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Influence of installation conditions on heating bodies thermal output: preliminary experimental results

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Abstract

Heating bodies are thermodynamic systems whose heat output is strongly dependent on boundary conditions and in about a century several attempts have been made for its experimental determination. To this aim, at the beginning of 60s, in Europe different national standards were adopted (e.g. in 1967 in Italy the UNI 6514/1967). At European level, the EN 442-1:2014 and EN 442-2:2014 allows the heating body heat output estimation with an expanded uncertainty lower than 1% and they are now accepted in various international markets. The EN 442 also allows heat output calculation in operating conditions different from standard ones by employing theoretical-experimental correlations that, by their nature, are not able to include any possible actual operating condition. In fact, in actual operating conditions the heating body heat output depends on several factors, among which: i) installation position with respect to the wall and the floor; ii) presence grid/shelf/niche or an obstruction caused by curtains on the heating body; iii) thermo-fluid-dynamic condition variations (inlet flow rate and temperature); iv) hydraulic connections. Radiators represent the most spread heating body (installed since the end of '800) and in the last decades different radiators typologies have been proposed on the market, characterized by different materials, sizes, shapes, etc. In the present paper the authors present the preliminary result of an experimental campaign on field for the heat output measurement of different radiators typologies (cast iron, aluminum) as a function of different installation and operating conditions. The influence on the heating body performance and the associate technical-economical consequences in terms of heat cost allocation accuracy have been investigated.

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Keywords: Radiators, standard heat output, intallation conditions, connection modes, heat allocation.

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1. Introduction

Thermal output of heating bodies depends on several aspects (average external surface temperature; shape, material, size and surface finish; water flow rate etc.) and is crucial for correct heating plants sizing and heat allocation. Heating bodies are classified as a function of material (steel, cast iron, aluminum) and shape (i.e. shaped panel, columns, etc.) [1-4]. An accurate methodology for the determination of thermal output has been achieved in the last years moving from the simple manufacturer's declaration at the beginning of sixties, to a standard estimation in the seventies, to an accurate and rigorous measure according to EN 442-1 [5] and EN 442-2 [6]. Originally the aim of technical standards was to ensure a market competition among manufacturers and only in recent years became crucial for a fair heat accounting. Unfortunately, most of existing heating plants are very old and accurate information about heating bodies thermal output is lacking or confused. The Italian Thermo-technical Committee (CTI) established that, for indirect heat accounting, heating bodies thermal output must be determined in accordance to the following hierarchy:

- level 1) according to EN 442 (available since 1995);
- level 2) for heating bodies installed before the entering into force of EN 442, according to available national standards (UNI or other UE member states standards);
- level 3) if level 1 and 2 are not applicable, output should be determined through non experimental methods if validated (such as the dimensional method described by UNI 10200 [7]).

Obviously, not experimental methods are not as accurate as EN 442 reference method. The dimensional method for the estimation of thermal output, takes into account geometrical data of heating bodies, such as the external volume, the material and the typology (columns width, hubs step, plate and fin type). Besides operating thermal output can be very different from reference standard value because of installation conditions of the heating body and actual thermo-fluid-dynamic operating conditions. In order to investigate issues related to indirect heat accounting, it is necessary a deep understanding of the heat transfer mechanism taking place, mainly combined radiation-convection and, to a negligible extent (unless in case of wrong installation), conduction. Limiting the attention to the so-called "radiators" and "convectors", natural convection plays a significant role and represents from 50% to 90% of the overall thermal output depending on the type of the heating body. In this paper the authors present the results of an on field experimental campaign aimed at the determination of deviation of operating thermal output from reference standard one. In particular, the following operating conditions have been analyzed: i) presence of a grid, a shelf, niche, an obstruction caused by curtains on the heating body; ii) installation position with respect to wall and floor; iii) thermal power variation with the connection mode.

2. Radiators thermal power measurement

Each radiator is characterized by a specific thermal output determined by an experimental method defined in the European standard EN 442 [5, 6]. In Italy, in order to allocate the heating costs, an empirical method is provided for radiators installed in the sixties. This method is indicated as dimensional method and it is described in the national standard UNI 10200 [7].

