White paper

CRITICAL ELEMENTS FOR CORRECT CLIMATE CONTROL DESIGN FOR ELECTRICAL PANELS

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CRITICAL ELEMENTS FOR CORRECT CLIMATE CONTROL DESIGN FOR ELECTRICAL PANELS

Moist air

Humid air is a term referred to the mix of dry air, made up of gas and water in the vapour state. This term is used because water is the only component subject to state changes at typical temperatures on earth and physically separate from air when condensing.

Psychrometry is the study of air and water mixes and their pertinent transformations.

Moist air and its properties

Referring to humid air, you must know the meaning of the following properties:

- Air temperature t_{BS}, also called “dry bulb”, is the actual temperature read by a normal mercury thermometer and is measured in **[°C]**;
- Relative humidity indicates the level of air saturation, and is the partial vapour pressure compared to the partial vapour pressure in saturation conditions at the same temperature:

$$U.R.= \frac{Pv}{Pv,\ sat\ (T)} .100\%$$

The hygrometer is an instrument used to measure relative humidity;

- Specific humidity **X** is the amount of water actually contained compared to the volume of considered dry air. It is measured in **[kgv/kgas]** or, more frequently, in **[gv/kgas]**

$$X= \frac{Mv}{Mas};$$

- Wet bulb temperature t_{BU} or, with good approximation, the saturation temperature at the same considered enthalpy;
- Dew point t_R indicates, for a certain specific humidity, the temperature where the water contained in humid air starts to condense, when an isobar cooling transformation occurs;
- Specific enthalpy **h** is the ratio between humid air enthalpy and the considered dry air mass:

