A Comparative Analysis of Simplified Calculation Procedures for Assessing the Energy Losses of Heating Emission Systems

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Abstract

In the assessment of energy performance of buildings, the efficiency of technical building systems, especially those related to heating and cooling services, has a significant impact on the overall energy consumption. For this reason, accurately determining the performance of these systems is of utmost relevance.

Current simplified procedures for evaluating technical building systems lack complete validation, potentially leading to undesired inaccuracies in the results.

This paper analyses the existing simplified procedures provided by standards for assessing heat emission and control subsystems. It examines the procedure currently in use in Europe and presents a comparative analysis with more detailed procedures. Through a case study approach, the research explores several configurations of a representative residential space, considering factors such as climatic data, envelope properties, emission terminals, and control strategies. By addressing these aspects, this research contributes to enhancing the understanding of the effectiveness and reliability of simplified procedures for assessing the performance of technical building systems.

1. Introduction

One of the key factors influencing building energy performance is the efficiency of the heat emission system. For this reason, precise calculation methods to assess emission losses are required, taking into account their connection with control systems, building thermal inertia, user behaviour, and other boundary conditions. However, complexities in modelling these interconnected systems limit the widespread use of highly accurate procedures. Hence, there is a need for approaches that balance simplicity and accuracy in assessment methods.

Following the publication of Mandate M/480 EN (European Commission, 2010), efforts were made to enhance the building energy performance assessment by updating the procedures to evaluate the efficiency of the heating and cooling systems. Nevertheless, emission terminals and control subsystems still require systematic revision. Standards like EN 15316-2 (CEN, 2017) and ISO 52031 (ISO, 2020), currently lack comprehensive validation. The application of these procedures is also insufficiently flexible, since they often rely on tabulated values, overlooking the actual emission terminal performance. Other existing calculation methods oversimplify the complexities involved in modelling the emission heat losses, often neglecting some physical phenomena related to the performance of these systems (e.g., non-uniform temperature distribution indoors).

Emission losses usually account for spatial temperature variations and component overheating. Stratification arises from different air temperatures across a space, influenced by heat exchanges between air and surrounding objects. Overheating results from excessive heat exchange from internal or external sources, notably affecting long-wave heat transfer. Factors influencing these losses are related to technical building system components and the building itself.

Comprehensive studies on enhancing simplified procedures for evaluating the thermal energy loss of emission and control systems are lacking in more recent research work. Initial efforts by Maivel et al. (2014) were put into the assessment of the hydronic emission system efficiency, revealing significant differences compared to detailed calculation methods, especially in low-temperature sys-

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tems. Maivel et al. (2015) also validated standard procedures for radiators and floor heating systems, emphasizing the interconnectedness of building, emission, and control systems on efficiency. Further studies by Maivel et al. (2018) explored the influence of stratification on emission efficiency, confirming methodological differences and highlighting the role of control strategies. Seifert et al. (2016) examined simplified procedures for radiators and control valves, assessing efficiency and accuracy through empirical analyses. Võsa et al. (2020) addressed the lack of standardized procedures, proposing an alternative method for analysing parameters in the EN 15316-2 (CEN, 2017) procedure.

1.1 Aim of the Research

This research aims to address existing knowledge gaps through the analysis of simplified calculation procedures for heat emitter losses, with the perspective of complete validation. While previous works, such as Bianco Mauthe Degerfeld et al. (2024), have analysed the effect of different heat emission terminals, this work focuses more on the influence of various control strategies.

The study involves a comparative analysis of energy losses in heating emitters under different control strategies, using simplified methods. A case study approach was employed, analysing a typical residential building in different configurations. Various Italian climates and envelope insulation levels were considered. Two types of emission terminals were analysed: radiators and low-temperature radiant systems. The effect of different control strategies (i.e., on/off and proportional) was also assessed to study the relevance of the control system in determining heat losses.

The simplified procedures analysed were implemented and simulated in EnergyPlus. The results were compared and evaluated based on the thermal output of the emission system, normalised over the heated floor area. Additionally, the influence of the calculation time-step was considered by performing simulations with both hourly and sub-hourly time-steps, to assess the relevance of more refined calculation intervals in evaluating the energy losses of the heating emission terminals.

Statistical indicators were used to compare the results and present yearly aggregated outputs.

2. Methods

In the following sections, the simplified and detailed procedures deployed in this work are presented. The control strategies coupled with the emission systems are described as well.

