DRAFT INTERNATIONAL STANDARD

ISO/DIS 11855-4

ISO/TC **205** Secretariat: **ANSI**

Voting begins on:
2020-03-16

Voting terminates on:
2020-06-08

Building environment design — Embedded radiant heating and cooling systems —

Part 4:

Dimensioning and calculation of the dynamic heating and cooling capacity of Thermo Active Building Systems (TABS)

Conception de l'environnement des bâtiments — Systèmes intégrés de chauffage et de refroidissement par rayonnement —

Partie 4: Dimensionnement et calculs relatifs au chauffage adiabatique et à la puissance frigorifique pour systèmes thermoactifs (TABS)

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ICS: 91.040.01

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Reference number
ISO/DIS 11855-4:2020(E)

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Published in Switzerland

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Foreword

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ISO 11855-4 was prepared by Technical Committee ISO/TC 205, *Building environment design*.

ISO 11855 consists of the following parts, under the general title *Building environment design — Design, dimensioning, installation and control of embedded radiant heating and cooling systems*:

— Part 1: *Definition, symbols, and comfort criteria*

— Part 2: *Determination of the design and heating and cooling capacity*

— Part 3: *Design and dimensioning*

— Part 4: *Dimensioning and calculation of the dynamic heating and cooling capacity of Thermo Active Building Systems (TABS)*

— Part 5: *Installation*

— Part 6: *Control*

— Part 7: Input parameters for the energy calculation

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Part 1 specifies the comfort criteria which should be considered in designing embedded radiant heating and cooling systems, since the main objective of the radiant heating and cooling system is to satisfy thermal comfort of the occupants. Part 2 provides steady-state calculation methods for determination of the heating and cooling capacity. Part 3 specifies design and dimensioning methods of radiant heating and cooling systems to ensure the heating and cooling capacity. Part 4 provides a dimensioning and calculation method to design Thermo Active Building Systems (TABS) for energy-saving purposes, since radiant heating and cooling systems can reduce energy consumption and heat source size by using renewable energy. Part 5 addresses the installation process for the system to operate as intended. Part 6 shows a proper control method of the radiant heating and cooling systems to ensure the maximum performance which was intended in the design stage when the system is actually being operated in a building. Part 7 presents a calculation method for input parameters to ISO 52031.

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Introduction

The radiant heating and cooling system consists of heat emitting/absorbing, heat supply, distribution, and control systems. The ISO 11855 series deals with the embedded surface heating and cooling system that directly controls heat exchange within the space. It does not include the system equipment itself, such as heat source, distribution system and controller.

The ISO 11855 series addresses an embedded system that is integrated with the building structure. Therefore, the panel system with open air gap, which is not integrated with the building structure, is not covered by this series.

The ISO 11855 series shall be applied to systems using not only water but also other fluids or electricity as a heating or cooling medium.

The object of the ISO 11855 series is to provide criteria to effectively design embedded systems. To do this, it presents comfort criteria for the space served by embedded systems, heat output calculation, dimensioning, dynamic analysis, installation, control method of embedded systems, and input parameters for the energy calculations.

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Building environment design — Embedded radiant heating and cooling systems —

Part 4:
Dimensioning and calculation of the dynamic heating and cooling capacity of Thermo Active Building Systems (TABS)

1 Scope

This part of ISO 11855 allows the calculation of peak cooling capacity of Thermo Active Building Systems (TABS), based on heat gains, such as solar gains, internal heat gains, and ventilation, and the calculation of the cooling power demand on the water side, to be used to size the cooling system, as regards the chiller size, fluid flow rate, etc.

This part of ISO 11855 defines a detailed method aimed at the calculation of heating and cooling capacity in non-steady state conditions.

The ISO 11855 series is applicable to water based embedded surface heating and cooling systems in residential, commercial and industrial buildings. The methods apply to systems integrated into the wall, floor or ceiling construction without any open air gaps. It does not apply to panel systems with open air gaps which are not integrated into the building structure.

