Research Fund for Coal & Steel

LVS3

Large Valorisation on Sustainability of Steel Structures

BACKGROUND DOCUMENT: USE PHASE - OPERATIONAL ENERGY

U C
FCTUC FACULDADE DE CIÊNCIAS E TECNOLOGIA UNIVERSIDADE DE COIMBRA

June 2014

Agenda

1) Operational energy quantification

- Introduction
- Building location and climate
- Energy need calculation method
- Algorithm for energy quantification (use phase)

2) Calibration and validation of algorithm

- Reference compartment (EN 15265:2007)
- Reference apartment (adapted from EN 15265:2007)
- Residential building case study

3) Final remarks

1) Operational energy quantification

Introduction

The algorithm for energy quantification

during use phase was previously developed

under the RFCS research project

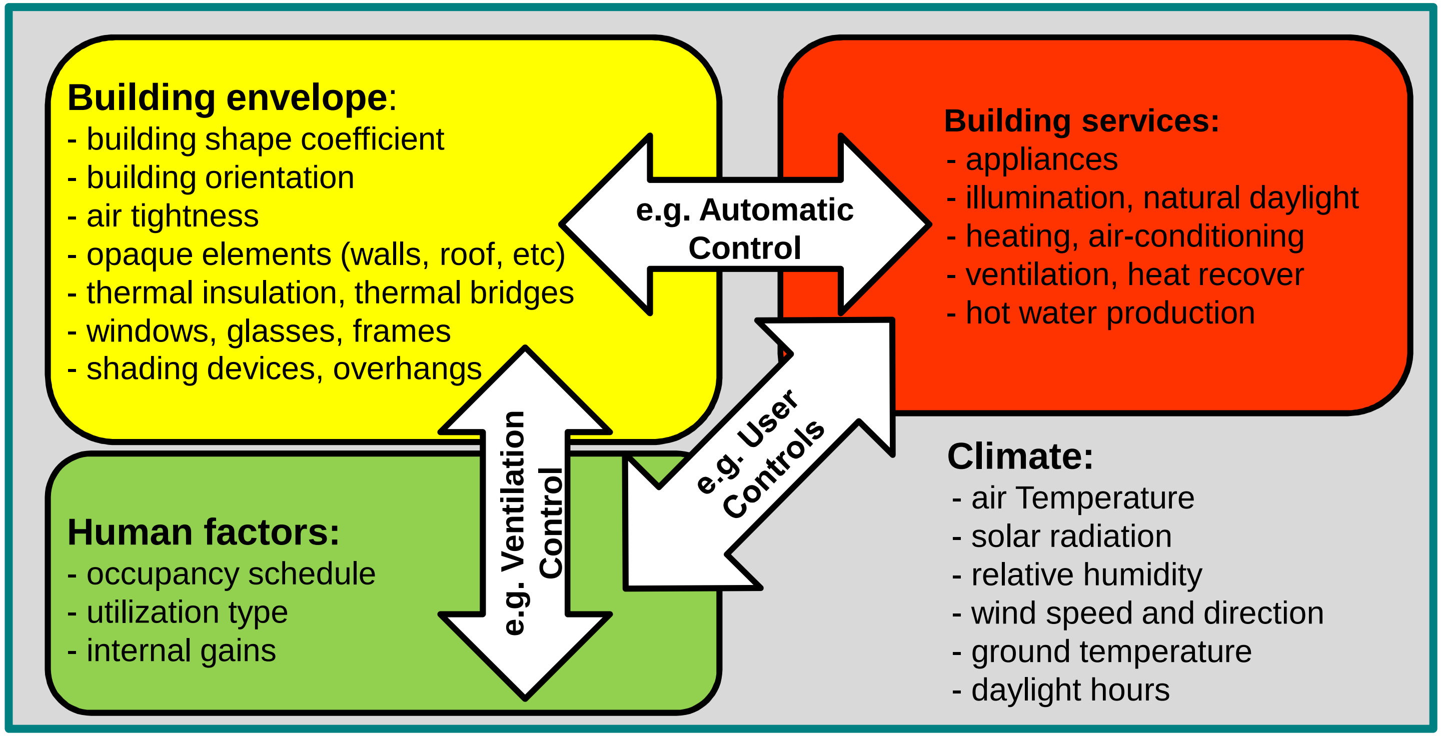
SB STEEL

SB_Steel (2014), Sustainable Building Project in Steel. Draft final report. RFSR-CT-2010-00027. Research Programme of the Research Fund for Coal and Steel.