2.1 Standard Procedure

The analysed simplified procedure is outlined in EN 15316-2 (CEN, 2017) and ISO 52031 (ISO, 2020). The methodology determines the energy loss due to the heat emission and control subsystems by modifying the indoor temperature. The set-point temperature is increased or decreased (in the case of cooling systems), depending on an analysis of the system properties. The consequent variation in heat exchange is considered equal to the heat loss of the analysed subsystems. This procedure is mainly performed through a qualitative assessment of the system properties. If detailed measured system information is available, this step can be performed with a higher level of detail. However, such data are often unavailable, so a tabular approach can be applied. Equations 1 to 3 present the procedure to determine the temperature variation.

$$\Delta\theta_{\mathrm{int,inc}} = \Delta\theta_{\mathrm{hydr}} + \Delta\theta_{\mathrm{emt,syst}} + \Delta\theta_{\mathrm{ctr,syst}} \tag{1}$$

$$\Delta\theta_{\mathrm{emt,syst}} = \Delta\theta_{\mathrm{str}} + \Delta\theta_{\mathrm{emb}} + \Delta\theta_{\mathrm{rad}} + \Delta\theta_{\mathrm{im,emt}} \tag{2}$$

$$\Delta\theta_{\mathrm{ctr,syst}} = \Delta\theta_{\mathrm{ctr}} + \Delta\theta_{\mathrm{im,ctr}} + \Delta\theta_{\mathrm{roomout}} \tag{3}$$

In Equations 1 to 3, $\Delta\theta_{\mathrm{int,inc}}$ is the equivalent internal temperature difference while all the other terms represent temperature variations. Specifically, $\Delta\theta_{\mathrm{emt,syst}}$ for the emission system, $\Delta\theta_{\mathrm{str}}$ for the air stratification, $\Delta\theta_{\mathrm{emb}}$ for embedded emitters, $\Delta\theta_{\mathrm{rad}}$ for the type of emission system, $\Delta\theta_{\mathrm{im}}$ for intermittent operation, $\Delta\theta_{\mathrm{ctr,syst}}$ for the control system, $\Delta\theta_{\mathrm{ctr}}$ for the control variation, $\Delta\theta_{\mathrm{roomout}}$ for the space automation of the system, and $\Delta\theta_{\mathrm{hydr}}$ for the hydraulic system balancing.

2.2 Detailed Procedure

Two detailed procedures for energy performance assessment were analysed: one for radiators and another for low-temperature radiant systems. These procedures are commonly integrated into detailed dynamic building energy assessment tools like EnergyPlus.

The first procedure, designed for radiators and convectors, accounts for both the convective and radiative heat transfer. The convective part and the radiative fraction on people and internal items with very low thermal capacity directly affect the air temperature, while the radiative fraction on the building components increases their surface temperature. Although this procedure accurately models the heat transfer between the room and the radiator, it neglects the effects on air stratification and emitter inertia.

The second procedure, designed for low-temperature radiant systems, evaluates the position of the piping within the building component through which the heat transfer fluid flows. The static and dynamic properties of the fluid and piping are assessed to define the temperature inside the component for the energy balance. Consequently, thermal inertia is properly considered in the performance assessment.

2.3 Control Strategies

In this work, two control strategies were implemented to analyse their influence on different calculation procedures: on/off control and proportional control.

The on/off control, also known as two-position control, operates in two states: fully open or fully closed. Typically, a deadband is employed. The system switches position when the lower or higher limit of the deadband is crossed. However, due to the system inertia, the latency in response may cause the measured parameter to exceed the deadband limits, causing overshoot and undershoot effects, respectively.

The proportional strategy involves a control deadband applied to a measurable variable. Depending on the measurement, an actuator modulates the control variable through a linear correlation., allowing for more precise control compared to the on/off strategy.

In control strategies applied to heat emission systems, the control variable is usually the flow rate of the heat transfer fluid. For hydronic systems, such as radiators, it involves water flow rate, while air flow rate is the control variable in air systems, such as VAVs.

3. Application

3.1 Case Study Description

The case study was based on the representative European room outlined in Annex C of ISO 52031 (ISO, 2020). This room is a residential space with a net floor area of 20 m² and a net volume of 54 m³. Three walls, the floor, and the ceiling are adjacent to internal spaces, and the heat exchange through these components is neglected. The south-oriented wall, adjacent to the external environment, contains two windows with a total area of 3 m². The opaque enclosure consists of brick walls with plaster finishing, and concrete slabs with parquetry. The envelope's main thermal properties are detailed in section 3.2.

