Hourly-Simplified Calculation to Identify Cost-Optimal Energy Performance Requirements for the Italian Building Stock

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Abstract

The 2010/31/EU Directive established a comparative methodology framework to determine minimum energy performance requirements based on a cost-optimal approach. This research investigates the cost-optimal outcomes resulting from the application of the monthly quasi-steady state method (UNI/TS 11300-1) and the simplified hourly dynamic model (EN ISO 52016-1), both aimed at determining the thermal energy needs for space heating and cooling. The technical building systems have been modelled by means of a monthly steady-state method, in agreement with the UNI/TS 11300 series. The global cost has been calculated from a financial perspective according to EN 15459-1. The proposed methodology has been applied to two buildings that differ in their climatic zone, construction period, and intended use. For this purpose, a single-family house located in Palermo and an office building sited in Milan have been assessed. To investigate the deviations between the two energy models, the results in terms of packages of energy efficiency measures and global cost have been compared.

1. Introduction

1.1 The Comparative Methodology Framework and the *EP* Assessment

The Commission Delegated Regulation No. 244/2012 (European Commission, 2012a), which supplements European Directive 2010/31/EU (European Commission, 2010a), specifies a comparative methodology framework and prescribes Member States to define minimum energy performance requirements for buildings to achieve “cost-optimal levels”, i.e., the lowest global cost (*GC*) during the building lifecycle. Moreover, the European Directive requires the Member States to update the applied methodology regularly. The Guidelines accompanying Commission Delegated Regulation No. 244/2012 (European Commission, 2012b) established three different applicable calculation methods to determine the building energy needs: monthly quasi-steady state, simple hourly, or fully dynamic approach. In Italy, the deployed comparative methodology, described by Corrado et al. (2018), provides for performing the calculations through a monthly quasi-steady state method, according to the UNI/TS 11300 series (UNI, 2010-2019).

Recently, the mandate of the European Commission M480 (European Commission, 2010b), aimed at developing a new harmonized package of EPB directives, has conceived the EN ISO 52016-1 standard (CEN, 2017b). Italy is finalizing its National Annex (NA) of EN ISO 52016-1 (CTI, 2021), providing some main improvements that are related to: a) a new discretization approach of opaque building components (Mazzarella et al., 2020); b) a more accurate method to determine the solar heat gains and the longwave radiation heat exchange with the sky vault; c) the introduction of a weighting factor for the *g*-value calculation that accounts for incident angle dependency on direct and diffuse solar irradiance.

1.2 Aim of the Research

This work is part of a study carried out in collaboration with the Italian National Agency for New Technologies, Energy and Sustainable Economic

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Development (ENEA; Corrado et al., 2021); it investigates the employment of the simplified dynamic hourly model, introduced by EN ISO 52016-1, for determining the minimum energy performance requirements to achieve the cost-optimal level. For this work, two representative case studies (a single-family house located in Palermo and an office building sited in Milan) have been selected between twenty-six buildings and have been simulated to upload the comparative methodology. These results have been compared, in terms of the optimal set of energy efficiency measures (EEMs) and global cost, with those derived from the application of the monthly quasi-steady state method, carried out in accordance with the UNI/TS 11300-1 (UNI, 2014) calculation procedures.

2. Methodology

The EPBD recast establishes the comparative methodology framework to set out the minimum energy performance requirements for new buildings and existing buildings undergoing a major renovation. This approach requires Member States to:

a) identify an adequate number of real and/or 'virtual' residential and non-residential reference buildings, representative of the national building stock,
b) define energy efficiency measures for the refurbishment of the building envelope and the technical building systems for each reference building, also detecting technologies that exploit renewable energy sources,
c) calculate the primary energy demand deriving from the application of different packages of energy efficiency measures for each identified reference building,
d) calculate the global cost associated with the different building energy renovation scenarios,
e) derive the cost-optimal level for each reference building that minimises the global cost value.