Introduction

The thermal performance and energy efficiency of buildings depends on many parameters.

Therefore it is very challenging to accurately predict the operational energy of a building.



This is even more difficult at early stages of design, given the scarce availability and imprecision of input data.

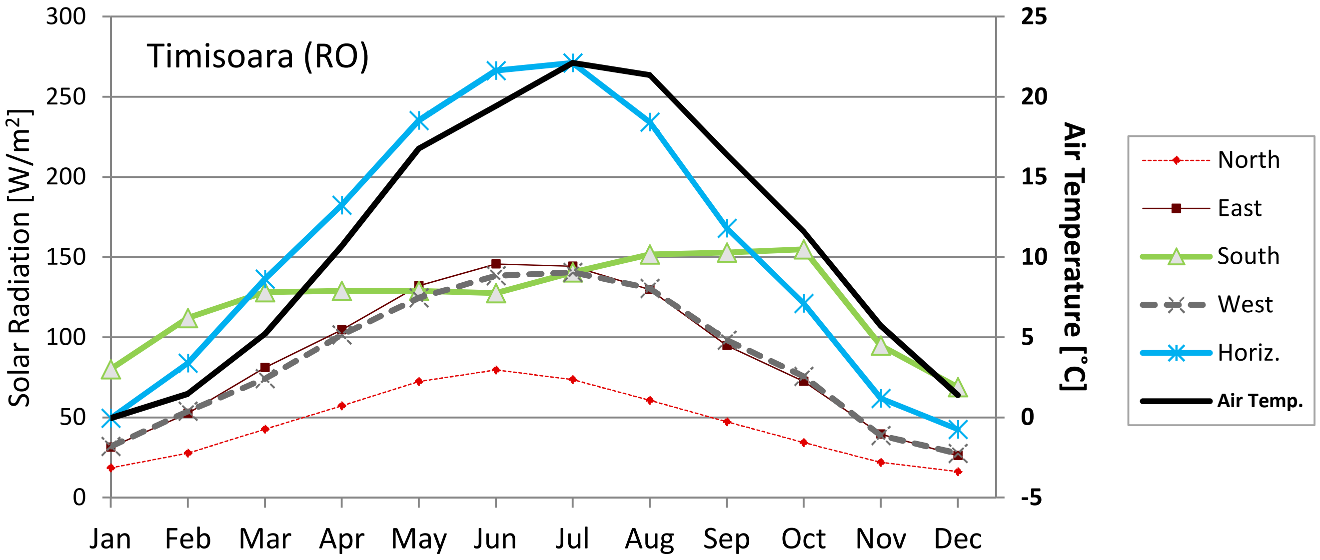
Building location and climate

The location of the building, in terms of climate conditions, is of vital importance in thermal behaviour calculations. Regarding this matter, two major climate parameters must be defined in order to undertake an energy need calculation:

- air temperature;
- solar radiation on a surface with a given orientation.

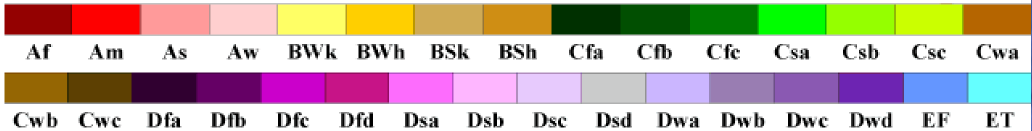
Most of this climate data was obtained in the EnergyPlus energy simulation software weather database (EERE-USDoE, 2014) and the remaining was provided by research project partners.