The profiles of internal gains, shown in Fig. 1, are defined according to EN 16798-1:2019 (CEN, 2019).

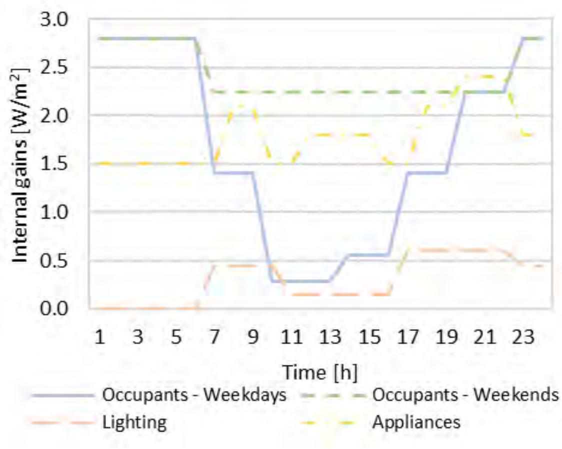

Fig. 1 – Profile of the internal gains by source type, normalised over the net floor area

Natural ventilation, with an air change rate of 1.4 h^{-1}, is considered according to the method based on the perceived air quality for residential spaces (CEN, 2019).

The building includes lighting, domestic hot water, and heating systems. For the purposes of this work, only the heating system is analysed in detail. It comprises a gas-condensing boiler for generation, well-insulated pipes for distribution, and either a radiator or a low-temperature radiant floor for emission. The building is assumed to be heated continuously during winter, with an operative temperature set-point of 20 °C.

3.2 Modelling Options

Different options were analysed and compared. As presented in Table 1, five aspects were considered: the calculation procedure, the climatic zone, the period of construction, the emission system, and the control strategy.

Table 1 – Calculation variants and codes

Aspect	Variant	Code
Calculation procedure	Standard	S
	Detailed	E
Climatic zone	Milan	M1
	Palermo	M2
Construction period	Old	I1
	New	I2
Heat emission terminal	Radiator	R
	Radiant floor	L
Control strategy	On/Off	C1
	Proportional	C2

The variants are detailed as follows:

- Calculation procedures: As described in sections 2.1 and 2.2;
- Climatic zones: Typical meteorological years (TMY) were deployed. Two cities, Milan (2404 HDD) and Palermo (751 HDD) were considered;
- Construction periods: The building labelled as "Old" was derived directly from standard values (ISO, 2020). The properties of the building labelled as "New" were determined from the "Old" building by increasing, if necessary, the thermal performance of the envelope components. The deployed values are presented in Table 2. The maximum thermal transmittance value (labelled as "max") was derived from the current Italian regulations (Italian Republic, 2015);
- Heat emission terminals: As described in sections 2.1 and 2.2;
- Control strategies: On/Off and proportional were considered. For both, a deadband of 1 °C was deployed (±0.5 °C from the temperature set-point).

Table 2 – Envelope properties

Component	Code	U (W m^{-2} K^{-1})
External wall	M1_I1	0.91
	M1_max	0.26
	M1_I2	0.26
	M2_I1	0.91
	M2_max	0.43
	M2_I2	0,43
Window	M1_I1	2.24
	M1_max	1.40
	M1_I2	1.40
	M2_I1	2.24
	M2_max	3.00
	M2_I2	2.24

Some consistency options were applied to the simulations. In particular, for the simplified procedure, only the terms that refer to the type of emission system, the embedded component, and the control variation were analysed, while the others (i.e., the air stratification, the intermittent operation, the space automation, and the hydraulic balancing) were neglected.

3.3 Comparison Procedure

The results of the different procedures were analysed in terms of the input thermal energy to the emission system normalised over the net floor area. The 32 simulations are presented in pairs, differing only in the calculation procedure, while the climatic data, construction period, the type of heat emission terminal, and the control strategy are fixed.
The 16 pairs are then analysed using two statistical indices, i.e., the mean bias error (*MBE*) and the coefficient of variation of the root mean square error (cv*RMSE*). The detailed procedure is used as the reference set of data to normalise the *MBE* and the cv*RMSE*.

4. Results and Discussion

This section presents the results of the procedures outlined earlier. Fig. 2 to 4 display the monthly actual energy needs absolute differences from the simplified and detailed methods for radiator and radiant floor heating in Milan and Palermo.