2.1. Experimental method EN 442

The EN 442 standard [5, 6] allows the thermal output measurement with an uncertainty lower than ±1%. The boundary conditions are controlled by using a test chamber closed and unventilated characterized by five water cooled walls and one not cooled. The radiator under test is exposed to this latter not cooled wall. All the walls are insulated, in this way the thermal conditions are independent from the external environment. The standard thermal output ϕ of the radiator under test is obtained at a temperature difference ΔT equal to 50°C. The characteristic equation of the tested model is:

$$\phi = K_m \cdot \Delta T^n \tag{1}$$

where K_m (W/K) is the radiator constant and *n* is the exponent of the characteristic generally ranging from 1.1 to 1.4 depending from the ratio between the thermal output exchanged by radiation and convection. Radiators are often made up of an identical number of vertical sections (elements or modules) and the thermal output of a single element can be obtained by the following relation:

$$\phi_L = \frac{\phi}{N_{el}} \quad (2)$$

where ϕ_L (W) is the thermal output of a single module and N_{el} is the number of elements. In the case the radiators are not splittable, a module corresponds to a radiator having a conventional length of 1 m.

The standard introduces the concept of "family" of radiators to take account of the dimensions variability (length, width and height), with the same materials and aesthetics. In order to reduce the number of models to test, also the concept of "type" was introduced, representing a subset of the family characterized by a constant dimension, perpendicular to the plane defined by the other two variable dimensions. Typically a radiator type is made of models with constant width and variable length and height. In accordance with EN 442 the standard thermal output of the type can be obtained by using the following equation:

$$\phi = K_T \cdot L^a \cdot H^b \cdot q_m^c \cdot \Delta T^{(c0+c1H)} \quad (3)$$

where K_T, a, b, c, c0 e c1 represent the characteristic constants of the radiator, H is the height, L is the length and $\Delta T = t_m - t_a$ is the difference between the average temperature of the radiator and the test environment. The characteristic constants can be determined through a minimum of 9 models for each radiator type including models of height lower than 1m, up to 16 models for radiator type including models exceeding 1 m. As a matter of facts, in the second case, 144 measurement in different regime conditions should be performed. Therefore, in order to reduce test costs, taking into account the technical experience gained in the last forty years [8-10], some simplifications of the European standards can be adopted which provide a direct proportionality between the elements number and the total thermal power of the radiators and the independence of the thermal power from the fluid flow rate. In case of radiators made up of different modules (typically steel or tubular radiators) it is necessary to test four models both for the minimum and the maximum length. The dependence of the thermal power from the length is then obtained by the linear function interpolating the experimental results for the two series of heights. On the manufacturer's request, the testing laboratory can evaluate the dependence of thermal power from the volumetric flow rate. In general for a radiator type, assuming the width to be constant and neglecting the flow rate effect, the so-called radiator type characteristic equation is obtained in the following simplified form:

$$\phi = K_T \cdot H^b \cdot \Delta T^{(c0+c1H)} \quad (4)$$

For the above mentioned heating elements, in general the characteristic equation of shorter length models and of greater length are released, together with a document showing the values of similar models calculated through a linear interpolation curve. Such approximation has been validated and provides results lower than 2% compared to the measured ones [11]. For each radiator type and model the manufacturers must declare at least the standard thermal output value ϕ_L of a single module and its characteristic equation. In modern systems the following characteristic equation is determined for the minimum and maximum length of a radiator type:

$$\phi = K_T \cdot H^b \cdot q_m^c \cdot \Delta T^{(c0+c1H)} \quad (5)$$

For similar models the laboratory gives the thermal output calculation validated according to EN 442.

2.2. Dimensional method UNI 10200

The dimensional method is mentioned, for some cases, in the Italian standard UNI 10200 [7] and allows to obtain, through an empirical calculation, the thermal output of the installed radiators. Such method is applicable only for radiators with simple structure such as plates. On the other hand, the method is not valid for convectors, fan coils, radiant panels or other systems based on the forced convection principle. The thermal output $\Phi_{\Delta T60}$, referred to a 60 °C difference between the average temperature of the radiator and the ambient one, can be obtained by the following relation, in which the radiative and convective contribution have been considered:

$$\phi_{\Delta T60} = 314 \cdot S + C \cdot V \quad (6)$$

where S (m^2) represents the radiator surface, C (W/m^3) is a characteristic coefficient of the heating body, experimentally evaluated for some radiator families of the eighties and available as a function of the radiator type, V (m^3) is the radiator volume. For simplicity, the dimensional method assumes, for the calculation of the radiator external surface (S) and the volume (V), the envelope parallelepiped of height H, depth D and width L. This method does not allows to determine the flow rate influence on the thermal power.