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The ISO 11855 series also applies, as appropriate, to the use of fluids other than water as a heating or cooling medium. The ISO 11855 series is not applicable for testing of systems. The methods do not apply to heated or chilled ceiling panels or beams.

2 Normative references

The following referenced documents are indispensable for the application 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 11855-1, *Building environment design — Embedded radiant heating and cooling systems — Part 1: Definition, symbols, and comfort criteria*

3 Terms and definitions

For the purposes of this document, the terms and definitions in ISO 11855-1 apply.

4 Symbols and abbreviations

For the purposes of this part of ISO 11855, the symbols and abbreviations in Table 1 apply:

Table 1 — Symbols and abbreviations

Symbol	Unit	Quantity
A_F	m^2	Area of the heating/cooling surface area
A_W	m^2	Total area of internal vertical walls (i.e. vertical walls, external façades excluded)
C	$J/(m^2 \cdot K)$	Specific thermal capacity of the thermal node under consideration

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Table 1 *(continued)*

Symbol	Unit	Quantity
C_{W}	J/(m^2·K)	Average specific thermal capacity of the internal walls
c_{j}	J/(kg·K)	Specific heat of the material constituting the j-th layer of the slab
c_{w}	J/(kg·K)	Specific heat of water
d_{a}	m	External diameter of the pipe
E_{Day}	kWh/m^2	Specific daily energy gains
$f_{\mathrm{rm}}^{\mathrm{h}}$	-	Running mode (1 when the system is running; 0 when the system is switched off) in the h-th hour
f_{s}	-	Design safety factor
$F_{\mathrm{v\ F\text{-}C}}$	-	View factor between the floor and the ceiling
$F_{\mathrm{v\ F\text{-}EW}}$	-	View factor between the floor and the external walls
$F_{\mathrm{v\ F\text{-}W}}$	-	View factor between the floor and the internal walls
$h_{\mathrm{A\text{-}C}}$	W/(m^2·K)	Convective heat transfer coefficient between the air and the ceiling
$h_{\mathrm{A\text{-}F}}$	W/(m^2·K)	Convective heat transfer coefficient between the air and the floor
$h_{\mathrm{A\text{-}W}}$	W/(m^2·K)	Convective heat transfer coefficient between the air and the internal walls
$h_{\mathrm{F\text{-}C}}$	W/(m^2·K)	Radiant heat transfer coefficient between the floor and the ceiling
$h_{\mathrm{F\text{-}W}}$	W/(m^2·K)	Radiant heat transfer coefficient between the floor and the internal walls
H_{A}	W/K	Heat transfer coefficient between the thermal node under consideration and the air thermal node (“A”)
H_{C}	W/K	Heat transfer coefficient between the thermal node under consideration and the ceiling surface thermal node (“C”)
H_{Circuit}	W/K	Heat transfer coefficient between the thermal node under consideration and the circuit
H_{CondDown}	W/K	Heat transfer coefficient between the thermal node under consideration and the next one
H_{CondUp}	W/K	Heat transfer coefficient between the thermal node under consideration and the previous one
H_{Conv}	-	Fraction of internal convective heat gains acting on the thermal node under consideration
H_{F}	W/K	Heat transfer coefficient between the thermal node under consideration and the floor surface thermal node (“F”)
H_{Inertia}	W/K	Coefficient connected to the inertia contribution at the thermal node under consideration
H_{IWS}	W/K	Heat transfer coefficient between the thermal node under consideration and the internal wall surface thermal node (“IWS”)
H_{Rad}	-	Fraction of total radiant heat gains impinging on the thermal node under consideration
h_{t}	W/(m^2·K)	Total heat transfer coefficient (convection + radiation) between surface and space
J	-	Number of layers constituting the slab as a whole
J_1	-	Number of layers constituting the upper part of the slab
J_2	-	Number of layers constituting the lower part of the slab
L_{R}	m	Length of installed pipes
$\dot{m}_{\mathrm{H,sp}}$	kg/(m^2·s)	Specific water flow in the circuit, calculated on the area covered by the circuit
m_{j}	-	Number of partitions of the j-th layer of the slab
n	-	Actual number of iteration in iterative calculations
n_{h}	h	Number of operation hours of the circuit

