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Hourly dynamic and monthly semi-stationary calculation methods applied to nZEBs: Impacts on energy and comfort

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Abstract. The EU Directive 2010/31 abstained from prescribing harmonized and strict requirements for nearly Zero Energy Buildings (nZEBs), to provide EU countries flexibility and room for maneuver in setting national targets, in view of the impact of local climatic conditions and specific territorial and socio-economical features on heating and cooling needs. Benchmarks are usually provided in terms of primary energy needs, however the definition of accurate calculation methodologies, notably as regards the cooling share, is a rather challenging task. Nonetheless, its accomplishment is cardinal to countries, like Mediterranean ones, where the building performance is mostly dictated by summertime sensitivities. This paper presents a cutting-edge approach to nZEB performance analysis: the monthly quasi steady-state (EN 13790 as implemented in Italian UNI/TS 11300) and hourly dynamic calculation methods (developed under the standard UNI EN ISO 52016-1:2018) are compared, with due attention to the cooling energy consumption, to spot pros and cons of a finer temporal discretization. Potential nZEB design alternatives in three different Italian climatic zones are contemplated and used to confront the effectiveness of the above procedures.

1. Introduction

Considering the tightening of global warming and the increasing occurrence of summer heat waves even in temperate climatic contexts, it is essential to tackle the design of a nearly Zero Energy Building (nZEB), that maintains high cooling performance and preserves summer comfort even under abnormal conditions [1], [2]. Despite the awareness of the international scientific community, the actions implemented by the national regulatory instruments, in response to the European Directive 2010/31/EU (EPBD recast) [3], merely aim at verifying envelope insulation and solar shadings compliance with prescribed performance indicators [4], [5], disregarding the higher degree of dynamism in summertime. The quasi steady-state calculation method of EN ISO 13790:2008 [6], gold standard for almost all EU countries today, is effective for the calculation of heating needs, but presents severe limitations in the case of cooling energy [7-12]. Also, the tools for dynamic calculation (e.g. TRNSYS and EnergyPlus) are sophisticated and still poorly used by designers, due to the considerable commitment of time and resources. In this context, newly introduced EN ISO 52016-1:2017 [13] (replacing EN ISO 13790) specifies calculation methods for the assessment of buildings energy need for heating and cooling, providing a novel simplified hourly method alongside the monthly method. The dynamic hourly method offers opportunities of great interest [14]. In fact, it is able to deliver more accurate results, without computational overload [15]. In EU countries this regulatory evolution entails the need to revise the current procedure for calculating heating and cooling needs, also in relation to nZEB.



This article reports the comparison between the results obtained, in terms of heating and cooling needs, from the assessment of the performance of a nZEB building in three different climatic zones, using the monthly quasi steady-state and hourly dynamic calculation methods. Section 2 shows the main innovations and calculation procedures introduced by UNI EN ISO 52016-1:2018, as implemented in the Italian context. Section 3 describes the selected case-study nZEB, while the assessment results are reported and discussed in Section 4.

2. The hourly method of standard UNI EN ISO 52016-1:2018

ISO 52016-1 standard defines the procedures for calculating buildings energy need for heating and cooling (on an hourly or a monthly basis), as well as the calculation method of internal temperatures and sensible and latent thermal load (on an hourly basis). The calculation algorithm returns, for each thermal zone, the hourly indoor air temperature ($^{\circ}\text{C}$), internal mean radiant temperature ($^{\circ}\text{C}$), internal operative temperature ($^{\circ}\text{C}$) and the actual heating or cooling load, which is fundamental for building energy assessment.

For the application of the hourly method the climatic parameters and the user profiles must be defined on an hourly basis. To determine the temperatures of the building structure layers (nodes) at each time step, the calculation algorithm requires the resolution of a system of energy balance equations carried out both at zonal and building component levels. Unlike the monthly method of EN ISO 13790, where the whole thermal zone is reduced to a single equivalent resistance-capacity network, in EN ISO 52016-1 each construction element is modelled as a series of nodes. Regarding the opaque components, there are different procedures for spatial discretization. The standard method reported in Annex B of EN ISO 52016-1 relies on four thermal resistances and on a number of thermal capacities depending on the position of the mass, regardless of the actual number of constructive layers. In Italy, the CTI (Italian Thermotechnical committee) [16] is discussing the implementation of a national annex to EN ISO 52016-1, including a more detailed discretisation procedure, based on a variable number of nodes depending on the actual number of layers of the structure and on thermal parameters of each layer. This will be able to take greater account of the real dynamic performance of massive construction solutions typical of the national building context [17].

