operational points.

The values of corresponding relative humidity could be changed based on the local weather data analysis as necessary.

If the range of the exterior temperature between adjacent operational points is equal to or larger than 20 K, the intermediate temperature should be added (see A.2.2.3 and A.2.2.4 as examples).

For special areas such as tropical or extreme cold conditions, the number of operational points are dependent on the project.

Procedure for decision of operational point matrix is described in Annex A with some examples.

Operational point matrix for PCM and PM shall be specified in the technical specification if required.

**Table 2 — Clustering operational point matrix for TISM and TRSM**

| **Specified operational points $T_{xx}$ for energy consumption analysis** | | | **$T_{em}$** °C | **$RH_{em}$** % | **Equivalent solar load** % | **Passenger load** % | | **Refer to ISO 19659-2** |
|---|---|---|---|---|---|---|---|---|
| **Cold area** | **Mild area** | **Hot area** | | | | **TISM** | **TRSM** | |
| | | | -40 | -- | 0 | 0 | 0 | $T_{em5}$ |
| | | | -30 | -- | 0 | 0 | 0 | $T_{em5}$ |
| | | | -25 | -- | 0 | 0 | 0 | $T_{em5}$ |
| | | | -20 | -- | 0 | 0 | 0 | $T_{em5}$ |
| | | | -10 | 80 | 0 | 0 | 0 | $T_{em5}$ |
| | | | 0 | 80 | 0 | 0 | 0 | $T_{em5}$, $T_{em7}$ |
| | | | 5 | 80 | 0 | 0 | 0 | $T_{em5}$, $T_{em7}$ |
| $T_{10}$ | $T_{10}$ | $T_{10}$ | 10 | 80 | 0 | 0 | 0 | - |
| $T_{15}$ | $T_{15}$ | $T_{15}$ | 15 | 80 | 0 | 50 | 0 | - |
| $T_{22}$ | $T_{22}$ | $T_{22}$ | 22 | 60 | 0 | 50 | 0 | - |
| | | | 22 | 80 | 0 | 50 | 0 | $T_{em4}$ |
| | | | 25 | 60 | 50 | 50 | 0 | $T_{em3}$ |
| | | | 26 | 55 | 50 | 50 | 0 | $T_{em3}$ |
| $T_{28}$ | $T_{28}$ | $T_{28}$ | 28 | 45 | 50 | 50 | 0 | $T_{em3}$ |
| | | | 28 | 45 (50) | 100 | 100 | 0 | $T_{em1}$ |
| | | | 28 | 60 | 0 | 50 | 0 | $T_{em4}$ |
| | | | 28 | 70 | 50 | 50 | 0 | $T_{em3}$ |
| | | | 32 | 50 | 100 | 100 | 0 | $T_{em1}$ |
| | | | 33 | 69 | 100 | 100 | 0 | $T_{em1}$ |
| | | | 35 | 50 | 100 | 100 | 0 | $T_{em1}$ |
| | | | 35 | 60 | 50 | 50 | 0 | $T_{em3}$ |

NOTE

— The train is considered to be at zero train speed for all points.

— $RH_{em}$(%) for $T_{em}$ equal to or less than 10 °C is only necessary for HVAC systems equipped with a heat pump.

**Table 2** *(continued)*

| Specified operational points $T_{xx}$ for energy consumption analysis | | | $T_{em}$ °C | $RH_{em}$ % | Equivalent solar load % | Passenger load % | | Refer to ISO 19659-2 |
|---|---|---|---|---|---|---|---|---|
| Cold area | Mild area | Hot area | | | | TISM | TRSM | |
| | | | 35 | 60 | 100 | 100 | 0 | $T_{em1}$ |
| | | | 35 | 65 | 100 | 100 | 0 | $T_{em1}$ |
| | | | 35 | 75 | 100 | 100 | 0 | $T_{em1}$ |
| | | | 40 | 40 (46) | 100 | 100 | 0 | $T_{em1}$ |
| | | | 40 | 60 | 100 | 100 | 0 | $T_{em1}$ |
| | | | 45 | 10 | 100 | 100 | 0 | $T_{em1}$ |
| | | | 45 | 30 | 100 | 100 | 0 | $T_{em1}$ |

NOTE

— The train is considered to be at zero train speed for all points.

— $RH_{em}$(%) for $T_{em}$ equal to or less than 10 °C is only necessary for HVAC systems equipped with a heat pump.



### 5.3.3 Weather data analysis

#### 5.3.3.1 General

The weather data which represents the local weather is collected and classified based on operating timetable and operating hours corresponding to each train mode and category. Then, the annual operating hours and the weighting factor for each operational point are calculated to estimate the total annual energy consumption of the HVAC system.

#### 5.3.3.2 Collection of Weather data

The weather data considered for the energy consumption shall be representative of the local weather.