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Table 1 *(continued)*

Symbol	Unit	Quantity
n^{Max}	-	Maximum number of iterations allowed in iterative calculations
$P_{\mathrm{Circuit}}^{\mathrm{Max,h}}$	W	Maximum cooling power reserved to the circuit under consideration in the h-th hour
$P_{\mathrm{Circuit,Spec}}^{\mathrm{Max}}$	W/m^2	Maximum specific cooling power (per floor square metre)
q_{i}	W/m^2	Inward specific heat flow
q_{u}	W/m^2	Outward specific heat flow
$Q_{\mathrm{C}}^{\mathrm{h}}$	W	Heat flow impinging on the ceiling surface (“C”) in the h-th hour
$Q_{\mathrm{Circuit}}^{\mathrm{h}}$	W	Heat flow extracted by the circuit in the h-th hour
$Q_{\mathrm{Conv}}^{\mathrm{h}}$	W	Total convective heat gains in the h-th hour
$Q_{\mathrm{F}}^{\mathrm{h}}$	W	Heat flow impinging on the floor surface (“F”) in the h-th hour
$Q_{\mathrm{IntConv}}^{\mathrm{h}}$	W	Internal convective heat gains in the h-th hour
$Q_{\mathrm{IntRad}}^{\mathrm{h}}$	W	Internal radiant heat gains in the h-th hour
$Q_{\mathrm{IWS}}^{\mathrm{h}}$	W	Heat flow impinging on the internal wall surface (“IWS”) in the h-th hour
$Q_{\mathrm{PrimAir}}^{\mathrm{h}}$	W	Primary air convective heat gains in the h-th hour
$Q_{\mathrm{Rad}}^{\mathrm{h}}$	W	Total radiant heat gains in the h-th hour
$Q_{\mathrm{Sun}}^{\mathrm{h}}$	W	Solar heat gains in the room in the h-th hour
$Q_{\mathrm{Transm}}^{\mathrm{h}}$	W	Transmission heat gains in the h-th hour
Q_{W}	W/m^2	Average specific cooling power
R	(m^2·K)/W	Generic thermal resistance
$R_{\mathrm{Add\ C}}$	(m^2·K)/W	Additional thermal resistance covering the lower side of the slab
$R_{\mathrm{Add\ F}}$	(m^2·K)/W	Additional thermal resistance covering the upper side of the slab
R_{int}	(m^2·K)/W	Internal thermal resistance of the slab conductive region
$R_{\mathrm{L,p}}$	(m^2·K)/W	Conduction thermal resistance connecting the p-th thermal node with the boundary of the (p+1)-th thermal node
R_{r}	(m^2·K)/W	Pipe thickness thermal resistance
R_{t}	(m^2·K)/W	Circuit total thermal resistance
$R_{\mathrm{U,p}}$	(m^2·K)/W	Conduction thermal resistance connecting the p-th thermal node with the boundary of the (p-1)-th thermal node
R_{Walls}	(m^2·K)/W	Wall surface thermal resistance
R_{w}	(m^2·K)/W	Water flow thermal resistance
R_{x}	(m^2·K)/W	Pipe level thermal resistance
R_{z}	(m^2·K)/W	Convection thermal resistance at the pipe inner side
s_{r}	m	Pipe wall thickness
s_1	m	Thickness of the upper part of the slab
s_2	m	Thickness of the lower part of the slab
W	m	Pipe spacing
´$_{\mathrm{j}}$	m	Thickness of the j-th layer of the slab