EERE-USDoE (2014), Energy Efficiency and Renewable Energy Website from the United States Department of Energy: http://apps1.eere.energy.gov/buildings/energyplus/cfm/weather_data2.cfm/region=6_europe_wmo_region_6

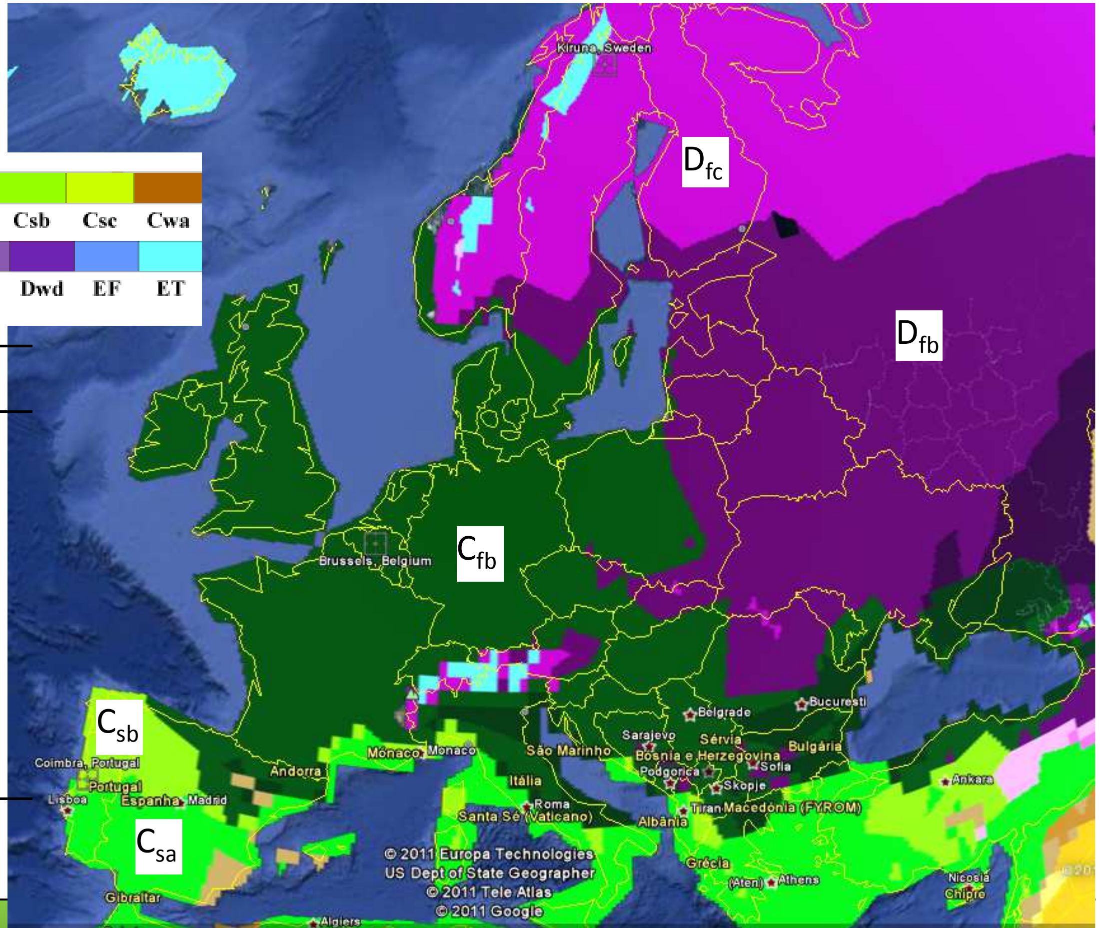


Building location and climate

The methodology is currently calibrated for five climatic regions, classified according with the Köppen-Geiger climate classification: (i) Csa; (ii) Csb; (iii) Cfb; (iv) Dfb; (v) Dfc.



Main Climates:	Precipitation:	Temperature:	
A: equatorial	W: desert	h: hot arid	F: polar frost
B: arid	S: steppe	k: cold arid	T: polar tundra
C: warm temperate	f: fully humid	a: hot summer	
D: snow	s: summer dry	b: warm summer	
E: polar	w: winter dry	c: cool summer	
	m: monsoonal	d: extremely continental	