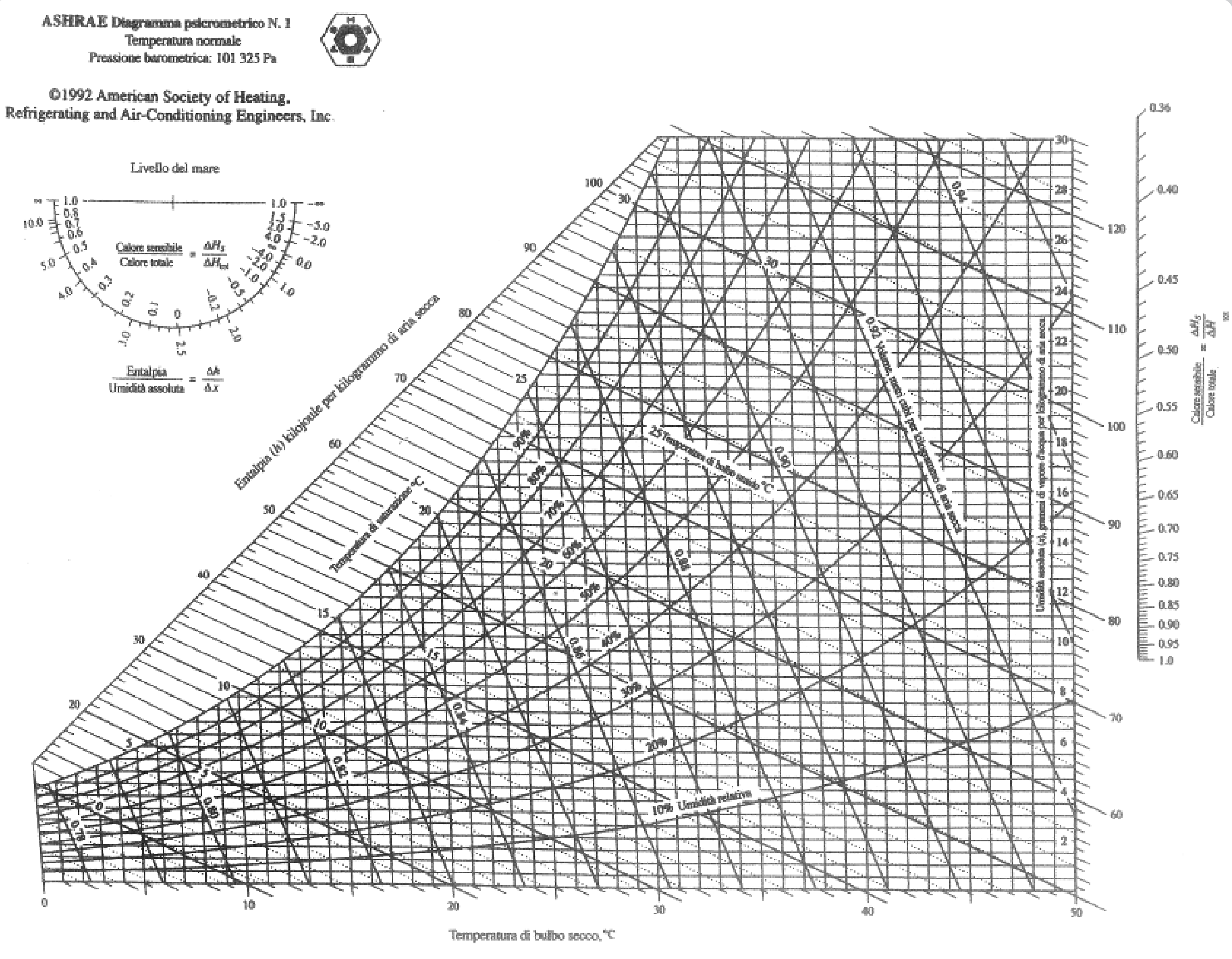
$$h= \frac{H}{Mas}.$$

It is calculated with formula $h=1{,}006t_{BS}+X*(2501+1{,}805*t_{BS})$ and is measured in **[kJ/kgas]**.

Psychrometric diagram

The properties can be calculated using the mentioned formulas or are directly found on the “**Psychrometric diagram**” on the following page in **figure 1**, applicable to moist air in standard conditions at atmospheric pressure **101325Pa**. Knowing two of the properties referred to moist air, a point on the psychrometric diagram is found; from this point, the other climate properties uniquely referred to it can be read.

Davide Rocca
Alberto Tonietti



1-ASHRAE PSYCHROMETRIC DIAGRAM, barometric pressure: 101325Pa

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Environmental conditions

Readers were provided with essential know-how on the humid air concept and concerning the psychrometric diagram in our last edition. We'll take another step in this publication to allow readers to understand why these topics are discussed and their pertinence in the electrical cabinet world.

Electrical cabinets contain components that make up an electrical panel. The latter can only work correctly if the climate conditions, also called "**design conditions**", are suitable.

First of all, the designer must set the "design conditions":

- Tin[°C] , **U.R.**in [%] (cabinet interior)
- Tout[°C] , **U.R.**out[%] (cabinet exterior)

This information must be entered in the formulas provided in the previous publication or in the psychrometric diagram to calculate other thermodynamic coordinates:

- **specific enthalpy** hin,hout [kJ/kgas]
- **specific humidity** Xin, Xout [gv/kgas]

Temperature control

All the above listed parameters are essential for residential designs. In electrical panels, the term that requires the highest focus is temperature. For the latter, each electrical panel component has a maximum design limit: the accidental phenomenon of excessive temperature translates into component deterioration, causing reduced performance and a reduction in durability and reliability. **CEI EN 61439** standard referred to low voltage electrical panel, does not indicate a precise numerical value for acceptable maximum pressure, but defers to standards referring to single devices and the limits stated by manufacturers. Therefore, the maximum design limit in a cabinet should not jeopardise the reliability of the contained equipment.

The same layout of the single components in the cabinet is important: temperatures are higher at the top, due to air stratification, thus it is best to install parts that generate more heat in the lower areas.