2.1 Thermal Energy Needs Calculation Models

The calculation tool used in Corrado et al. (2018) has been updated for the sake of the present study to determine the thermal energy needs for space heating and cooling according to the EN ISO 52016-1 simplified hourly method (Corrado et al., 2021). For consistency with the quasi-steady state UNI/TS 11300-1 calculation method, some of the improved calculation options introduced by the Italian NA have been implemented, namely the hourly variations of the sky temperature and of the total solar energy transmittance of the glazed components. In the NA, the sky temperature is determined by means of the formulation presented in UNI/TS 11300-1, and it depends on the external vapor pressure. Moreover, the solar gains through windows are determined with a weighting factor for the *g*-value. The correction factor is formulated as a function of the solar angle, exposure, and glazing type. While in the quasi-steady method, the values are determined for each month through a tabular approach, in the Italian NA the properties are defined on an hourly basis.

2.2 The Cost-Optimal Approach

The cost-optimization procedure employed in this work is a single-objective optimization approach that applies discrete energy efficiency options (EEOs) one at a time to obtain a new partial optimized building for each step of the calculation. The full procedure is described in Corrado et al. (2014) and is based on the methodology proposed by Christensen et al. (2006). In particular, the identification of the cost-optimal level has been performed by applying at the same time more EEMs in an iterative procedure, to exploit the synergy effects of different measures. For each step of the calculation, the algorithm identifies a new renovation scenario, associated with a combination of EEMs, and calculates both the primary energy demand and the global cost. If the subsequent package of energy efficiency measures results in a lower *GC*, then the procedure sets a new partial optimum. The optimization proceeds until the package of EEMs that determines the lowest global cost is found.

Starting from a reference set of EEMs, the optimization procedure will test the different EEOs until the energy efficiency package of measures that guarantees the minimum global cost is found.

The energy efficiencies of the technical building subsystems have been evaluated considering the UNI/TS 11300 series monthly steady-state method. The investment costs of EEMs have been derived from DEI (2017). Then, the global cost has been calculated according to EN 15459-1 (CEN, 2017a), considering a lifespan of 30 years and the financial perspective, i.e., analysing the mere evaluation of the private investment. In the assessment, a real interest rate of 4% has been assumed. Moreover, the cost-optimality approach, being a comparative methodology for the determination of the *GC*, neglects the same cost categories repeated for several measures (safety costs, ancillary charges, etc.), and the cost items on building materials whose installation does not have an impact on the energy performance of the building.

3. Application

3.1 Case Studies

In the present work, the reference buildings have been assumed to be located in two different Italian climatic zones (Palermo and Milan), and two construction periods have been considered (an existing building, built in the period 1977-90, and a new building). Two different intended uses have been assumed: residential and non-residential.

The single-family house sited in Palermo was selected from the IEE-TABULA project (*Typology Approach for Building Stock Energy Assessment*; Loga et al., 2012), while the office located in Milan was derived from the survey of Margiotta & Puglisi (2009). Both buildings present a reinforced concrete structure, with reinforced concrete and hollow brick slabs. Brick masonry cavity walls for the single-family house and hollow brick masonry walls for the office have been assumed, respectively. The upper slabs face the external environment, while the bottom floor is adjacent to an unconditioned zone (cellar). Table 1 reports the main geometrical characteristics.

In its current state, the single-family house, located in Palermo, presents single-glazed windows without external solar shading devices installed. The residential house is equipped with a heat generator for space heating and domestic hot water, and a multi-split system for space cooling (see Table 2).

Table 1 – Geometrical characteristics of the case studies

	Residential/Existing bldg/Palermo	**Office/New bldg/Milan**
V_g [m³]	725	6100
A_f [m²]	199	1519
A_{env} / V_g [m⁻¹]	0,72	0,35
A_w [m²]	25	434
no. storeys	2	4

3.2 Energy Efficiency Measures

Sixteen categories of EEMs have been defined, considering up to five different energy efficiency options for each EEM, characterised by increasing levels of performance. The EEMs are classified into three different groups according to their application field: a) the thermal insulation of the building fabric (i.e., opaque and transparent building envelope components) and installation of solar shading devices; b) the replacement of technical building systems components (i.e., heating, cooling, and domestic hot water generators, ventilation, and lighting systems); c) the installation of renewable energy plants. The considered number of EEOs is variable depending on both the reference building and the specific EEM. In Table 2, the thermo-physical parameters and costs associated with each EEO are reported per each EEM.