Building location and climate

52 cities database

City	Country	Climatic Region	City	Country	Climatic Region	City	Country	Climatic Region
Amsterdam	Netherlands	Cfb	Kiev	Ukraine	Dfb	Oslo	Norway	Dfb
Ankara	Turkey	Csb	Kiruna	Sweden	Dfc	Ostersund	Sweden	Dfc
Arhanglesk	Russia	Dfc	Kraków	Poland	Cfb	Paris	France	Cfb
Athens	Greece	Csa	La Coruña	Spain	Csb	Porto	Portugal	Csb
Barcelona	Spain	Csa	Lisbon	Portugal	Csa	Poznan	Poland	Cfb
Berlin	Germany	Cfb	Ljubljana	Slovenia	Cfb	Prague	Czech Republic	Cfb
Bilbao	Spain	Cfb	London	England	Cfb	Rome	Italy	Csa
Bratislava	Slovakia	Cfb	Lublin	Poland	Dfb	Salamanca	Spain	Csb
Brussells	Belgium	Cfb	Madrid	Spain	Csa	Sanremo	Italy	Csb
Cluj-Napoca	Romania	Dfb	Marseille	France	Csa	Sevilla	Spain	Csa
Coimbra	Portugal	Csb	Milan	Italy	Cfb	Stockholm	Sweden	Dfb
Gdansk	Poland	Cfb	Minsk	Belarus	Dfb	Tampere	Finland	Dfc
Genova	Italy	Csb	Montpellier	France	Csa	Timisoara	Romania	Cfb
Graz	Austria	Dfb	Moscow	Russia	Dfb	Vienna	Austria	Dfb
Hamburg	Germany	Cfb	Munich	Germany	Cfb	Warsaw	Poland	Dfb
Helsinki	Finland	Dfb	Nantes	France	Cfb	Wroclaw	Poland	Cfb
Istambul	Turkey	Csa	Nice	France	Csb			
Katowice	Poland	Cfb	Opole	Poland	Cfb			

Energy need calculation method

The simplified algorithm implemented in AMECO 3 allow to predict the building energy need for:

- Space heating;
- Space cooling;
- Domestic hot water (DHW) supply.

This algorithm is based in the prescriptions contained in several international standards.

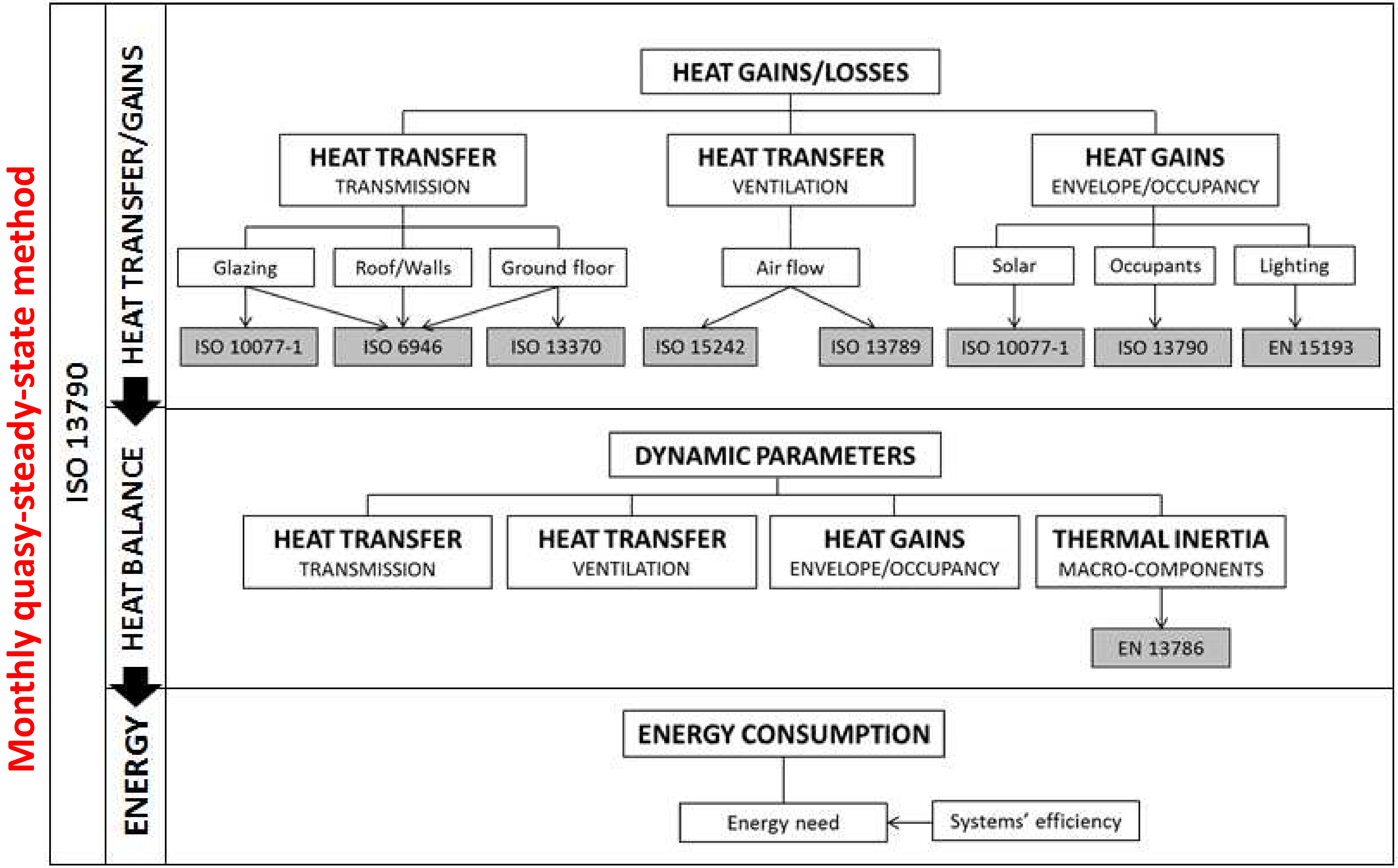
The calculation of heating and cooling consumptions follows the monthly quasi-steady-state method provided by ISO 13790 (2008).