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Table 1 *(continued)*

Symbol	Unit	Quantity
$\Delta\theta$	K	Generic temperature difference
$\Delta\theta_{\mathrm{Comfort}}^{\mathrm{Max}}$	K	Maximum operative temperature drift allowed for comfort conditions
Δt	s	Calculation time step
$\theta_{\mathrm{A}}^{\mathrm{h}}$	°C	Temperature of the air thermal node (“A”) in the h-th hour
$\theta_{\mathrm{C}}^{\mathrm{h}}$	°C	Temperature of the ceiling surface thermal node (“C”) in the h-th hour
$\theta_{\mathrm{Comfort}}^{\mathrm{Max}}$	°C	Maximum operative temperature allowed for comfort conditions
$\theta_{\mathrm{Comfort,Ref}}$	°C	Maximum operative temperature allowed for comfort conditions in the reference case
$\theta_{\mathrm{F}}^{\mathrm{h}}$	°C	Temperature of the floor surface thermal node (“F”) in the h-th hour
$\theta_{\mathrm{IW}}^{\mathrm{h}}$	°C	Temperature of the core of the internal walls thermal node (“IW”) in the h-th hour
$\theta_{\mathrm{IWS}}^{\mathrm{h}}$	°C	Temperature of the internal wall surface thermal node (“IWS”) in the h-th hour
$\theta_{\mathrm{MR}}^{\mathrm{h}}$	°C	Room mean radiant temperature in the h-th hour
$\theta_{\mathrm{Op}}^{\mathrm{h}}$	°C	Room operative temperature in the h-th hour
$\theta_{\mathrm{p}}^{\mathrm{h}}$	°C	Temperature of the p-th thermal node in the h-th hour
$\theta_{\mathrm{PL}}^{\mathrm{h}}$	°C	Temperature of the pipe level thermal node (“PL”) in the h-th hour
$\theta_{\mathrm{Slab}}^{\mathrm{Av}}$	°C	Daily average temperature of the conductive region of the slab
$\theta_{\mathrm{Water,In}}^{\mathrm{h}}$	°C	Water inlet actual temperature in the h-th hour
$\theta_{\mathrm{Water,In}}^{\mathrm{Setp,h}}$	°C	Water inlet set-point temperature in the h-th hour
$\theta_{\mathrm{Water,In,Ref}}^{\mathrm{Setp}}$	°C	Water inlet set-point temperature in the reference case
$\theta_{\mathrm{Water,Out}}^{\mathrm{h}}$	°C	Water outlet temperature in the h-th hour
λ_{b}	W/(m·K)	Thermal conductivity of the material of the pipe embedded layer
»$_{\mathrm{j}}$	W/(m·K)	Thermal conductivity of the material constituting the j-th layer of the slab
λ_{r}	W/(m·K)	Thermal conductivity of the material constituting the pipe
ξ	K	Actual tolerance in iterative calculations
ξ_{Max}	K	Maximum tolerance allowed in iterative calculations
ρ_{j}	kg/m^3	Density of the material constituting the j-th layer of the slab
ω	various	Slope of correlation curves

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5 The concept of Thermally Building Active Surfaces (TABS)

A Thermally Active Building Surface (TABS) is an embedded water based surface heating and cooling system, where the pipe is embedded in the central concrete core of a building construction (see Figure 1).

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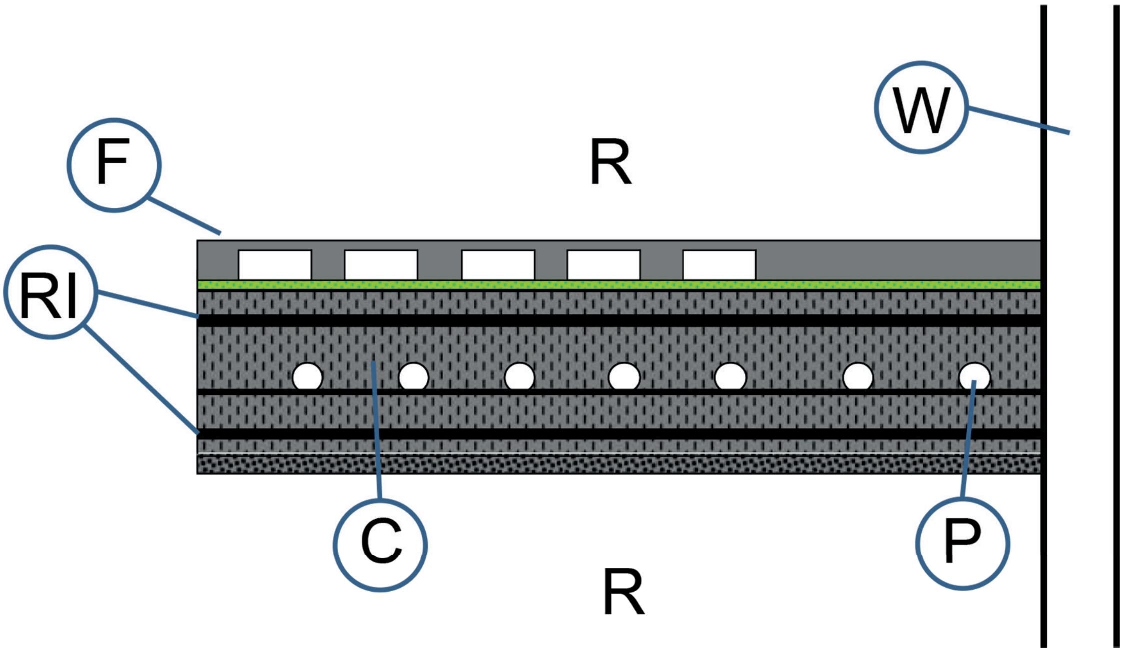