Overheating is due to the environmental conditions in which the panel is installed and, on this topic, the **CEI EN 61439** standard sets the maximum air temperature and relative environmental humidity. For both indoor and outdoor installation, the standard sets **+40°C** as the maximum environmental temperature. To meet this requirement, in heat dimensioning we recommend setting design temperature to **35°C** for the cabinet interior (average temperature; there will be hotter areas at the top and colder ones in lower zones). In this design condition, hot-spots will not reach the **40°C** limit and, albeit indirectly, **35°C** will make condensate formation highly improbable.

In indoor installation, internal **35°C** also avoid condensate when cooling is created by mixing internal air with an air flow from the exterior, using Fan-filters or exhaust units.

For outdoor units, to avoid condensation problems, since relative environmental humidity is **not** a controllable parameter and can frequently be high, we recommend a different solution that guarantees a net separation between external and internal air (TCUs, conditioners, air-air exchangers, water-air exchangers). Specifically, the conditioner permits air dehumidifying and is perhaps the best solution for highly humid outdoors.

The **CEI EN 61439-1** standard sets the following climate conditions indicated in **figures 1** and **2** referred to the installation environment:

ENVIRONMENTAL INSTALLATION CONDITIONS FOR OUTDOORS

Table 3.2

Relative humidity	Air temperature	Altitude
100% temporary (for maximum temperature of 25°C)	maximum temperature ≤40°C	not more than 2000m
	maximum average temperature in a period of 24 hours ≤35°C	
	minimum temperature ≥-25°C for temperate climates	
	minimum temperature ≥-50°C for arctic climates	

1 - Environmental installation conditions according to CEI EN 61439-1

ENVIRONMENTAL INSTALLATION CONDITIONS FOR INDOOR

Table 3.1

Relative humidity	Air temperature	Altitude
50% (for maximum temperature of 40°C) 90% (for maximum temperature of 20°C)	maximum temperature ≤40°C	not more than 2000m
	maximum average temperature in a period of 24 hours ≤35°C	
	minimum temperature ≥-5°C	

2 - Environmental installation conditions according to CEI EN 61439-1

Once the admissible limits are set, ΔT=Tout-Tin , the temperature difference between the cabinet interior and exterior, also called “thermal gradient”, is set.

ΔT is calculated for two distinct cases:

1.ΔTrisc to design heating systems;

2.ΔTraff to design cooling systems.

In heating system designs, the minimum temperature possible in the installation environment and the minimum required inside the electrical cabinet are considered.

In cooling system designs, the maximum temperature that can occur in the installation environment and the maximum required inside the electrical cabinet are considered.

In both design cases, we recommend setting 35°C as the internal electrical cabinet temperature.

Davide Rocca
Alberto Tonietti

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Internal and external adduction coefficient calculation

The “Electrical cabinet thermal balance” WHITE PAPER discussed thermal transmittance and the formula used to calculate them. The formula components that deserve greater attention are the internal α_{in} and external α_{out} adduction thermal exchange. The numerical values of the latter can be read from the table shown in the previous WHITE PAPER, or calculated according to the **UNI EN ISO 6946** 6946standard as explained below.

The **adduction coefficients** α include thermal exchanges that take place both by convection and by radiation and are determined by the formula:

$\alpha = \alpha_{conv} + \alpha_{irr}$

1 - Radiative coefficient

$h_r = \varepsilon^* h_{r0}$ (real radiative coefficient)

$h_{r0} = 4\sigma T_m^3$ (black body radiative coefficient)

Where:

- ε it is the superficial emissivity and depends on the type of surface considered;

- σ is the Stefan-Boltzmann constant and equal to 5,67*10^(-8) W/m2K4 ;

- $\mathbf{T_m}$ is called “thermodynamic temperature” defined, as the function derived from internal energy **U** compared to entropy **S** constant volume **V**.

U=U(S,V,M) ; **S=S(U,V,M)**.

Considering constant mass **M**, the variations of **U** and **S** are independent of this parameter.