2.3. Thermal output in operating conditions

The radiator thermal output is inversely proportional to its total thermal resistance which can be expressed through the following relation:

$$R_T = R_i + R_p + R_e \quad (7)$$

where R_i is the internal convective/radiative resistance, R_p is the wall conductive resistance, R_e is the convective/radiative external resistance. R_e value is always higher than R_i that is considerably higher than R_p. Therefore the thermal output Φ_{eff} exchanged between the radiator external surface and the surrounding environment depends mainly from R_e. Unfortunately, on the field, thermo-fluid-dynamic conditions are very different from the test ones (e.g. due to different flow rate in respect to the test one, different connections) and different radiator temperatures often occurs. Therefore, the actual thermal output should be calculated by the following relation:

$$\phi_{eff} = \phi \cdot F = \phi \cdot \left(F_{\Delta T} \cdot F_{con} \cdot F_{q_m} \cdot F_{in} \cdot F_{vr} \cdot F_P\right) \quad (8)$$

where F (dimensionless) is the overall correction factor, given by the product of the following specific correction factors: i) $F_{\Delta T}$ for the different fluid temperature, ii) F_{con} for the connections; iii) F_{q_m} for the average flow rate; iv) F_{in} for the installation of the radiator; v) F_{vr} for the painting of the radiator; vi) F_P for the atmospheric pressure.

The experimental analysis were carried out at the “Laboratorio Misure Ricerche Termotecniche (MRT)” of the Politecnico of Milan (for tests according to EN 442-1 and EN 442-2 in the reference conditions) and at the “Laboratorio di Misure Industriali (LAMI)” of the University of Cassino and Southern Lazio (for tests in operating conditions). MRT is head European Reference Laboratory for the definition of the procedures of CE Mark laboratories and operates according to EN 442 [11-14]. On the other hand, the LAMI test rig has been specifically designed to test radiators at operating conditions and it is made up of: i) a domestic heat generator (with a nominal power of 23.7 kW); ii) an auxiliary thermo-convector (for the thermal power dissipation and stabilization); a controlled aluminum frame allowing the vertical and horizontal adjustment of the radiator; iii) a direct heat meter; iv) an acquisition and data processing system. Tests were conducted employing commercial radiators, selected among the most used types in the last decades, removed from an existing heating plant.

The experimental campaign was aimed to analyze the thermal output deviation in the operating conditions with respect to the reference ones and in the evaluation of the consequences of such deviation on the heat allocation accuracy [15-17]. To this end authors designed the following test: i) on the field, radiators installed by 10-15 years; ii) in the laboratory, new and used radiators. The technical characteristics of investigated radiators are reported in Tab.1. The tests carried out were:

- analysis of deviation between the declared standard thermal output and the corresponding one estimated through the dimensional method;
- analysis of the influence of installation conditions (i.e. shelf, grid, niches, obstructions due to curtains, positioning);
- analysis of the influence of connections.

Table 1. Technical characteristics of the investigated radiators

Material	***Cast iron***	***Alluminum***
Tipology	Large culumns	Finned
Depth (mm)	145	96
N.elements	9 (reduced to 3 and 6)-	9
Height (mm)	890	879
Wheelbase (mm)	800	800
Lenght (mm)	60	80
Connections	---	G1
Water content (L)	0.99	0.60
Weight (kg)	9.27	2.13
Thermal power ϕ_L (W)	125.50 (ΔT 50K) - 161.77 (ΔT 60K)	184.42 (ΔT 50K) - 236.04 (ΔT 60K)
Exponent n	1.28243 (9 elem.) - 1.26662 (6 elem.) - 1.23768 (3 elem).	1.3535
$K_{m\ EN\ 442}$ (W/K)	0,8181	0.9252
$C_{UNI\ 10220}$ (W/m^3)	17000	28100

3. Results

3.1. Analysis of the standard thermal output

Before analyzing in detail the various installation effects, the authors tested the difference between the standard thermal output declared by the manufacturer (or otherwise determined by the EN 442) and the one estimated through the dimensional method. In case of aluminum radiator the deviation is approximately equal to 3.5%, while cast iron radiator presented a deviation of approximately the 13.5%.