Key

C	concrete
F	floor
P	pipes
R	room
RI	reinforcement
W	window

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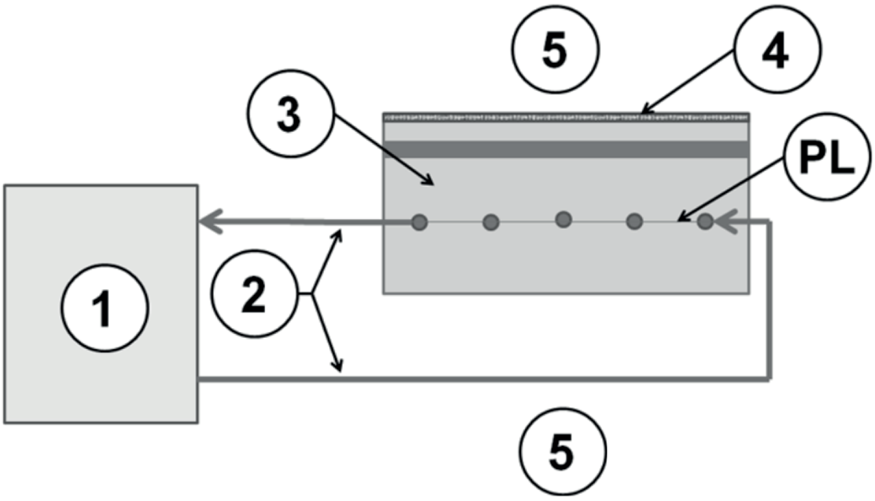
Figure 1 — Example of position of pipes in TABS

The building constructions embedding the pipe are usually the horizontal ones. As a consequence, in the following sections, floors and ceilings are usually referred to as active surfaces. Looking at a typical structure of a TAS, heat is removed by a cooling system (for instance, a chiller), connected to pipes embedded in the slab. The system can be divided into the elements shown in Figure 2.



Key

1	heating/cooling equipment
2	hydraulic circuit
3	slab including core layer with pipes
4	possible additional resistances (floor covering or suspended ceiling)
5	room below and room above
PL	pipe level

Figure 2 — Simple scheme of a TAS

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Thermally active surfaces exploit the high thermal inertia of the slab in order to perform the peak-shaving. The peak-shaving consists in reducing the peak in the required cooling power (see Figure 3), so that it is possible to cool the structures of the building during a period in which the occupants are absent (during night time, in office premises). This way the energy consumption can be reduced and a lower night time electricity rate can be used. At the same time a reduction in the size of heating/cooling system components (including the chiller) is possible.