We can now define the formula for calculating the **thermodynamic temperature**:

$$Tm = \left(\frac{\partial U}{\partial S} \right)_{(V=cost)}$$

- h_{r0} **, black body radiative coefficient,** temperature-dependent and have tabular values shown in the following table:

T[°C]	h_{ro} [w/m²K]
-10	4,1
0	4,6
10	5,1
20	5,7
30	6,3

1 - Black body radiative coefficients h_{r0} according to temperature

The **surface emissivity** ε referred to the electrical cabinet walls must be know to calculate h_r.

In this case the structural materials of the electrical cabinets are considered to determine the values of ε:

A. Mild steel (sheet metal): ε_A**= 0,07**;

B. Plastic: ε_B**= 0,84**;

C. Stainless steel: ε_C **= 0,07**;

D. Aluminium: ε_D **= 0,89**;

E. PE (polyethylene): ε_E **=0,84**;

F. Paint on steel: ε_F **=0.265** (cabinet interior and exterior).

After calculating **h_{r0}**, **h_{ri}** and **h_{re}** are found by applying the formula **$h_r=\varepsilon^* h_{r0}$** .

2 - Convective coefficients

The type of climate control (heating or cooling) requires different convective coefficients, because they depend on the air speed on the surfaces. For the definition of these coefficients we distinguish two cases:

-heating designs, for which the air is almost still in the electrical cabinet and therefore low values of the convection coefficients are to be assumed;

- cooling designs, for which the air is moved in the electrical cabinet and therefore it is appropriate to assume higher values for the convective coefficients.

The two solutions concern thermal exchanges, which however depend on air motions governed by different laws. In heating, emitted heat dominates the convective flows inside the cabinet because the solutions are or are almost "mechanically motionless". In contrast, fans are integrated in almost every cooling system which makes convection air flow-dependent.

a) Heating designs for which convection is due to thermal power alone.
In this case, reference is made to the values in the following table:

HEAT FLOW DIRECTION	COEFF. CONV. INTERNAL h_{ci}[W/m²K]
ASCENDING	5
DESCENDING	0,7
HORIZONTAL	2,5

2 - Internal convective coefficients hci referred to the direction of heat flow

The heat flow is dominated by thermal temperature gradient and is directed from warmer areas to colder ones.

b) Areas where wind speed is relevant (electrical cabinet interior or exterior with high ventilation flows.

The following formula can be applied to calculate the convective coefficient:

$hc=4+4v$

*v = wind speed [m/s]

For the electrical cabinet interior, when using a fan filter or a running TCU, since both have a fan, you can hypothesize v of about **0.5m/s**.

Three reference cases were identified for the electrical cabinet exterior:

1) **Outdoor without wind or indoor**: low speed but not null, established around **1.1m/s**;

2) **Outdoor with weak wind**: speed around **4m/s**;

3) **Outdoor with strong wind**: speed around **8.6m/s**.

Using these inputs in an Excel thermal balance software, the coefficients were verified with laboratory tests.

From the radiative h_r and convective h_c values obtained, adduction coefficients are calculated:

$\alpha_i = h_{ci} + h_{ri}$ *Referred to the electrical cabinet interior

$\alpha_e = h_{ce} + h_{re}$ *Referred to the electrical cabinet exterior

In some cases examined in particular, fixed values were assigned to these coefficients, specifically:

- α_i=8.3W/m2K(Heating designs);
- α_i=10.5W/m2K(Cooling designs);
- α_e=13W/m2K(Outdoor without wind or indoor);
- α_e=24.8W/m2K(Outdoor with weak wind);
- α_e=43W/m2K(Outdoor with strong wind).

After calculating the values of α_i, R_{tot}, α_e, the cabinet wall transmittance U can be calculated with the following formula:

$U=1/(1/1in + s1/\lambda 1 + s2/\lambda 2 + ... \ sn/\lambda n + 1/\alpha out)$ [W/m²K].

Davide Rocca
Alberto Tonietti

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Electrical cabinet thermal balance

The “Moist air” and “Environmental conditions” WHITE PAPERS introduce the concepts necessary to understand what is meant by “electrical cabinet thermal balance”. The designer’s goal is to achieve the desired conditions inside the cabinet, in terms of relative humidity and above all of temperature.