3.2. Analysis for different installation conditions

In table 2 the on field measurements results of the installation conditions influence, for both the aluminum and cast iron radiators, are reported. In particular some common installation were analyzed as: i) shelf; ii) niches; iii) grids; iv) vertical and horizontal positioning; iv) obstructions due to curtains on the heating body. The major deviation between the actual thermal output and the standard one have been observed in the presence of a grid for both the analyzed radiators.

Table 2. Influence factors of the installation conditions on the effective thermal power.

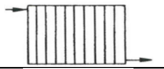
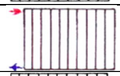
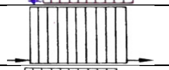
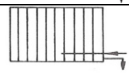
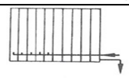
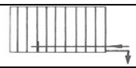
Installation type	*Cast iron*			*Aluminium*		
	wall distance, *cm*	floor distance, *cm*	Δφ%	wall distance, *cm*	floor distance, *cm*	Δϕ%
correct installation	6	11	0.00	2	10,5	0.00
Shelf	6	11	0.47	2	10,5	0.18
Niche	6	11	-1.83	2	10,5	-6.3
Grid	6	11	-16.2	2	10,5	-11
horizontal position	-	-	-	16	10,5	-0.5
vertical position	6	19	-0.29	16	19	2.96
	6	26	0.24	16	26,5	3.87
partial covering	-	-	-	16	10,5	-17.7

In the case of aluminum radiators, the partial coverage of the radiator causes a reduction of the actual thermal output of about 18% compared to the standard one.

3.3. Analysis for different connection

In table 3 the on field measurements results of the connections influence on the actual thermal output of the radiators are reported at high and low flow rates. In particular, the most common connections were analyzed, such as: i) mixed flow (inlet left high/outlet right low); ii) counter-current flow (inlet left high/ outlet left low); iii) cross-flow (inlet left low/outlet right low); iv) single pipe with short stemmed valve; v) single pipe with medium stemmed valve; vi) single pipe with long stemmed valve and nozzles; vii) single pipe with long stemmed valve and separator. The higher deviations between the actual thermal output and the standard one were observed with single pipe valve at low flow rate. In such conditions the deviations in respect to the reference optimal configuration can be also higher than 20%.

Table 3. Thermal power variation with the connection mode

Connection	*Scheme*	*High flow rate (about 200 kg/h)*		*Low flow rate (about 70 kg/h))*	
		$\phi_{\Delta T60}$, *W*	$\Delta\phi\%$	$\phi_{\Delta T60}$, *W*	$\Delta\phi\%$
A (Mixed flow)		1779	0.0%	1770	-0.5%
B (Counter-current flow)				1761	-1.0%
C (Crossflow)		1701	-4.4%	1552	-12.8%
D (single pipe with short stemmed valve)		1527	-14.2%		
E (Single pipe with medium stemmed valve)				1440	-19.1%
F (Single pipe with long stemmed valve and nozzles)		1628	-8.5%	1388	-22.0%
G (Single pipe with long stemmed valve and separator)		1727	-2.9%	1547	-13.0%

4. Conclusions

On the basis of measurements it can be evidenced that heating bodies thermal output strongly depends on typology and shape, operating conditions (average temperature, water flow rate, pressure) and installation (number of elements, installation position, connection type, presence of grids, shelf, niches or obstructions). The adoption of thermostatic valves and the improvement of building envelope and windows insulating performance determines a reduction of required thermal output from heating bodies. As a consequence, radiators operate at lower temperatures that results in an improved heating plant efficiency. Such operating condition is not taken into account by international standards for heat cost allocators, that refer to $\Delta T = 60$ K. The only exception is represented by the mean temperature difference between the heat transfer fluid and the environment, even though such temperature is sometimes not measured and the definition of the reference position is not a simple issue. As a consequence, required overall plant heating output can result underestimated and heat cost allocation can be unreliable. In particular, major issues are associated to:

- connection type adopted, that determines reduction up to about 15% (in the case of single pipe short-stemmed valve) and between 10% and 20% for flow rates of 30% of maximum value in the case of non-conventional connections (mixed flow or counter-flow);
- installation conditions that evidence a difference between operating and standard thermal output between 5% and 15%.

An argumentative aspect is that while the designer can take into account the above described aspects to correct the standard thermal output declared by the manufacturer in accordance to EN 442. In fact indirect heat accounting according to EN 834 and the UNI 10200 prescribe the adoption of the standard thermal output without any correction. As a consequence, since standard and operating conditions could be significant different, not negligible errors in heat cost allocation can occur.

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