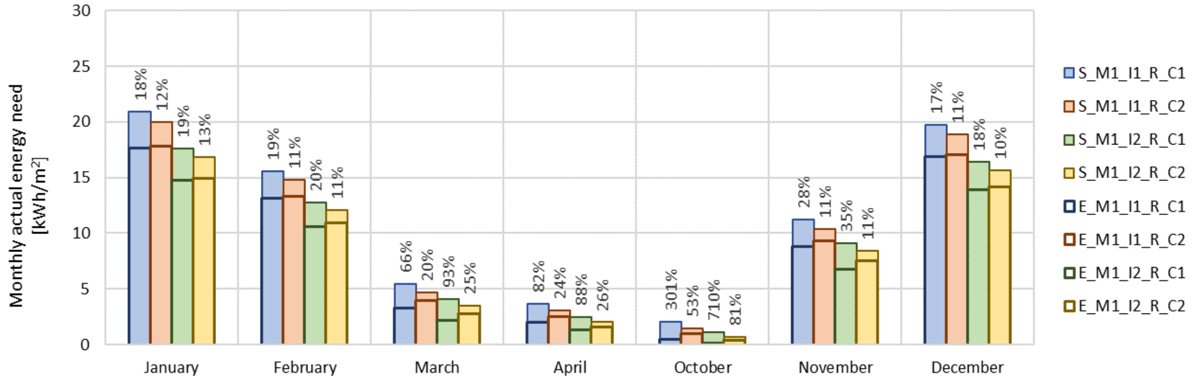

Fig. 2 – Monthly actual energy needs normalised over the net floor area for the radiator in the city of Milan

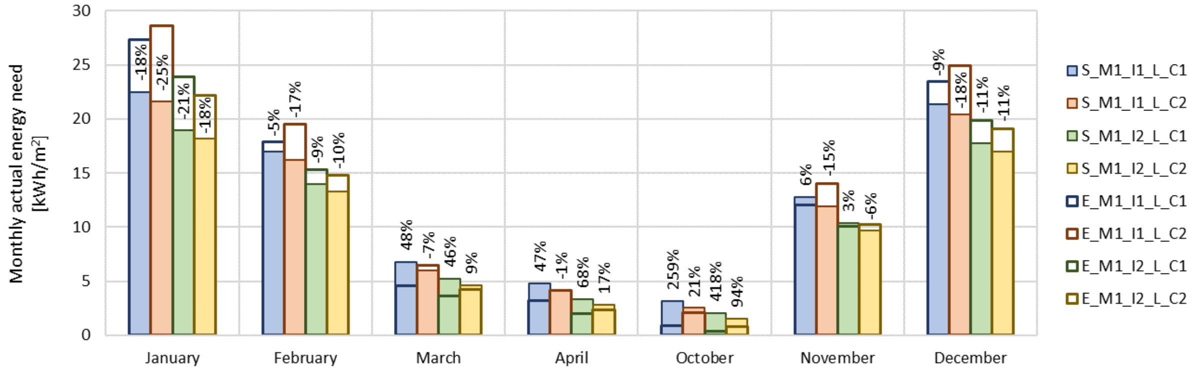

Fig. 3 – Monthly actual energy needs normalised over the net floor area for the radiant floor in the city of Milan

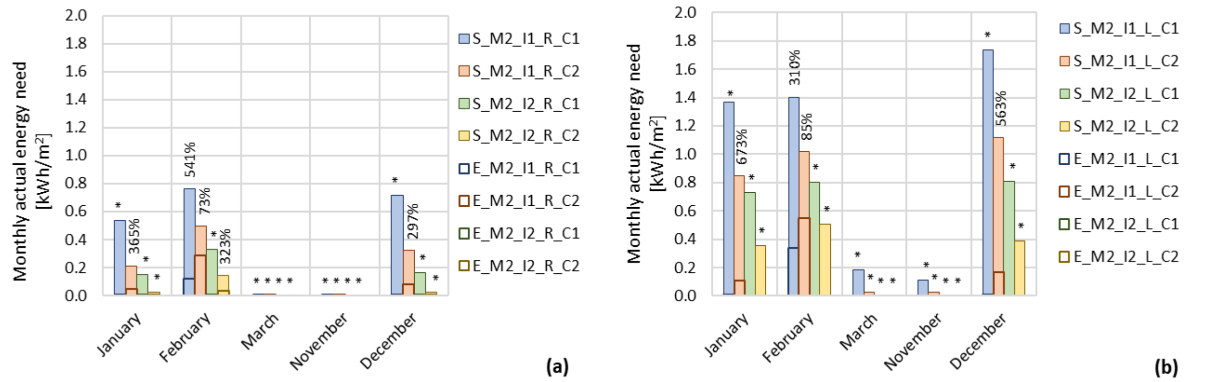

Fig. 4 – Monthly actual energy needs normalised over the net floor area for the radiator (a) and the radiant floor (b) in the city of Palermo, ("*" in case of monthly results close to zero)