In the case of stationary thermal balance, or in the absence of thermal inertia, the sum of all the powers involved is zero.

To guarantee the thermal balance, the following ratio is valid: $\Sigma \mathbf{Q_i} \mathbf{=0}$,

where $\mathbf{Q_i}$ indicates the n-th thermal power and $\Sigma \mathbf{Q_i}$ is the sum of all thermal powers that effect the electrical cabinet.

All possible situations are not considered in the design phase but only the most hostile to the electrical panel, namely:

- Maximum possible and maximum acceptable ambient temperature inside the electrical cabinet;
- Minimum verifiable and minimum acceptable ambient temperature in the electrical cabinet.

Through this distinction, as well as in the civil sphere, the design conditions are “**winter case**” and “**summer case**”, for electrical panels the dimensioning is divided into thermal balance for “**heating**” and for “**cooling**”. Furthermore, an additional differentiation must be made in designs for “**indoor**” and “**outdoor**” environments.

The calculation formulas to be used for the thermal balances are:

1. Heating: **Qdiss+Qrisc=0**

(Qdiss=dissipation through the wall; Qrisc=required heating power)

2. Cooling: **Qdiss+QJoule+Qsolar+Qraff=0**

(Qsolar = power due to solar irradiation, to be considered only for outdoor installations; Qraff = required cooling power)

*all **1** and **2** balance powers are measured in heat **[W]** .

Formulas 1 and 2 include many thermal power components, but at this stage, the objective of the WHITE PAPER is to provide guidance for the calculation of heat dissipated through the electrical cabinet walls: we only consider **Qdiss**.

Electrical cabinet wall thermal transmittance

To determine the thermal power passing through the electrical cabinet it is necessary to calculate the transmittance of materials that constitute it, i.e. the heat transfer capacity of each wall.

The general formula of thermal transmittance is:

$U=1/(1/\alpha in + s1/\lambda 1 + s2/\lambda 2 + ... \; sn/\lambda n + 1/\alpha out)$ [W/m²K] 1

- α_{in} indicates the internal adduction exchange coefficient;
- **sn** is the n-th thickness of the considered wall;
- **λn** is the thermal conductivity of the wall construction material;
- α_{out} indicates the external adduction exchange coefficient;

In common practice, the calculation methods for thermal dimensioning do **not** take into account the possible variations of the adduction components. For completeness, it was decided to study the extent of the individual parameters that make up the transmittance U, adduction coefficients α included, determined experimentally or from technical literature.

The **adduction coefficients** α include thermal exchanges that take place both by convection and by radiation and are determined by the formula:

$$\alpha=\alpha_{conv}+\alpha_{irr}$$

The **thermal conductivity** λ_n are intrinsic to the cabinet construction material so they remain fixed and do not depend on the installation site.

a - Electrical cabinet construction material thermal conductivity at room temperature [20°C]

A. Mild steel (sheet metal): λ_A =54[W/mK] ;

B. Plastic: λ_B=0.19[W/mK];

C. Stainless steel: λ_C =16[W/mK];

D. Aluminium: λ_D=204[W/mK];

E. PE(polyethylene): λ_E=0.35[W/mK];

F. Paint on steel: λ_F =0.265[W/mK] (cabinet interior and exterior).

Once the thickness of each layer is known, the respective thermal resistances are calculated with the formula **Rn=sn/λn[m²K/W]**.

The total resistance to heat conduction through the walls is given by the formula

$R_{tot}=\sum sn/\alpha n$ [m^2K/W] 2

***In the case of "painted steel", the heat resistance of the steel layer and 2 paint layers, internal and external, are added. Because of the irrelevant thicknesses of the same, it is possible to neglect the resistive contribution to heat passage.**

b - Interna (α_i) and external (α_e) adduction coefficients

Heat flow direction	ASCENDING	DESCENDING	HORIZONTAL
α_i	10	7,7	5,88
α_e	25	25	25

1 - internal adduction Coefficients (α_i) and external (α_e) for various geometric situations

The coefficients indicated in **table 1** can be used, or for more precise dimensioning, calculate h_r and h_c according to **UNI EN ISO 6946**, standards as explained in the "Internal and external adduction coefficient calculation" WHITE PAPER.