The minimum requirements for the contents of the weather data:

— weather data shall be from a validated source;

— recent weather data source is recommended. (ideally not older than ten years);

— the data shall cover a period of at least five complete years to average;

— it is recommended to consider at least one data per hour;

— the minimum data shall be the exterior temperature (protected from the sun and wind).

Collected weather data is classified based on operating timetable and operating hours corresponding to each train mode and category as defined in Table 1, for the preparation of annual operating hours and weighting factor calculation.

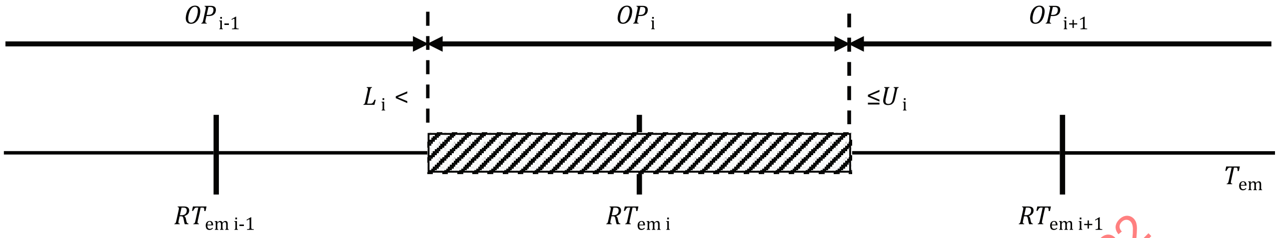
The procedure for the collection of weather data, as an example, is described in Annex B. One location is selected to introduce the procedure for weather data analysis. For the usage of the train in a large region common for Category 1, the weather data of several representative locations could be used and averaged. In that case, the annual operating hours in 5.3.3.4 can be obtained by averaging those at each location. The average weighting factor in 5.3.3.5 can be calculated from the average annual operating hours.

Operating timetable and operating hours for PCM and PM shall be specified in the technical specification if annual energy consumption for each train mode is required.

#### 5.3.3.3 Operational point range

$T_{em}$ in Table 2 is considered as $RT_{em}$ of all values in the operational point range. The range of operational point i ($OP_i$) is defined to be greater than $L_i$ and equal to or less than $U_i$ shown in Figure 1.




**Key**

$OP_i$ operational point i

$T_{em}$ mean exterior temperature, in °C

$RT_{em\ i}$ representative mean exterior temperature at operational point i ($OP_i$), in °C

$L_i$ mean exterior temperature at lower end of operational point i ($OP_i$), in °C
$L_i = (RT_{em\ i-1} + RT_{em\ i}) / 2$

$U_i$ mean exterior temperature at upper end of operational point i ($OP_i$), in °C
$U_i = (RT_{em\ i} + RT_{em\ i+1}) / 2$

**Figure 1 — Range of operational point i ($OP_i$)**

#### 5.3.3.4 Calculation of annual operating hours

The annual operating hours for a specific operational point are the addition of all occurrence of all exterior temperatures in the range of operational point. Therefore, the total annual operating hours for each train mode is calculated as the sum of operating hours for a specific operational point. See Formula (1).

$$h_x = \sum_{i=1}^{n} (h_{x\_OPi}) \quad (1)$$

where

x is the train mode (TISM, TRSM, PCM and PM);

$h_x$ is the number of total annual operating hours for train mode x, in *h*;

n is the number of operational points;

$h_{x\_OPi}$ is the number of total annual operating hours for a specific operational point ($OP_i$) of train mode x, in *h*.

The procedure for the calculation of annual operating hours, as an example, is described in Annex B.

If total annual operating hours for PCM and PM are required, they shall be specified in the technical specification.

#### 5.3.3.5 Calculation of weighting factor

The weighting factor is the ratio of the annual operating hours for a specific operational point ($OP_i$) to the total annual operating hours for each train mode. See Formula (2).

$$w_{x\_Opi} = h_{x\_OPi} / h_x \tag{2}$$

where $w_{x\_OPi}$ is the weighting factor for a specific operational point ($OP_i$) of train mode x.

If the weighting factor represents less than 1 % of the global weighting factor, the corresponding operational point could be removed. In that case, its operating hours should be added to its nearest operational point.

The procedure for the calculation of weighting factor, as an example, is described in Annex B.

If weighting factor for PCM and PM are required, they shall be specified in the technical specification.

# 6 Assessment methods

## 6.1 General

The average power of the HVAC system for a specific operational point is simulated by the computer and the annual energy consumption is calculated by the sum of the products of total annual operating hours, weighting factor and average power for a specific operational point. Finally, it shall be verified by the measurements in a climatic facility (Method I) or by the measurements on a train placed on a track in an outdoor environment, for example in a depot or siding at zero train speed of the vehicle (Method II) for the assessment.

Some post-processing of the measured and/or calculated data might be necessary.

## 6.2 Simulation and calculation

### 6.2.1 Simulation

Computer simulation is performed to obtain the average power of the HVAC system for each operational point in 5.3.2, $P_{x\_OPi}$.