3.3 Consistency Options

As introduced, the cost-optimal packages of energy efficiency measures determined by means of the monthly and the simplified hourly dynamic methods respectively are compared in the present work. To make the results of the two calculation methods comparable, some consistency options have been considered:

a) Typical Meteorological Years (TMY) elaborated by the Italian Thermo-technical Committee (CTI, 2015) have been adopted in both calculation methodologies,

b) diversity factors for energy calculation on an hourly basis have been introduced to eval-

Table 2 – EEOs per EEMs for residential and non-residential buildings

EEMs		Residential/Existing bldg/Palermo					Office/New bldg/Milan				
		EEOs					EEOs				
		1 (*)	2	3	4	5	1	2	3	4	5
External wall thermal insulation	U_{wl} [W m^{-2}K^{-1}]	-	0,54	0,45	0,40	0,26	1,50	0,36	0,30	0,26	0,17
	$c_{el,i}$ [€ m^{-2}]	-	79	83	85	96	-	58	62	66	80
or Cavity wall thermal insulation	U_{wl} [W m^{-2}K^{-1}]	1,10	0,37	-	-	-					
	$c_{el,i}$ [€ m^{-2}]	-	21	-	-	-					
Roof thermal insulation	$U_{fl,up}$ [W m^{-2}K^{-1}]	2,16	0,41	0,34	0,32	0,26	1,50	0,30	0,25	0,22	0,18
	$c_{el,i}$ [€ m^{-2}]	-	45	50	52	59	-	40	45	48	55
Floor thermal insulation	$U_{fl,lw}$ [W m^{-2}K^{-1}]	0,78	0,58	0,48	0,42	0,28	1,50	0,36	0,30	0,26	0,17
	$c_{el,i}$ [€ m^{-2}]	-	9	9	9	12	-	12	14	16	26
Windows	U_w [W m^{-2}K^{-1}]	4,90	3,80	3,20	3,00	1,60	5,00	2,20	1,80	1,40	1,10
	$c_{el,i}$ [€ m^{-2}]	-	300	306	346	624	200	365	379	388	391
Solar shading devices	F *or* M (**) / τ_{sh} [-]	-	F / 0,20	M / 0,20	-	-	F / 0,20	M / 0,20	-	-	-
	$c_{el,i}$ [€ m^{-2}]	-	170	26	-	-	170	26	-	-	-
Chiller	*EER* [-]	2,35	3,30	-	-	-	3,30	-	-	-	-
	C [k€]	-	3,77	-	-	-	71,90	-	-	-	-
plus Heat generator for space heating	*COP* [-]	-	3,70	4,10	-	-					
	c [€ kW^{-1}]	-	451	493	-	-					
plus Heat generator for domestic hot water	$\eta_{W,gn}$ [-]	-	0,93	1,00	-	-					
	c [€ kW^{-1}]	-	210	629	-	-					
or Combined heat generator for space heating and domestic hot water	$\eta_{H+W,gn}$ [-]	0,73	0,93	1,00	-	-	0,93	1,05	-	-	-
	c [€ kW^{-1}]	-	264	209	-	-	179	124	-	-	-
or Heat pump for space heating, domestic hot water, and space cooling	*COP* [-] *and* *EER* [-]	-	4,10 3,50	-	-	-	3,00 2,80	3,50 3,20	-	-	-
	c [€ kW^{-1}]	-	967	-	-	-	329	372	-	-	-
Thermal solar system	A_{coll} [m^2]	-	1	2	3	-	2	4	6	8	10
	c_{coll} [k€ m^{-2}]	-	1,40	1,40	1,40	-	1,40	1,40	1,20	1,00	0,80
Photovoltaic system	W_p [kW]	-	1,36	1,70	2,04	-	8,80	11,00	13,20	-	-
	c [k€ kW^{-1}]	-	1,50	1,50	1,50	-	1,25	1,25	1,25	-	-
Heat recovery ventilation system	η_{ru} [-]						0,60	0,70	0,90	-	-
	C [k€]						3,79	9,76	17,67	-	-
Space heating control sub-system	$\eta_{H,rg}$ [-]	0,78÷ 0,89	0,94	0,98	0,99	-	0,94	0,98	0,99	-	-
	C [€]	-	52	288	90	-	358	1.075	394	-	-
Lighting system	P_n [W m^{-2}] F_O [-] F_C (F_D) [-]						6,00 1,00 1,00	6,00 0,80 0,90	-	-	-
	c_l [€ m^{-2}]						24	30	-	-	-