3. The application to a nZEB case-study

The case-study is a 3-floor residential nZEB, composed by six apartments (figure 1). Geometry and construction elements reflect the Italian technological landscape: the building is a steel-reinforced concrete frame, with pored bricks cladding and external insulation coating. The flat, non-walkable roof is built with insulated and impermeable hollow-core concrete structure.

In the first instance, the energy performance is assessed in three different climatic zones according to the legislation in force (the monthly quasi steady-state method described in UNI/TS 11300-1/2) to verify the compliance with the nZEB requirements for the Italian territory and determine the optimal configuration per each location. Secondly, the hourly dynamic calculation method (ISO 52016-1) is applied to compute the useful energy demand and the operative temperature on hourly basis.

At this junction, the analysis focuses on the thermal behaviour of the top floor apartment, due East (red marked in the floor plan in figure 1), whose geometrical specifications are listed in Table 1. The AC system is set to maintain the indoor temperature at 20°C in winter and 26°C in summer. Therefore, the method returns the energy consumption to track the above setpoints.

To draw a national-scale characterization, three Italian cities, representative of different climatic conditions are selected: Palermo, Rome and Milan. Hourly climatic data were recently published by the CTI and reported in UNI 10349-1:2016 as monthly means. Climate-specific design solutions are adopted to guarantee nZEB features in each location (e.g. by adjusting the insulation thickness and the shading systems). Horizontal overhangs are used on south-exposed facades.

Italian technical specifications from UNI/TS 11300 constitute the input to all the three models, based on the following assumptions: usage profiles 24/24h, internal heat gains rate at 5.72 W/m^2 and

ventilation rate at 0.5 h^{-1} . Table 2 recaps the thermal properties of opaque elements for each configuration.

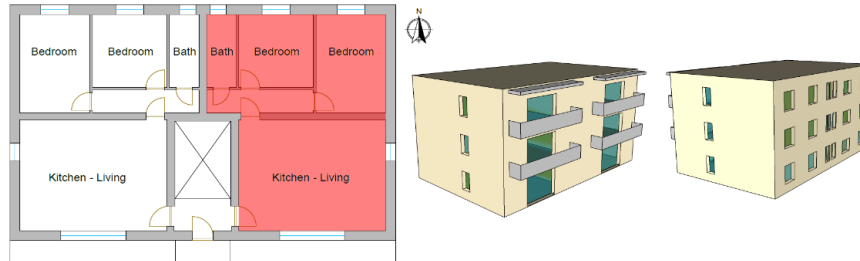


Figure 1. Building plan, South-West view and North-East view

Table 1. Geometrical features

	Unit	Single flat
Net floor area	[m ²]	63.73
Net height	[m]	2.70
Net volume	[m ³]	172.07

Table 2. Opaque envelope thermophysical parameters

Thermophysical parameters	Unit	Milan	Rome	Palermo	
External wall	Thermal transmittance (U)	[W m ⁻² K ⁻¹]	0.26	0.31	0.41
	Periodic thermal transmittance (Yie)	[W m ⁻² K ⁻¹]	0.01	0.01	0.04
	Time shift (Δt)	[h]	17.99	17.22	16.79
Stairwell wall	Thermal transmittance (U)	[W m ⁻² K ⁻¹]	0.24	0.29	0.40
	Periodic thermal transmittance (Yie)	[W m ⁻² K ⁻¹]	0.04	0.05	0.03
	Time shift (Δt)	[h]	13.79	13.50	17.58
Ground floor	Thermal transmittance (U)	[W m ⁻² K ⁻¹]	0.26	0.30	0.46
	Periodic thermal transmittance (Yie)	[W m ⁻² K ⁻¹]	0.03	0.04	0.08
	Time shift (Δt)	[h]	13.22	12.98	12.12
Roof	Thermal transmittance (U)	[W m ⁻² K ⁻¹]	0.22	0.27	0.35
	Periodic thermal transmittance (Yie)	[W m ⁻² K ⁻¹]	0.03	0.04	0.05
	Time shift (Δt)	[h]	11.89	11.53	11.20

Although simplified, the hourly dynamic method requires more input parameters compared to the monthly method, notably in terms of climatic data and occupancy patterns, as highlighted in Table 3.

Table 3. Main differences on input data between the monthly quasi steady-state and the hourly dynamic calculation methods

	UNI/TS 11300	UNI EN ISO 52016-1
Weather data	Differentiated by province in ISO 10349-1:2016.	CTI database, but for solar radiation on vertical surfaces, to be computed according to UNI 10349-1:2016.
Internal gain profiles	Single value, defined in function of the intended use.	Hourly utilization profiles.
Ventilation rate profiles	Single value, defined in function of the intended use.	Hourly utilization profiles.
Power supplied profiles	Useful energy demand computed disregarding the technical system characteristics.	Hourly power supplied by the technical systems required to compute the zonal energy budget.