The simulation shall consider a thermally stable train that is with constant temperature in the equipment during the entire energy calculation period and is at zero train speed of the vehicle for all modes.

### 6.2.2 Calculation of the total annual energy consumption

#### 6.2.2.1 Calculation of the total annual energy consumption for the HVAC system

The total annual energy consumption for the HVAC system $E_{HVAC}$ is calculated as the sum of total annual energy consumptions of all four train modes in 6.2.2.2. See Formula (3).

$$E_{HVAC} = \sum E_X \tag{3}$$

where

$E_{HVAC}$ is the total annual energy consumption for the HVAC system, in kWh;

$E_x$ is the total annual energy consumption for train mode x, in kWh.

NOTE If a certain train mode is not relevant in a specific project, the respective total energy consumption value can be set to 0 kWh.

#### 6.2.2.2 Calculation of the total annual energy consumption for train mode

The total annual energy consumption for train mode is the sum of the products of total annual operating hours in 5.3.3.4, weighting factor in 5.3.3.5 and average power for each operational point in 5.3.2. See Formula (4).

$$E_x = \sum_{i=1}^{n} \left( h_x \times w_{x\_OPi} \times P_{x\_OPi} \right) \quad (4)$$

where

$E_x$ is the total annual energy consumption for train mode x, in kWh;

$h_x$ is the number of total annual operating hours for train mode x, in $h$;

n is the number of operational points;

$w_{x\_OPi}$ is the weighting factor for a specific operational point ($OP_i$) of train mode x;

$P_{x\_OPi}$ is the average power for a specific operational point ($OP_i$) of train mode x, in kW. This value is obtained in 6.2.1.

### 6.2.3 Calculation of the total annual energy efficiency

#### 6.2.3.1 Calculation of the total annual energy efficiency for the HVAC system

The total annual energy efficiency for the HVAC system $AEE_{HVAC}$ is calculated as the ratio of the sum of total annual heating and cooling load of all four train modes in 6.2.3.2 devided by the total annual energy consumption for the HVAC system $E_{HVAC}$ in 6.2.2.1. See Formula (5).

$$AEE_{HVAC} = \sum THCL_x \, / \, E_{HVAC} \quad (5)$$

where

$AEE_{HVAC}$ is the total annual energy efficiency for the HVAC system;

$THCL_x$ is the total annual heating and cooling load for train mode x, in kWh;

$E_{HVAC}$ is the total annual energy consumption for the HVAC system, in kWh.

NOTE If a certain train mode is not relevant in a specific project, the respective total heating and cooling load value can be set to 0 kWh.

#### 6.2.3.2 Calculation of the total annual heating and cooling load for train mode

The total annual heating and cooling load for train mode is the sum of the products of total annual operating hours in 5.3.3.4, weighting factor in 5.3.3.5 and heating and cooling load for each operational point in 5.3.2. See Formula (6).

$$THCL_x = \sum_{i=1}^{n} \left( h_x \times w_{x\_OPi} \times HCL_{x\_OPi} \right) \quad (6)$$

where

$THCLx$ is the total annual heating and cooling load for train mode x, in kWh;

$h_x$ is the number of total annual operating hours for train mode x, in h;

n is the number of operational points;

$w_{x\_OPi}$ is the weighting factor for a specific operational point ($OP_i$) of train mode x;

$HCL_{x\_OPi}$ is the heating and cooling load for a specific operational point ($OP_i$) of train mode x, in kW.

Refer to JIS E 6603 and ASHRAE Guideline 23 Clause 6 as examples.

#### 6.2.4 Documentation

The results of the calculations shall be documented in a report. The minimum requirements for the contents of the report are:

a) information about operational and environmental input data, such as passenger load, other internal loads e.g. lights, other influencing conditions e.g. condition of driving cab, temperature set points, exterior temperature, corresponding relative humidity, equivalent solar load;

b) HVAC - relevant key data of the train, such as air volume flow rates, vehicle surfaces, heat transfer coefficients;

c) average power demand [kW] for all operational points of each train modes (TISM, TRSM, PCM and PM);

NOTE If a certain train mode is not relevant in a specific project, the respective average power demand value can be set to 0 kW;

d) total annual energy consumption [kWh] for all train modes according to the tables with operational points and number of operating hours and

e) information about the use of on-board energy storage systems, energy management or other energy efficient technologies: The state of energy of any on-board energy storage system shall be documented at the beginning and after the simulation.

### 6.3 Verification

#### 6.3.1 General

To verify the results of the calculation performed in 6.2, one of the Methods (I) or (II) in 5.2 shall be used.

Recording and measuring instruments, position of measuring points shall be performed as set out in ISO 19659-2, Clause 11 and Clause 12. Additionally, the air volume flow rate shall be verified by measurements in ISO 19659-2, Clause 8 (for example during the ventilation test of the vehicle).