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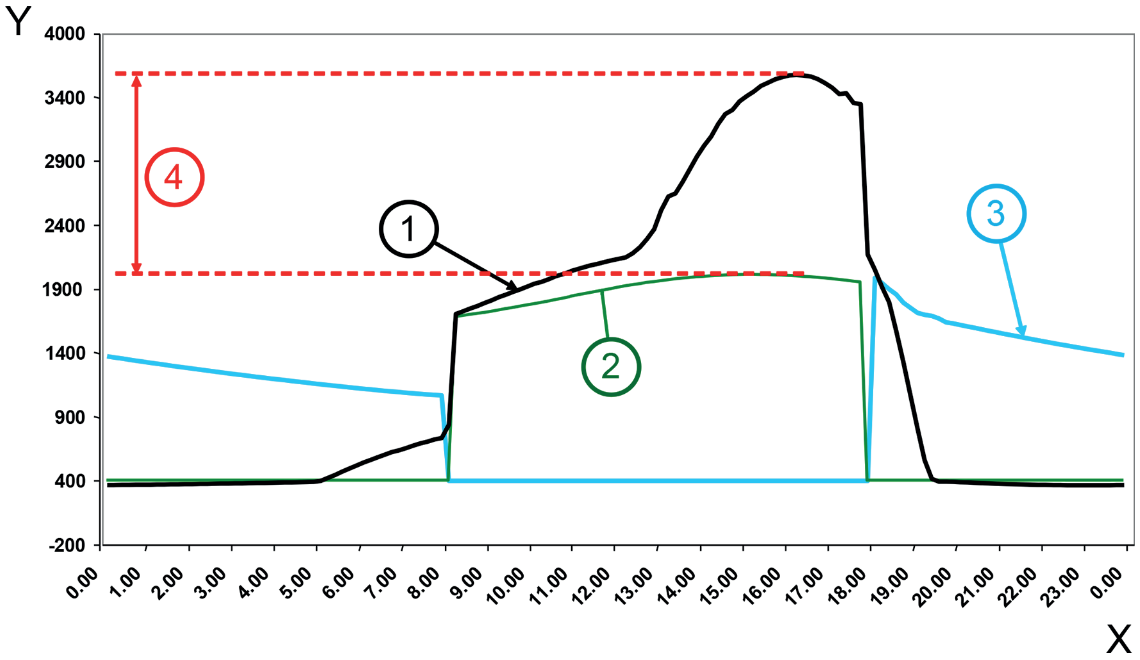

Key

X	time, h
Y	cooling power, W
1	heat gain
2	cooling power needed for conditioning the ventilation air
3	cooling power needed on the water side
4	reduction of the required peak power

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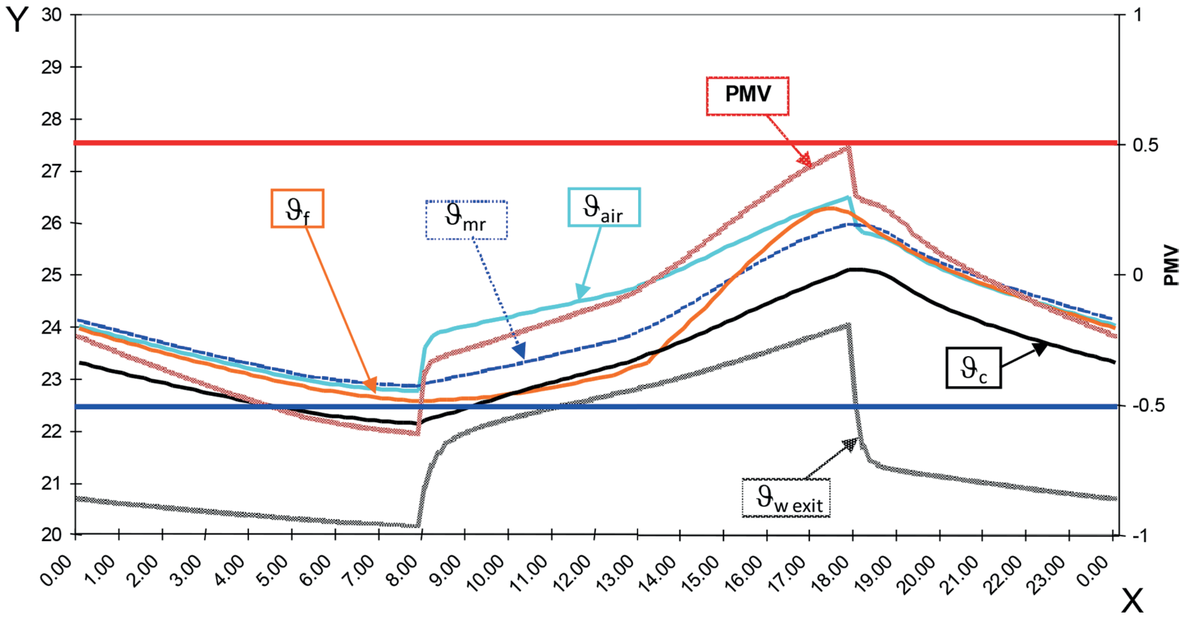
Figure 3 — Example of peak-shaving effect