Davide Rocca
Alberto Tonietti

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Thermal exchange surfaces

In this WHITE PAPER the goal is to provide a method to determine the unknown not yet treated and present in the formula for calculating thermal dissipations through the electrical cabinet: **the wall exposure surface towards the installation environment.**

Ai[m^2] indicates the i-th surface of each exposed wall. In fact, in the context of electrical panels, the exchange surfaces with the environment must be multiplied by specific corrective coefficients, which depend both on the walls considered and on the layout of the cabinet in space.

Referring to the case, we indicate the dimensions in **[mm]**, defining:

- **L** = width;

- **H** = height,

- **P** = depth.

We list 12 possible layouts of the electrical cabinets in space, the calculation formulas of the total surface A [m^2] is shown with the relative correction coefficients for each:

1) Single cabinet, free on all walls

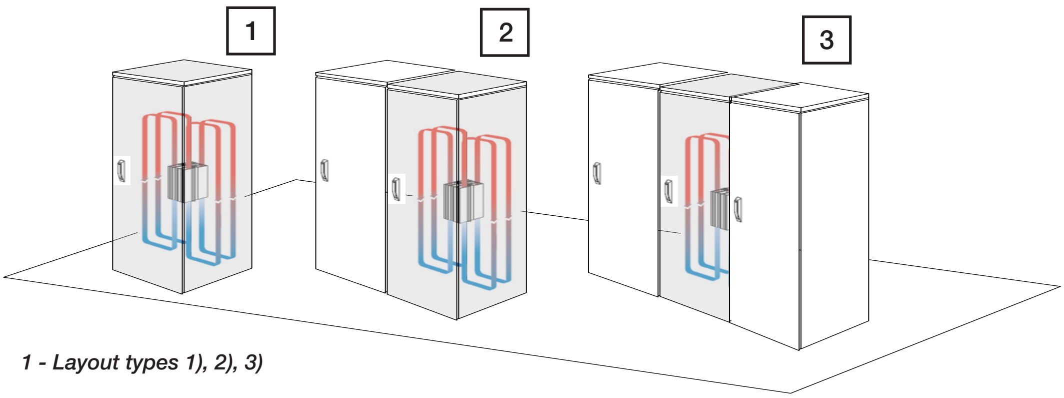
$$A[m^2] = \frac{1.8*H*(L+P)+1.4*L*P}{1000000}$$

2) First or last cabinet, with one wall in contact

$$A[m^2] = \frac{1.4*P*(L+H)+1.8*L*H}{1000000}$$

3) Central cabinet, with two walls in contact

$$A[m^2] = \frac{1.8*L*H+1.4*L*P+P*H}{1000000}$$



1 - Layout types 1), 2), 3)

4) Single wall cabinet

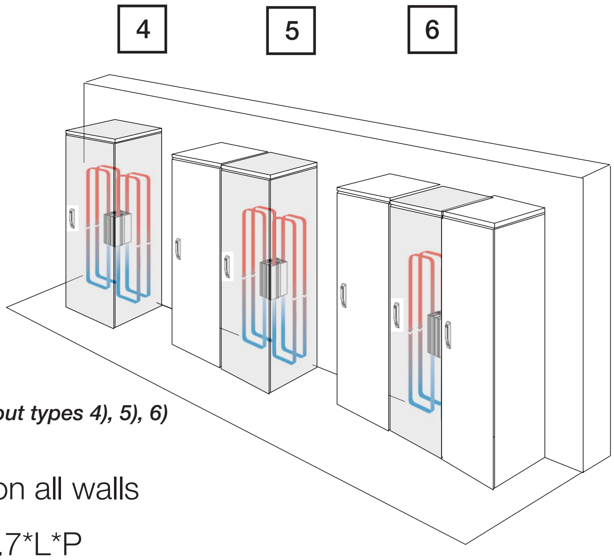
$$A[m^2]=\frac{1.4*L*(H+P)+1.8*P*H}{1000000}$$