#### 6.3.2 Test rules

In addition to all requirements specified in Clause 5, the test shall be performed using the following rules:

— A test plan shall be defined prior to the tests;

— The train shall be in a fully operational condition and equipped with serial software where all parameters which are relevant to energy consumption are specified;

— It is recommended to measure the energy consumption of all installed HVAC units and if present the energy consumption of auxiliary heaters/fans etc. additionally;

— Measurements of average power shall start 30 min after the vehicle has reached steady state conditions and be carried out for at least 60 min or three similar consecutive control cycles in case of oscillating power (for example switch on and off controller used for heating and cooling devices);

— For Method I, the environmental tolerances shall be in accordance with ISO 19659-2, Clause 10.

  For Method II, the following environmental tolerances are allowed:

  — exterior temperature ±2 K;

  — relative humidity ±15 % RH during cooling test;

  — equivalent solar load ±200 W/m$^2$.

For HVAC systems equipped with a heat pump, the tolerance of relative humidity for heating test is not specified because it is difficult to control relative humidity artificially under low exterior temperature.

In this case, the post-processing method shall be mutually agreed by the contracting parties.

NOTE For efficiency, the verification test could be reduced if vehicles of the same platform are already verified by Method I or Method II and are in use in multiple countries and/or by multiple operators. Validated simulation agreed by the contracting parties could be used to reduce the effort of testing.

### 6.3.3 Documentation

The results of the verification measurements shall be documented in a report. The minimum requirements for the contents of the report are:

a) key information about the train (at least parameters in 6.2.4);

   NOTE The value of heat transfer coefficient is indicated in the test report if it is measured, otherwise a theoretical value could be indicated.

b) description of the measurement equipment used;

c) measured energy for TISM, TRSM, PCM and PM;

d) any observations during the tests which might affect the interpretation of the test results for example; train identification number, relative humidity, temperature, time and date, rate of clouds / clearness, rain, location, parking position of the train, sun or shadow.

## 6.4 Post-processing

Ideally, no post-processing of measured or calculated data are necessary. In this case, a final report, containing the comparison between calculation and measurement is issued, and the process is closed.

However, it might be difficult to fully control all conditions during tests in the real railway system, under the influence of environmental conditions. Therefore, some post processing of the measurements, with or without repetition of calculations, shall be tolerated.

Post-processing of results with respect to the external temperature, relative humidity, equivalent solar load and internal temperature not matching the values of 5.3.2, Table 2, 6.3.2, ISO 19659-2, Clause 6 and ISO 19659-2, 7.2 shall be done by means of repetition of the calculation. In this case, the same conditions as during the tests are applied, with all deviated test conditions changed using the conditions defined in 5.3.2, Table 2 and ISO 19659-2, Clause 6. Extrapolation could be accepted as one of the methods within a reasonable range (for example, no change of state of aggregation such as icing on the heat exchanger). The documentation shall give evidence that the model for the train is completely unchanged for the repeated calculations.

EXAMPLE

We consider in this example two cases of post-processing.

Case 1

The simulation and the test shall be performed with the following conditions.

Exterior condition: $T_{em}$ 28 °C, $RH_{em}$ 60 % and equivalent solar load 0 %

Interior condition: $T_{im}$ 25 °C and 50 % of passengers

Category of passenger railway vehicle: Category 1

The result of average power of this simulation is called Simulation 1 and the result of average power of this test is called Test 1 in this case. For example, we consider *Simulation 1* = 30 kW.

If during the test the external relative humidity was not reaching $RH_{em}$ 60 % but only $RH_{em}$ 50 % (The test result of average power at $RH_{em}$ 50 % is called Test 2.), this means Test 1 could not be obtained. The results between the test (*Test 2*) and the simulation (*Simulation 1*) are not consistent, as ISO 19659-2, 10.3 recommends the preferable tolerance of relative humidity during cooling test is within ±5 %. For example, we consider *Test 2* = 28 kW.

In this case post-treatment of the measurement shall be done to demonstrate that the model used in the simulation phase is correct. The simulation is re-run but with the conditions $T_{em}$ 28 °C, $RH_{em}$ 50 %, equivalent solar load 0 %, 50 % of passengers and $T_{im}$ 25 °C. The simulation result of average power at $RH_{em}$ 50 % is called Simulation 2 in this case.

A comparison of average power is done between the test (*Test 2*) and the simulation (*Simulation 2*) with both 50 % relative humidity. The percentage of deviation is calculated with the following Formulae (7) and (8).

$$deviation = \frac{(Test\,2 - Simulation\,2)}{Simulation\,2} \tag{7}$$

If *Simulation 2* = 27 kW in this case the deviation is

$$deviation = \frac{(28 - 27)}{27} = 0{,}037 \tag{8}$$

The post-treatment is applied for the correction of the deviation to the initial simulation result (*Simulation 1*).