TABS may be used both with natural and mechanical ventilation (depending on weather conditions). Mechanical ventilation with dehumidifying may be required depending on external climate and indoor humidity production. In the example in Figure 3, the required peak cooling power needed for dehumidifying the air during day time is sufficient to cool the slab during night time.

As regards the design of TABS, the planner needs to know if the capacity at a given water temperature is sufficient to keep the room temperature within a given comfort range. Moreover, the planner needs also to know the heat flow on the water side to be able to dimension the heat distribution system and the chiller/boiler. This part of ISO 11855 provides methods for both purposes.

When using TABS, the indoor temperature changes moderately during the day and the aim of a good TABS design is to maintain internal conditions within the range of comfort, i.e. $-0,5 < PMV < 0,5$, during the day, according to ISO 7730 (see Figure 4).



Key

X	time, h
Y	temperature, °C
PMV	Predicted Mean Vote
θ_{air}	air temperature
θ_c	ceiling temperature
θ_{mr}	mean radiant temperature
θ_f	floor temperature
$\theta_{w\ exit}$	water return temperature

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Figure 4 — Example of temperature profiles and PMV values vs. time

Some detailed building system calculation models have been developed to determine the heat exchanges under unsteady state conditions in a single room, the thermal and hygrometric balance of the room air, prediction of comfort conditions, check of condensation on surfaces, availability of control strategies and calculation of the incoming solar radiation. The use of such detailed calculation models is, however, limited due to the high amount of time needed for the simulations. The development of a more user friendly tool is required. Such a tool is provided in this part of ISO 11855, and allows the simulation of TAS.

The diagrams in Figure 5 show an example of the relation between internal heat gains, water supply temperature, heat transfer on the room side, hours of operation and heat transfer on the water side. The diagrams refer to a concrete slab with raised floor (R = 0,45 (m^2·K)/W) and an allowed room temperature range of 21°C to 26°C.

The upper diagram shows on the Y-axis the maximum permissible total heat gain in space (internal heat gains plus solar gains) [W/m^2], and on the X-axis the required water supply temperature. The lines in the diagram correspond to different operation periods (8 h, 12 h, 16 h, and 24 h) and different maximum amounts of energy supplied per day [Wh/(m^2·d)].

The lower diagram shows the cooling power [W/m^2] required on the water side (to dimension the chiller) for TAS as a function of supply water temperature and operation time. Further, the amount of energy rejected per day is indicated [Wh/(m^2·d)].

The example shows that, for a maximum internal heat gain of 38 W/m^2 and 8 h operation, a supply water temperature of 18,2 °C is required. If, instead, the system is in operation for 12 h, a supply water temperature of 19,3 °C is required. In total, the amount of energy rejected from the room is approximately 335 Wh/m^2 per day. In the same conditions, the required cooling power on the water side