The months without heating energy need were excluded from the graphical representation.
For each month and variant, a label with the difference between the simplified and detailed method results normalised over the detailed method result is presented. In the case one or both monthly results are close to or equal to zero, a "*" is indicated on the label.
An initial analysis of the results of the 16 simulations pairs reveals significant differences between the two methods.
The results for the city of Milan highlight similarities in the trends when the radiator is deployed as the emission terminal, as shown in Fig. 2. On the other hand, the results of the simulations carried out deploying the radiant floor heating system present higher differences, as illustrated in Fig. 3. This may be caused by the inefficacy of the standard procedure in reproducing the energy need fluctuations due to the system inertia.
The results for the city of Palermo, presented in Fig. 4, exhibit a significant variation in the results. The detailed procedure presents in almost all the cases an actual energy need equal to or close to zero. For this reason, the percentage variation of the differences from the detailed procedure results presents values over 300 % in almost every month. This is mainly caused by the differences in the two procedures.
The detailed procedures assess the system efficiency changes, a task that can only be performed in time-steps where the space presents an energy need for heating (or cooling). In contrast, the standard procedure, by increasing the set-point temperature of the building, generates two effects. Firstly, it increases the actual energy needs to assess the effect of the emission and control subsystems, as intended. Secondly, it generates energy needs for time-steps where the energy need should be zero.
While this effect may impact the results when energy needs are not null for most time-steps in an insignificant way, it can significantly affect low-energy buildings.
The analysis of the calculated statistical indicators, presented in Table 3 further highlights the difference between the two analysed cities and the two emission terminals presented before.
The results also show that the cv*RMSE* is lower when the proportional control is applied compared to the cases where the on/off control is used.
This is probably related to the fact that the proportional control gives a more stable output to the emission system, reducing the fluctuations and the errors.

Table 3 – Statistical indicators

Case	***MBE* [%]**	**cv*RMSE* [%]**
M1_I1_R_C1	26	36
M1_I1_R_C2	13	16
M1_I1_L_C1	-1	233
M1_I1_L_C2	-17	42
M1_I2_R_C1	29	43
M1_I2_R_C2	13	17
M1_I2_L_C1	-4	151
M1_I2_L_C2	-9	23
M2_I1_R_C1	1596	1124
M2_I1_R_C2	150	400
M2_I1_L_C1	1306	566
M2_I1_L_C2	267	443
M2_I2_R_C1	-	-
M2_I2_R_C2	452	820
M2_I2_L_C1	-	-
M2_I2_L_C2	-	-

5. Conclusion

In this paper, a comparison between different procedures to assess the energy losses of the emission and control subsystems was carried out.
Both simplified and detailed procedures were analysed and implemented in a dynamic simulation tool, EnergyPlus, to standardise the calculation procedure enabling the comparison.

A case study approach was adopted, varying climatic data, envelope properties, emission terminals, and heat control strategies within a representative residential space.
The results revealed notable differences between the procedures. In particular, the simplified procedure yielded higher input energy to the emission terminal for radiators, and lower energy consumption for floor heating systems when considering yearly results.
Moreover, the analysis of control systems showed significant monthly differences in energy consumption. Proportional control showed better coherence between the results of the analysed procedures compared to the on/off control.
The results underscored the unreliability of the simplified method in assessing energy consumption for buildings with low energy needs, particularly evident in warm climates. However, this limitation is not limited to warm climates, as there is an increasing number of zero energy buildings across all climates. Mandated by current European Directives, will be impacted.
Future studies will explore phenomena such as air stratification, not addressed in this study, to further enhance understanding of overall building energy performance.

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Nomenclature

Symbols

cv*RMSE*	coefficient of variation of the root mean square error (%)
MBE	mean bias error (%)
U	thermal transmittance (W m^{-2} K^{-1})
θ	temperature (°C)

Subscripts/Superscripts

ctr	control
emb	embedded
emt	emitter
hydr	hydraulic balancing
im	intermittent
inc	increased
int	initial
rad	radiant
roomout	room automation
str	stratification
syst	system

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