The value to consider for the post-treatment simulation is according to the following Formulae (9) and (10).

$$Simulation\,1_{\mathrm{PostTreated}} = Simulation1 \times (1 + deviation) \tag{9}$$

$$Simulation\,1_{\mathrm{PostTreated}} = 30 \times (1 + 0{,}037) = 31{,}1\,[kW] \tag{10}$$

This calculated value will be equivalent to the estimated value of Test 1.

Case 2

The simulation and the test shall be performed with the following conditions.

Exterior condition: $T_{em}$ 35 °C, $RH_{em}$ 60 % and equivalent solar load 100 %

Interior condition: $T_{im}$ 26 °C and 100 % of passengers

Category of passenger railway vehicle: Category 1

The result of average power of this simulation is called Simulation 3 and the result of average power of this test is called Test 3. For example, we consider *Simulation 3* = 40 kW.

If during the test the mean interior temperature was $T_{im}$ 25 °C instead of $T_{im}$ 26 °C. (The test result of average power at $T_{im}$ 25 °C is called Test 4.), this means Test 3 could not be obtained. For example, we consider *Test 4* = 41 kW.

In this case, as the temperature difference is 1 K and it complies the standard, ISO 19659-2, 7.2.1, basically the post-processing is not required. However, if the contracting parties judge the necessity of post-processing, the post-treatment of the measurement can be done to demonstrate that the model used in the simulation phase is correct.



The simulation is done with the condition $T_{im}$ 25 °C. The simulation result of average power at $T_{im}$ 25 °C is called Simulation 4 in this case.

A comparison of average power is done between the test (*Test 4*) and the simulation (*Simulation 4*) with both 25 °C interior temperature. The percentage of deviation is calculated with the following Formulae (11) and (12).

$$deviation = \frac{(Test\,4 - Simulation\,4)}{Simulation\,4} \tag{11}$$

If *Simulation 4* = 41,5 kW in this case the deviation is

$$deviation = \frac{(41 - 41{,}5)}{41{,}5} = -0{,}012 \tag{12}$$

The post-treatment is applied for the correction of the deviation to the initial simulation result (*Simulation 3*).

The value to consider for the post-treatment simulation is according to the following Formulae (13) and (14).

$$Simulation\,3_{\mathrm{PostTreated}} = Simulation\,3 \times (1 + deviation) \tag{13}$$

$$Simulation\,3_{\mathrm{PostTreated}} = 40 \times (1 - 0{,}012) = 39{,}5\,[kW] \tag{14}$$

This calculated value will be equivalent to the estimated value of Test 3.



# Annex A
(informative)

# Procedure for decision of operational point matrix

## A.1 General

Procedure for decision of operational point matrix is introduced with some examples of Japan and China.

In Annex A, operational points for TISM and for TRSM are introduced. Operational points for PCM and for PM are not introduced here, as they are options so that the required specification depends on a case-by-case basis.

## A.2 Decision of operational point matrix

### A.2.1 Case of Japan

According to ISO 19659-2, climatic design condition for summer in Table 1, Japan belongs to “TS3” and climatic design condition for winter in Table 2, Japan belongs to “TW6”.

Refer to Table 2 in 5.3.2 and pick up operational points corresponding to $T_{em5}$ in Table 2, $T_{em7}$ in Table 11 for “TW6”, and $T_{em1}$ in Table 1, $T_{em3}$ and $T_{em4}$ in Table 9 for “TS3”, that are listed in ISO 19659-2.

As a result, five operational points for $T_{em5}$ = 0 °C, $T_{em7}$ = 5 °C, $T_{em4}$ = 22 °C, $T_{em3}$ = 28 °C and $T_{em1}$ = 33 °C are picked up. By adding two specified operational points for $T_{10}$ = 10 °C and $T_{15}$ = 15 °C, seven operational points are selected in total.

Table A.1 shows the operational point matrix in Japan.

**Table A.1 — Operational point matrix in Japan**

| Operational point | $T_{em}$ °C | $RH_{em}$ % | Equivalent solar load % | Passenger load % | | Refer to ISO 19659-2 | Remark |
|---|---|---|---|---|---|---|---|
| | | | | TISM | TRSM | | |
| OP1 | 0 | 80 | 0 | 0 | 0 | $T_{em5}$ | |
| OP2 | 5 | 80 | 0 | 0 | 0 | $T_{em7}$ | |
| OP3 | 10 | 80 | 0 | 0 | 0 | - | $T_{10}$ |
| OP4 | 15 | 80 | 0 | 50 | 0 | - | $T_{15}$ |
| OP5 | 22 | 80 | 0 | 50 | 0 | $T_{em4}$ | |
| OP6 | 28 | 70 | 50 | 50 | 0 | $T_{em3}$ | |
| OP7 | 33 | 69 | 100 | 100 | 0 | $T_{em1}$ | |

NOTE $RH_{em}$ for $T_{em}$ equal to or less than 10 °C is only necessary for HVAC systems equipped with a heat pump.