4. Results

The results of the monthly quasi steady-state method are summarized in Table 4.

Table 4. Standard nZEBs energy assessment for the considered case studies

	Unit	Milan	Rome	Palermo
Energy performance indicator for heating ($EP_{H,nd}$)	[kWh m ⁻²]	14.49	4.14	7.55
Energy performance indicator for cooling ($EP_{C,nd}$)	[kWh m ⁻²]	24.63	34.74	35.55
Global average heat transfer coefficient ($H't$)	[W m ⁻² K ⁻¹]	0.32	0.37	0.58
Equivalent solar area/Floor area ($A_{sol,est}/A_{sup,utile}$)	-	0.02	0.02	0.01

Figure 2 shows the daily energy demand, computed through the hourly dynamic method for the reference nZEBs in Milan, Rome and Palermo. The method guarantees a higher level of detail, which helps spotting the dynamic variation of the building energy performance. The colored areas in the figure allow immediate comparison of the energy consumption throughout the year: expectedly given the external air temperature trends, Palermo's nZEB would consume less than Milan's nZEB in summertime, and reverse the roles in wintertime. The annual heating/cooling consumptions would hit 1486/1541 kWh/y in Milan, 974/1897 kWh/y in Rome and 543/2143kWh/y in Palermo.

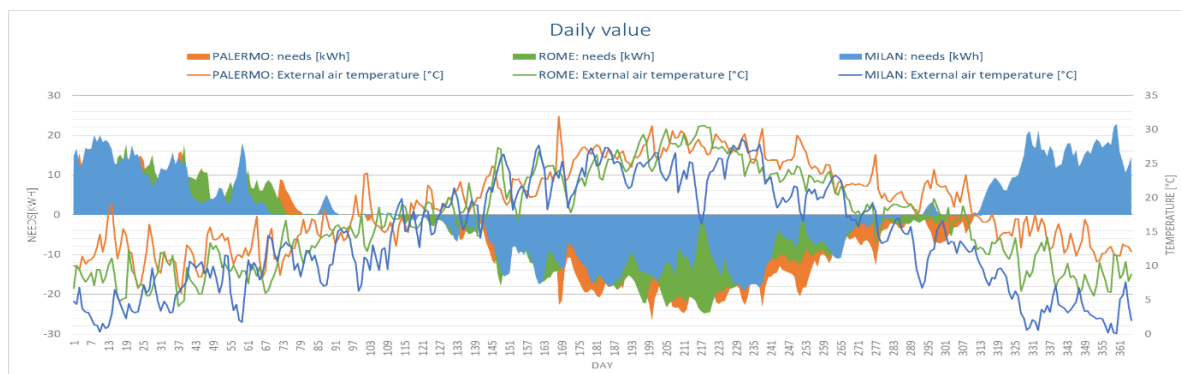


Figure 2. Daily average of hourly load and external air temperature (UNI EN ISO 52016-1)

Figure 3 compares the results of the two calculation methods in terms of monthly energy needs for heating and cooling, obtained in the three climatic zones under test. In wintertime, the monthly, semi-stationary method tends to underestimate the useful energy in Milan and Rome (up to -100%) and to overestimate it in Palermo (up to +59%). Conversely, in summertime, the discrepancy narrows down and greater accordance is achieved (differences no higher than 11%).

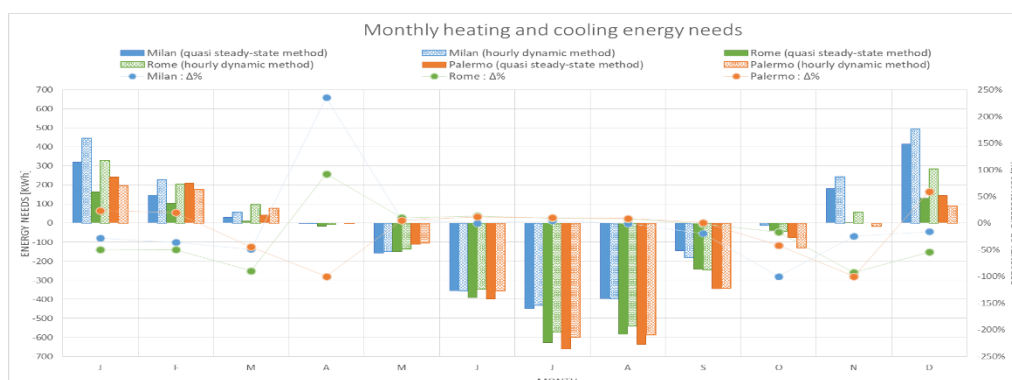


Figure 3. Monthly heating and cooling energy needs obtained with the monthly quasi steady-state method (UNI/TS 11300) and the hourly dynamic method (UNI EN ISO 52016-1), and their percentage differences ($\Delta\%$)

Figure 4 displays average and standard deviation of the hourly energy needs, computed in the three climatic zones on monthly basis by means of the hourly dynamic method. These results are contrasted with the mean hourly needs obtained by dividing the monthly total by the number of hours per each month. Apparently, although the results look similar in terms on monthly means, there exist significant dispersion in terms of hourly data, notably during the cooling season.