(*) For the existing building the first column represents the current state

(**) F = fixed louvres, M = mobile louvres uate the temporal distribution of the internal heat gains, in accordance with EN 16798-1 (CEN, 2019),

c) in the simplified hourly model, the mass of the internal horizontal partitions has been associated with the internal node of the conduction model. Moreover, the specific heat capacity of air and furniture has been neglected.

4. Results

The results of the optimization procedure are presented in terms of the overall non-renewable energy performance ($EP_{\mathrm{gl,nren}}$) vs. the global cost in Fig. 2 and Fig. 1 for the single-family house and the office building respectively. Both partial optimum and the cost-optimal points, calculated on a monthly and hourly basis, are shown. Moreover, Table 3 specifies the cost optimal EEMs packages for each reference building and for the two calculation methods (monthly and hourly).

The comparative analysis shows slight differences between the global costs and the cost-optimal package of energy efficiency measures. In light of the comparison between the two case studies and the two calculation methodologies, *GC* and $EP_{\mathrm{gl,nren}}$ of the cost-optimal levels present negligible deviations. The $EP_{\mathrm{gl,nren}}$ deviation of the hourly cost-optimal level with respect to the monthly one is equal to 11% and -3% for the single-family house and the office respectively. For both buildings, from the global cost view, the relative variation of the global cost is close to 1%. The cost-optimal combination of EEMs varies between the two calculation models, as highlighted in Table 3 (coloured cells). For both buildings, a different level of thermal insulation of the bottom floor in the cost-optimal EEMs is displayed when applying a different calculation model. More evident variations occur for the single-family house, in which different levels of the EEOs for the solar shading devices and the photovoltaic system are reported.

Primarily, deviations in the results can be ascribed to major differences in the calculation methods, such as the deployment of a different model for the heat conduction assessment in every building component and the approach to determine the heat transfer through unconditioned zones. From the optimal package of EEMs view, although the determination of the thermal energy needs for space heating and cooling is strictly related to the building fabric energy performance, this does not necessarily imply that the EEOs of the technical building system cannot vary between the two calculation methods. In fact, the energy cost, which is a term of the global cost calculation, is directly influenced by the building energy needs. Moreover, most of the sensitivity in the EEO variation is related to the measures with the minimal difference cost as a consequence of the energy efficiency increase. A significant example that describes this phenomenon is represented by the floor thermal insulation (see Table 3).

5. Conclusion

The comparative methodology applied in 2018 to identify the cost-optimal minimum energy performance requirements for the Italian building stock has been updated with the new simplified hourly model specified by EN ISO 52016-1 and by its National Annex. In the present work, the outcomes of the comparative analysis for a single-family house located in Palermo and for an office building situated in Milan have been presented. For each building, the cost-optimal energy efficiency measures resulting from the calculation of the thermal energy needs for space heating and cooling both on a monthly basis (UNI/TS 11300-1) and on an hourly basis (EN ISO 52016-1) have been assessed and compared. The outcomes, which are presented in terms of the cost-optimal package of EEMs and global cost, do not lead to significant differences under application of a different calculation method.

Future works will provide an update of the cost-optimal methodology to assess the technical building system performance on an hourly basis.