### A.2.2 Case of China

#### A.2.2.1 General

According to ISO 19659-2, climatic design condition for summer in Table 1, China belongs to “TS8” for Zone I, “TS5” for Zone II and “TS1” for Zone III, and climatic design condition for winter in Table 2, China belongs to “TW5” for Zone I, “TW3” for Zone II and “TW1” for Zone III. Therefore, nine combinations can be selected as matrix of operational points in China.

NOTE As to “Zone I”, “Zone II” and “Zone III”, refer to ISO 19659-2, A.3.

In this subclause, three cases of them are introduced.

#### A.2.2.2 Case 1: Zone I for both summer and winter

Refer to Table 2 in 5.3.2 and pick up operational points corresponding to $T_{em5}$ in Table 2, $T_{em7}$ in Table 11 for “TW5”, and $T_{em1}$ in Table 1, $T_{em3}$ and $T_{em4}$ in Table 9 for “TS8”, that are listed in ISO 19659-2.

As a result, five operational points for $T_{em5}$ = -10 °C, $T_{em7}$ = 0 °C, $T_{em4}$ = 22 °C, $T_{em3}$ = 28 °C and $T_{em1}$ = 40 °C are picked up. By adding two specified operational points for $T_{10}$ = 10 °C and $T_{15}$ = 15 °C, seven operational points are selected in total.

Table A.2 shows the operational point matrix for Zone I for both summer and winter in China

**Table A.2 — Operational point matrix for Zone I for both summer and winter**

| Operational point | $T_{em}$ °C | $RH_{em}$ % | Equivalent solar load % | Passenger load % | | Refer to ISO 19659-2 | Remark |
|---|---|---|---|---|---|---|---|
| | | | | TISM | TRSM | | |
| OP1 | -10 | 80 | 0 | 0 | 0 | $T_{em5}$ | |
| OP2 | 0 | 80 | 0 | 0 | 0 | $T_{em7}$ | |
| OP3 | 10 | 80 | 0 | 0 | 0 | - | $T_{10}$ |
| OP4 | 15 | 80 | 0 | 50 | 0 | - | $T_{15}$ |
| OP5 | 22 | 80 | 0 | 50 | 0 | $T_{em4}$ | |
| OP6 | 28 | 70 | 50 | 50 | 0 | $T_{em3}$ | |
| OP7 | 40 | 46 | 100 | 100 | 0 | $T_{em1}$ | |

NOTE $RH_{em}$ for $T_{em}$ equal to or less than 10 °C is only necessary for HVAC systems equipped with a heat pump.

#### A.2.2.3 Case 2: Zone II for both summer and winter

Refer to Table 2 in 5.3.2 and pick up operational points corresponding to $T_{em5}$ in Table 2, $T_{em7}$ in Table 11 for “TW3”, and $T_{em1}$ in Table 1, $T_{em3}$ and $T_{em4}$ in Table 9 for “TS5”, that are listed in ISO 19659-2.

As a result, five operational points for $T_{em5}$ = -25 °C, $T_{em7}$ = 0 °C, $T_{em4}$ = 22 °C, $T_{em3}$ = 28 °C and $T_{em1}$ = 35 °C are picked up. By adding two specified operational points for $T_{10}$ = 10 °C and $T_{15}$ = 15 °C, and furthermore operational point for -10 °C to supplement the temperature range between $T_{em5}$ = -25 °C and $T_{em7}$ = 0 °C, eight operational points are selected in total. (Refer to 5.3.2)

Table A.3 shows the operational point matrix for Zone II for both summer and winter in China.



**Table A.3 — Operational point matrix for Zone II for both summer and winter**

| Operational point | $T_{em}$ °C | $RH_{em}$ % | Equivalent solar load % | Passenger load % | | Refer to ISO 19659-2 | Remark |
|---|---|---|---|---|---|---|---|
| | | | | TISM | TRSM | | |
| OP1 | -25 | - | 0 | 0 | 0 | $T_{em5}$ | |
| OP2 | -10 | 80 | 0 | 0 | 0 | - | supplement |
| OP3 | 0 | 80 | 0 | 0 | 0 | $T_{em7}$ | |
| OP4 | 10 | 80 | 0 | 0 | 0 | - | $T_{10}$ |
| OP5 | 15 | 80 | 0 | 50 | 0 | - | $T_{15}$ |
| OP6 | 22 | 80 | 0 | 50 | 0 | $T_{em4}$ | |
| OP7 | 28 | 70 | 50 | 50 | 0 | $T_{em3}$ | |
| OP8 | 35 | 60 | 100 | 100 | 0 | $T_{em1}$ | |

NOTE $RH_{em}$ for $T_{em}$ equal to or less than 10 °C is only necessary for HVAC systems equipped with a heat pump.

### A.2.2.4 Case 3: Zone III for both summer and winter

Refer to Table 2 in 5.3.2 and pick up operational points corresponding to $T_{em5}$ in Table 2, $T_{em7}$ in Table 11 for "TW1", and $T_{em1}$ in Table 1, $T_{em3}$ and $T_{em4}$ in Table 9 for "TS1", that are listed in ISO 19659-2.