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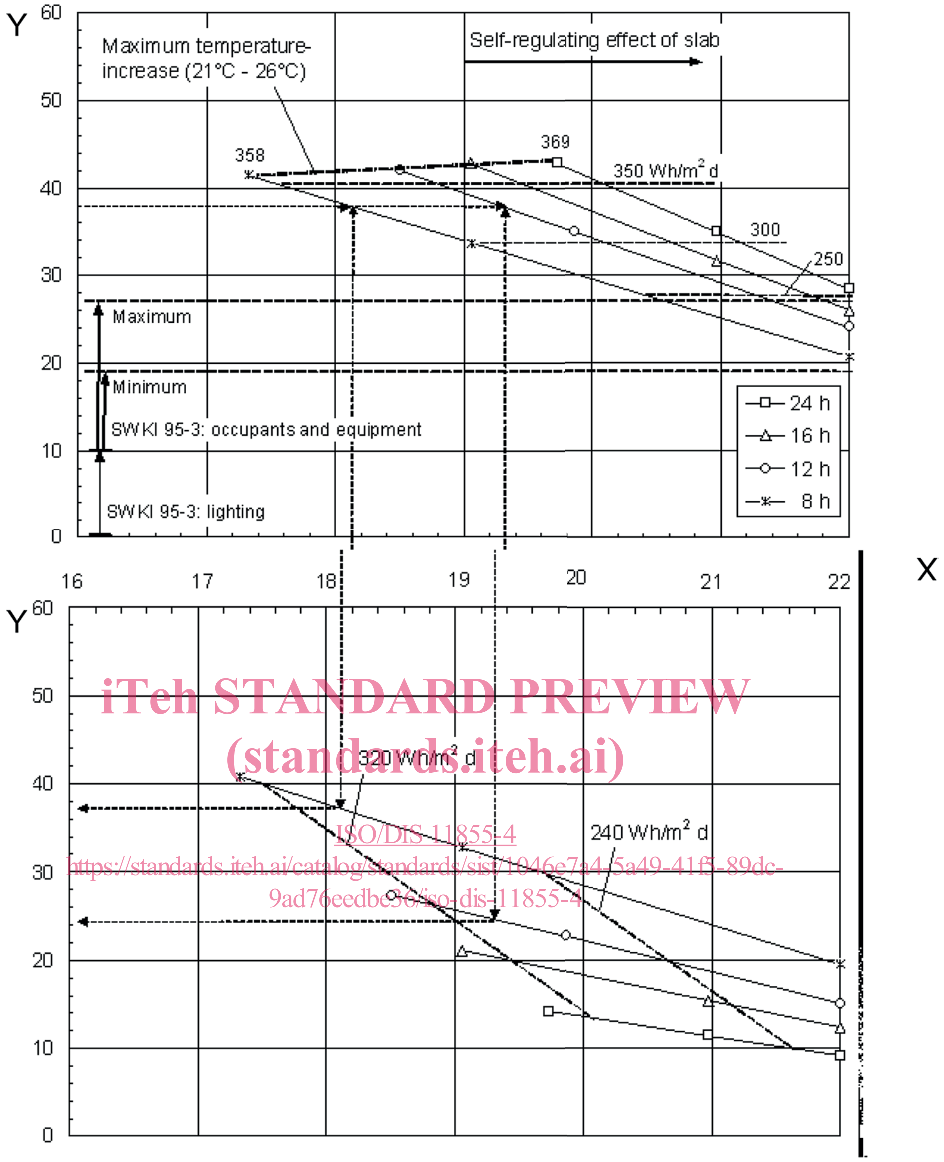
is 37 W/m^2 (for 8 h operation) and 25 W/m^2 (for 12 h operation) respectively. Thus, by 12 h operation, the chiller can be much smaller.



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Key

X (upper diagram)	supply temperature tabs, °C
Y (upper diagram)	maximum total heat gain in space (W/m^2, floor area)
Y (lower diagram)	mean cooling power tabs (W/m^2, floor area)

Figure 5 — Working principle of TABS

6 Calculation methods

6.1 General

TABS are systems with high thermal inertia. Therefore, for sizing chillers coupled with them, dynamic simulations have to be carried out. In principle, the solution of heat transfer inside structures with embedded pipes has to deal with 2-D calculations (see Figure 6). The calculation time required to consider the 2-D thermal field and the overall balance with the rest of the room is usually too high.