Table 3 – Optimal EEM packages resulting from different calculation methods, for residential and non-residential buildings

EEM		Optimal EEO Residential/Existing bldg/Palermo		Optimal EEO Office/New bldg/Milan	
		Monthly method	*Hourly method*	*Monthly method*	*Hourly method*
External wall thermal insulation *or*	U_{wl} [W m⁻²K⁻¹]	-	-	0,36	0,36
cavity wall thermal insulation		1,10	1,10		
Roof thermal insulation	$U_{fl,up}$ [W m⁻²K⁻¹]	0,41	0,41	0,30	0,30
Floor thermal insulation	$U_{fl,lw}$ [W m⁻²K⁻¹]	0,28	0,78	0,30	0,36
Windows	U_w [W m⁻²K⁻¹]	4,90	4,90	1,10	1,10
Solar shading devices	F *or* M (*) / τ_{sh} [-]	F / 0,20	M / 0,20	M / 0,20	M / 0,20
Chiller	*EER* [-]	2,35	2,35	-	-
plus Heat generator for space heating	*COP* [-]	-	-		
plus Heat generator for domestic hot water	$\eta_{W,gn}$ [-]	-	-		
or Combined heat generator for space heating and domestic hot water	$\eta_{H+W,gn}$ [-]	1,00	1,00	-	-
or Heat pump for space heating, domestic hot water, and space cooling	*COP* [-]	-	-	3,50	3,50
	EER [-]	-	-	3,20	3,20
Thermal solar system	A_{coll} [m²]	absent	absent	2,00	2,00
Photovoltaic system	W_P [kW]	1,36	2,04	13,20	13,20
Heat recovery ventilation system	η_{ru} [-]			0,60	0,60
Space heating control sub-system	$\eta_{H,rg}$ [-]	0,99	0,99	0,99	0,99
Lighting system	P_n [W m⁻²]			6,00	6,00
	F_O [-]			0,80	0,80
	F_C (F_D) [-]			0,90	0,90

(*) F = fixed louvres, M = mobile louvres

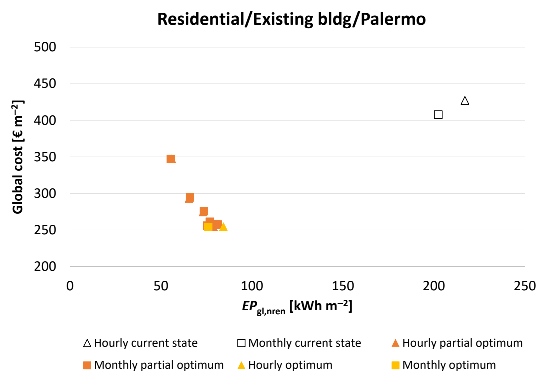

Fig. 1 – Cost-optimal level for the single-family house

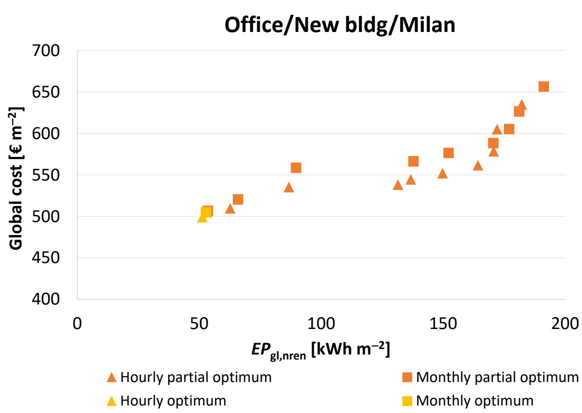

Fig. 2 – Cost-optimal level for the office building

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Nomenclature

Symbols

A	area (m²)
C	cost (€)
c	specific cost (€ m^{-2}) *or* (€ kW^{-1})
COP	coefficient of performance (-)
EER	energy efficiency ratio (-)
EP	energy performance indicator (kWh m^{-2})
F	factor (-)
P	lighting power density (W m^{-2})
U	thermal transmittance (W $m^{-2}K^{-1}$)
V	volume (m³)
W	peak power (kW)
η	efficiency (-)
τ	coefficient of transmission (-)

Subscripts/Superscripts

C	constant illuminance
coll	solar collector
D	daylight dependency
eli	building element
env	building envelope
f	net floor
fl,lw	lower floor
fl,up	upper floor
g	gross
gl	overall
gn	generation sub-system
H	space heating
n	number of luminaires in the zone
nren	non-renewable
O	occupancy dependency
p	peak
rg	control sub-system
ru	heat recovery unit
sh	shading
W	domestic hot water
w	window
wl	wall

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