As a result, five operational points for $T_{em5}$ = -40 °C, $T_{em7}$ = 0 °C, $T_{em4}$ = 22 °C, $T_{em3}$ = 25 °C and $T_{em1}$ = 28 °C are picked up. By adding two specified operational points for $T_{10}$ = 10 °C and $T_{15}$ = 15 °C, and furthermore operational point for -20 °C to supplement the temperature range between $T_{em5}$ = -40 °C and $T_{em7}$ = 0 °C, eight operational points are selected in total. (Refer to 5.3.2)

Table A.4 shows the operational point matrix for Zone III for both summer and winter in China.

**Table A.4 — Operational point matrix for Zone III for both summer and winter**

| Operational point | $T_{em}$ °C | $RH_{em}$ % | Equivalent solar load % | Passenger load % | | Refer to ISO 19659-2 | Remark |
|---|---|---|---|---|---|---|---|
| | | | | TISM | TRSM | | |
| OP1 | -40 | - | 0 | 0 | 0 | $T_{em5}$ | |
| OP2 | -20 | - | 0 | 0 | 0 | - | supplement |
| OP3 | 0 | 80 | 0 | 0 | 0 | $T_{em7}$ | |
| OP4 | 10 | 80 | 0 | 0 | 0 | - | $T_{10}$ |
| OP5 | 15 | 80 | 0 | 50 | 0 | - | $T_{15}$ |
| OP6 | 22 | 80 | 0 | 50 | 0 | $T_{em4}$ | |
| OP7 | 25 | 60 | 50 | 50 | 0 | $T_{em3}$ | |
| OP8 | 28 | 50 | 100 | 100 | 0 | $T_{em1}$ | |

NOTE $RH_{em}$ for $T_{em}$ equal to or less than 10 °C is only necessary for HVAC systems equipped with a heat pump.



# Annex B
(informative)

# Procedure for weather data analysis

## B.1 General

In this annex, the procedure for weather data analysis is introduced with the example considering Category 1 train line. Firstly, the method of weather data collection and its clustering into the operational point matrix which is given in Annex A are presented. Secondly, the annual operating hours is calculated on each operational point for each train mode. Finally, the weighting factor is obtained.

## B.2 Collection of weather data

The collected data should be compliant with the requirements specified in 5.3.3.2.

The example shown in this annex considers a train travelling in a large region like Category 1. In that case, it is recommended to select a location that represents typical weather conditions where the train stops.

This example shows the data collected at Tokyo in Japan.

The fulfilment of the requirements in 5.3.3.2 is as follows;

- Source: Japan Meteorological Agency (https://www.data.jma.go.jp/gmd/risk/obsdl/)
- Collection period: 2010-01-01 through 2019-12-31 (ten years)
- Interval: one hour
- Item: exterior temperature
- Location: Tokyo, Japan

The collected weather data is classified into each train mode as shown in Table B.1 according to the operating timetable of Category 1. In this case, only two train modes, TISM and TRSM, are considered.

**Table B.1 — Weather data collection (Tokyo)**

| Date | Time | Exterior temperature °C | TISM | TRSM |
|---|---|---|---|---|
| 2010/1/1 | 1:00 | 2,5 | N/A | N/A |
| 2010/1/1 | 2:00 | 2,4 | N/A | N/A |
| 2010/1/1 | 3:00 | 1,3 | N/A | N/A |
| 2010/1/1 | 4:00 | 0,8 | N/A | N/A |
| 2010/1/1 | 5:00 | 0,7 | ✓ | ✓ |
| 2010/1/1 | 6:00 | 0,7 | ✓ | ✓ |
| 2010/1/1 | 7:00 | 1,8 | ✓ | N/A |
| ✓: applicable,<br>N/A: not applicable | | | | |