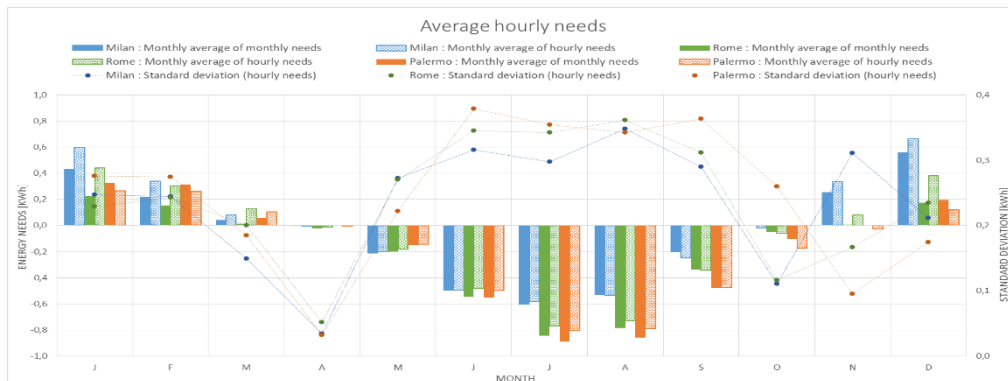


Figure 4. Mean and standard deviation of the hourly needs obtained with the hourly dynamic method compared to the average hourly values obtained with the monthly quasi steady-state method

Furthermore, the hourly method includes the calculation of the operative temperature for each thermal zone. Thus, it is possible to compute the following comfort ranges in accordance with EN 15251 [18] thresholds: high level of expectation (Cat. I), normal level of expectation (Cat. II), moderate level of expectation (Cat. III). Figure 5 shows how the discomfort hours tend to decrease from Milan to Rome and from Rome to Palermo. Discomfort mostly occurs because of operative temperatures below the comfort lower limit for the three above-mentioned categories.

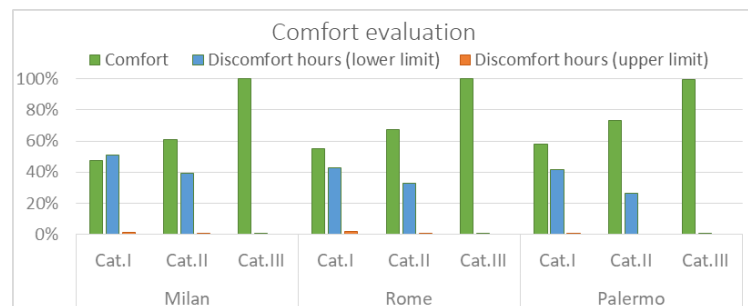


Figure 5. Comfort evaluation

5. Conclusions

In Italy, the current legislation on how to reduce the energy consumption in summertime still lacks a cohesive and detailed approach.

The monthly quasi steady-state method described in UNI/TS 11300-1/2 (transposition of European ISO 13790:2008) fails at accurately depicting the dynamic changes of boundary conditions and utilization profiles, as well as of the building inertial response.

EN ISO 52016-1 suggests a simplified hourly method with a potential in terms of accuracy and insight into the thermal behavior of buildings, which could turn out especially useful in the design of nZEB solutions.

The finer time discretization allows to examine the real energy needs and comfort levels, by recalculating the set of input parameters hour by hour at the expense of a greater number of input parameters (e.g. utilization schedules, internal gains, ventilation profiles and plants' power). Such detailed results could pave the way for a more rigorous optimization of solar shadings and HVACs size

and control logic, of which cooling-dominated climates would especially benefit. The dynamic hourly method does not imply significant extra computational load and could be thus be utilized for simplified energy audit and diagnosis.

The scientific debate on input parameterization is still ongoing. Thus, this study is a first step and will proceed along with the deepening and consolidation of the method. Additionally, further verification will be conducted by comparison with dynamic analysis software (e.g. TRNSYS or EnergyPlus).

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