5) First or last wall cabinet

$$A[m^2]=\frac{1.4*H*(L+P)+1.4*L*P}{1000000}$$

6) Central wall cabinet

$$A[m^2]=\frac{1.4*L*(P+H)+P*H}{1000000}$$



2 - Layout types 4), 5), 6)

7) Single cabinet with cover, free on all walls

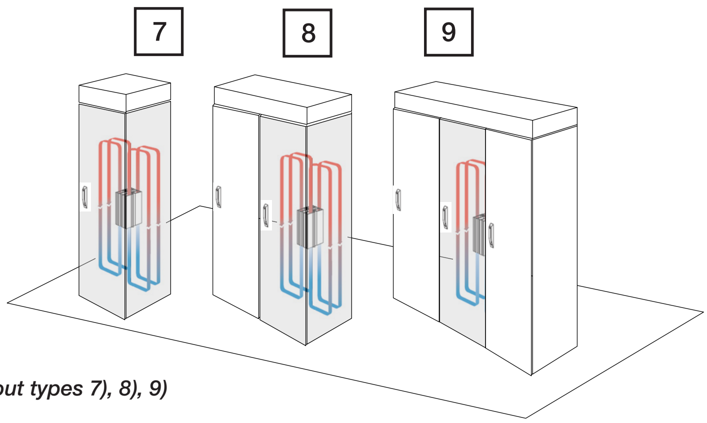
$$A[m^2]=\frac{1.8*H*(L+P)+0.7*L*P}{1000000}$$

8) First or last cabinet with cover, with one wall in contact

$$A[m^2]=\frac{1.4*P*H+1.8*L*H+0.7*L*P}{1000000}$$

9) Central cabinet with cover, with two walls in contact

$$A[m^2]=\frac{1.8*L*H+0.7*L*P+P*H}{1000000}$$



3 - Layout types 7), 8), 9)

10) Single cabinet with cover, on the wall

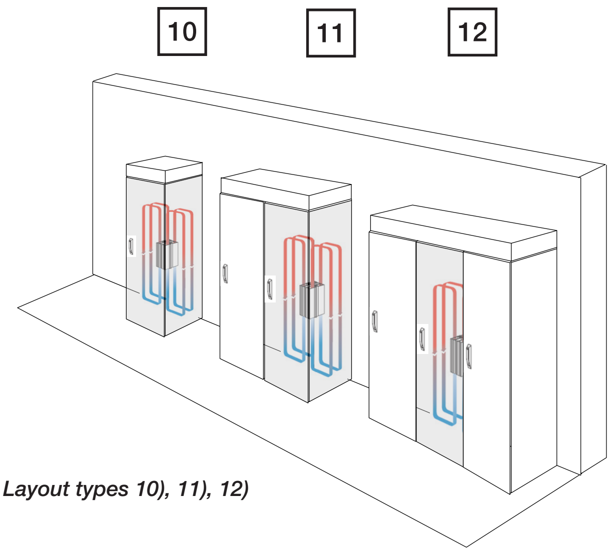
$$A[m^2]= \frac{1.4*L*H+1.8*P*H+0.7*L*P}{1000000}$$

11) First or last cabinet with cover, on the wall

$$A[m^2]= \frac{1.4*H*(L+P)+0.7*L*P}{1000000}$$

12) Central cabinet with cover, on the wall

$$A[m^2]= \frac{1.4*L*H+0.7*L*P+P*H}{1000000}$$



4 - Layout types 10), 11), 12)

In each project, the actual layout of the cabinets must be inserted for the correct calculation of the thermal exchange surface. The coefficients used result in a smaller exchange surface than the geometric one of the cabinet, since they take into account any physical barriers and secondary factors, which reduce the maximum transfer of power theoretically possible.