**Table B.1** *(continued)*

| Date | Time | Exterior temperature<br>°C | TISM | TRSM |
|---|---|---|---|---|
| 2010/1/1 | 8:00 | 2,7 | ✓ | N/A |
| 2010/1/1 | 9:00 | 4,1 | ✓ | ✓ |
| 2010/1/1 | 10:00 | 5,3 | ✓ | ✓ |
| 2010/1/1 | 11:00 | 6,3 | ✓ | ✓ |
| 2010/1/1 | 12:00 | 8,5 | ✓ | ✓ |
| 2010/1/1 | 13:00 | 8,2 | ✓ | ✓ |
| 2010/1/1 | 14:00 | 9,1 | ✓ | ✓ |
| 2010/1/1 | 15:00 | 8,5 | ✓ | ✓ |
| 2010/1/1 | 16:00 | 7,9 | ✓ | ✓ |
| 2010/1/1 | 17:00 | 7,5 | ✓ | N/A |
| 2010/1/1 | 18:00 | 6,7 | ✓ | N/A |
| 2010/1/1 | 19:00 | 6,4 | ✓ | ✓ |
| 2010/1/1 | 20:00 | 6,0 | ✓ | ✓ |
| 2010/1/1 | 21:00 | 4,5 | ✓ | ✓ |
| 2010/1/1 | 22:00 | 5,1 | ✓ | ✓ |
| 2010/1/1 | 23:00 | 5,5 | ✓ | ✓ |
| 2010/1/2 | 0:00 | 2,9 | N/A | N/A |
| 2010/1/2 | 1:00 | 4,7 | N/A | N/A |
| 2010/1/2 | 2:00 | 4,4 | N/A | N/A |
| 2010/1/2 | 3:00 | 3,4 | N/A | N/A |
| : | : | : | : | : |
| 2019/12/31 | 17:00 | 8,1 | ✓ | N/A |
| 2019/12/31 | 18:00 | 7,1 | ✓ | N/A |
| 2019/12/31 | 19:00 | 6,0 | ✓ | ✓ |
| 2019/12/31 | 20:00 | 5,1 | ✓ | ✓ |
| 2019/12/31 | 21:00 | 4,8 | ✓ | ✓ |
| 2019/12/31 | 22:00 | 4,3 | ✓ | ✓ |
| 2019/12/31 | 23:00 | 4,3 | ✓ | ✓ |
| 2020/1/1 | 0:00 | 3,7 | N/A | N/A |
| ✓: applicable,<br>N/A: not applicable | | | | |



## B.3 Calculation of operational point range

In order to classify the weather data into each operational point, operational point range is calculated in accordance with the formula specified in 5.3.3.3. For the Japanese case, the following table is defined based on Annex A and 5.3.3.3.

**Table B.2 — Operational point matrix in Japan**

| Operational point<br>($OP_i$) | Representative mean exterior temperature ($RT_{em}$)<br>°C | Range of operational point<br>°C |
|---|---|---|
| OP1 | 0 | $T_i \leqq 2,5$ |

**Table B.2** *(continued)*

| Operational point ($OP_i$) | Representative mean exterior temperature ($RT_{em}$) °C | Range of operational point °C |
|---|---|---|
| OP2 | 5 | $2,5 < T_i \leqq 7,5$ |
| OP3 | 10 | $7,5 < T_i \leqq 12,5$ |
| OP4 | 15 | $12,5 < T_i \leqq 18,5$ |
| OP5 | 22 | $18,5 < T_i \leqq 25,0$ |
| OP6 | 28 | $25,0 < T_i \leqq 30,5$ |
| OP7 | 33 | $30,5 < T_i$ |

Based on the range of operational point, the weather data is classified into each operational point. Table B.3 is obtained from Table B.1 and Table B.2. After that, counting the total hours of occurrence for each operational point over the foreseen period (in this case 10 years) on Table B.3 results in Table B.4(a) for TISM and Table B.4(b) for TRSM.

## B.4 Calculation of annual operating hours

The total hours in Table B.4(a) and Table B.4(b) are accumulated values for 10 years so that they shall be divided by ten to obtain the annual data. In addition, the values of total hours consist of the entire period of timetable for the relevant train mode. Therefore, they shall be converted to the actual operating hours. For example, the timetable of TISM for Category 1 is from 5:00 to 24:00 so that the daily total hours are 19 hours. Since the daily operating hours are 12 hours, the total hours shall be multiplied by 12/19. In the case of TRSM, the timetable doesn't include peak time, then the daily total hours are 15 hours. The operating hours are 4 hours so that the values shall be multiplied by 4/15.

The above calculation results in the annual operating hours of each operational point for each train mode.

## B.5 Calculation of weighting factor

Dividing the annual operating hours of each operational point by the total annual operating hours of all operational points provides the weighting factor for each operational point. Consequently, Table B.5(a) and Table B.5(b) can be obtained.

**Table B.3 — Weather data collection classified by operational point (Tokyo)**

| Date | Time | Exterior temperature °C | Relevant Operational Point ($OP_i$) | |
|---|---|---|---|---|
| | | | TISM | TRSM |
| 2010/1/1 | 1:00 | 2,5 | N/A | N/A |
| 2010/1/1 | 2:00 | 2,4 | N/A | N/A |
| 2010/1/1 | 3:00 | 1,3 | N/A | N/A |
| 2010/1/1 | 4:00 | 0,8 | N/A | N/A |
| 2010/1/1 | 5:00 | 0,7 | OP1 | OP1 |
| 2010/1/1 | 6:00 | 0,7 | OP1 | OP1 |
| 2010/1/1 | 7:00 | 1,8 | OP1 | N/A |
| 2010/1/1 | 8:00 | 2,7 | OP2 | N/A |
| 2010/1/1 | 9:00 | 4,1 | OP2 | OP2 |
| ✓: applicable, N/A: not applicable | | | | |