Once the heat exchange surfaces are also determined, it is possible to determine the numerical value of the thermal dissipations of the electrical cabinet, as will be summarised in the final WHITE PAPER.

Davide Rocca
Alberto Tonietti

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Calculation of the thermal dissipations of the electrical cabinet

In the previous WHITE PAPERS, all the concepts necessary for the calculation of the thermal dissipations through the walls of the electrical cabinet have been provided. It is now possible to proceed with the determination of the thermal power through the walls, which must be defined both to design the heating and cooling system of the electrical cabinet and which can be calculated with the following relation:

$$Q_{diss} = U*A*\Delta T \ [W] \qquad 1$$

-**U**$\left[\frac{W}{m2K}\right]$ is the thermal transmittance of the walls of the electrical cabinet, which can be determined as described in the WHITE PAPERS **"Thermal balance of the electrical cabinet"** and **"Adduction coefficient calculation"**;

-**A[m²]** is the total heat exchange area, calculated taking into account the surface coefficients mentioned in the WHITE PAPER **"Thermal exchange surfaces"**;

- **ΔT[K]** is the temperature difference between the cabinet exterior and interior ($T_{environment}$-$T_{cabinet}$). This term must be determined in the following way:

• Replacing the maximum possible temperature in the installation environment and the maximum acceptable inside the electrical cabinet (recommended at 35° C) for the calculation of dissipations **Qdiss**, to be used to dimension the cooling system;

• Replacing the minimum verifiable temperature in the installation environment and the minimum acceptable in the electrical cabinet for the calculation of dissipations **Qdiss**, to be used to dimension the heating system.

According to the sign convention used, all the thermal powers entering the electrical cabinet are considered positive, while the outgoing ones are negative.

Replacing the numerical values of the individual terms in formula **1**, the thermal power passing through the walls of the electrical cabinet is determined, separately for designing the heating and cooling systems.

To dimension the heating system to be installed, it is possible to refer to the mathematical formulas discussed in the WHITE PAPER **"Thermal balance of the electrical cabinet"**, in particular:

1. Heating: **Qdiss+Qrisc=0 [W]**

where, replacing the numeric value of **Qdiss, Qrisc,** the only unknown, can be easily found.

Dimensioning the cooling system instead requires a more complex analysis, because, as shown in the following formula, it requires the calculation of further terms in addition to the thermal dissipations and not treated in this series of WHITE PAPERS:

2. Cooling: **Qdiss + QJoule + Qsolar + Qraff = 0 [W]**

Conclusions

The dimensioning of the heating and cooling systems of the electrical panels is essential for correct operation and to avoid failure phenomena due to overheating or condensation.

Through the basic notions described in this "White paper", it is possible to understand which factors are related to the thermal balance of the electrical cabinet:

- Desired environmental conditions inside the electrical cabinet and the most hostile possible in the installation environment;

-Electrical cabinet construction material and wall thickness;

- Convection of air flows inside and outside the electrical cabinet;

- Layout of the cabinet in space.

Lastly, the $\mathbf{Q_{diss}=U*A*\Delta T}$ **[W]** formula determines the thermal power passing through the cabinet walls for both heating and cooling. It is important to remember that this power is **not** the only one necessary for the resolution of thermal balance formulas **1** and **2** in paragraph "**Thermal balance of the electrical cabinet"** therefore, it is sufficient to determine the heating power to be installed on an electrical cabinet, not to determine the cooling one.

Davide Rocca
Alberto Tonietti

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Fandis
colors of engineering

Fandis S.p.A.
Via per Castelletto 65/69 - 28040 Borgo Ticino (NO) - Italy
Tel. +39 0321 96 32 32 - Fax +39 0321 96 32 96
info@fandis.it

AZIENDA CON SISTEMA DI GESTIONE QUALITÀ CERTIFICATO DA DNV GL = ISO 9001 =

Per maggiori info:
www.fandis.it

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