The energy needs for DHW production is calculated according to EN 15316-3-1 (2007).

ISO 13790 (2008), Energy performance of buildings – Calculation of energy use for space heating and cooling, CEN – European committee for Standardization.

EN 15316-3-1 (2007), Heating systems in buildings – Method for calculation of system energy requirements and system efficiencies – Part 3.1 Domestic hot water systems, characterisation of needs (tapping requirements), CEN – European committee for Standardization.

Energy need calculation method



Algorithm for energy quantification (use phase)

Main inputs

BUILDING LOCATION → related with climate (for a specific city or climatic region):

i) air temperature;

ii) solar radiation on a surface with a given orientation.

BUILDING TYPE: e.g. residential, offices, commercial or industrial.

BUILDING ENVELOPE based in a macro-components (e.g. walls, floors, roofs, ground floor, openings).

BUILDING DIMENSIONS and ORIENTATION (e.g. length, width, height and n. of floors).

INDOOR CONDITIONS: heating and cooling setpoints, air-flow rate regarding ventilation.

BUILDING SYSTEMS for space heating and cooling, and for DHW production.

Main outputs

Energy for space heating, space cooling and DHW production.

Heat balance through the main building construction elements (e.g. walls, roof, windows).

Algorithm for energy quantification (use phase)

Main procedures to compute the Energy Need for Space HEATING, $Q_{H,nd}$:

1) Heat Balance assuming CONTINUOUS heating:

a) $Q_{H,ht}$ Total heat transfer (by transmission + by ventilation) → (heat losses)

b) $Q_{H,gn}$ Total heat gains (internal + solar)

c) $\eta_{H,gn}$ Gain utilization factor

$$\boxed{Q_{H,nd} = Q_{H,nd,cont} = Q_{H,ht} - \eta_{H,gn}\, Q_{H,gn}}$$

2) Correction for INTERMITTENT heating:

a) Reduction factor for intermittent heating ($a_{\mathrm{H,red}}$)

$$\boxed{Q_{\mathrm{H,nd,interm}} = a_{\mathrm{H,red}}\, Q_{\mathrm{H,nd,cont}}}$$

Algorithm for energy quantification (use phase)

Main procedures to compute the Energy Need for Space COOLING*, $Q_{C,nd}$:

1) Heat Balance assuming CONTINUOUS cooling:

a) $Q_{C,ht}$ Total heat transfer (by transmission + by ventilation)

b) $Q_{C,gn}$ Total heat gains (internal + solar)

c) $\eta_{C,ls}$ Loss utilization factor for cooling mode

Comparison with heating mode

$$\boxed{Q_{H,nd} = Q_{H,nd,cont} = Q_{H,ht} - \eta_{H,gn}\, Q_{H,gn}}$$

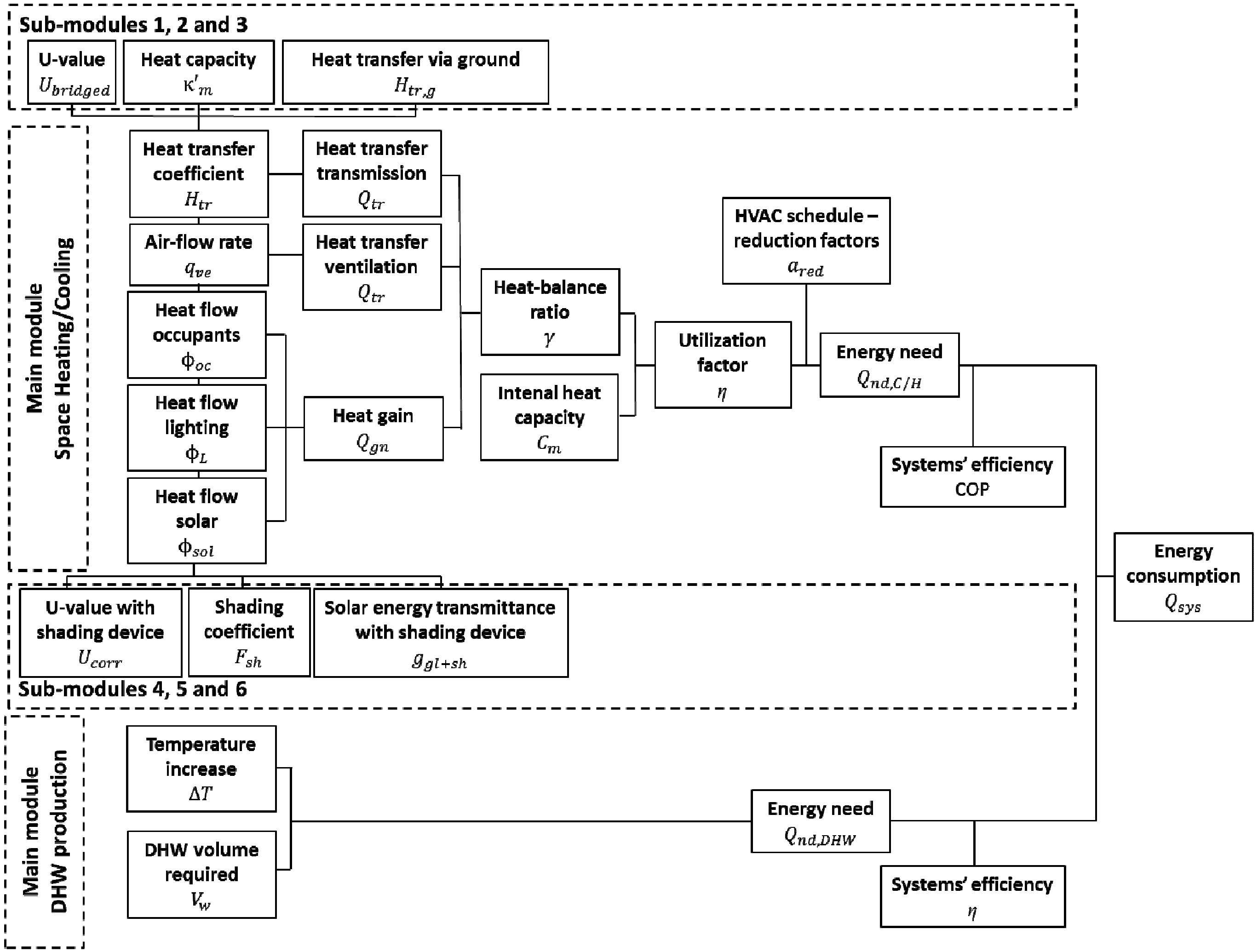
$$\boxed{Q_{C,nd} = Q_{C,nd,cont} = Q_{C,gn} - \eta_{C,ls}\, Q_{C,ht}}$$

2) Correction for INTERMITTENT cooling :

a) Reduction factor for intermittent cooling

* Similar approach as for heating mode

Algorithm for energy quantification (use phase)



2) Validation of adopted methodologies

Energy need calculation

The algorithm implemented to predict the energy need for space heating/cooling of the building was calibrated and its precision was verified at different levels (Santos *et al.* 2014):

- Reference compartment (EN 15265:2007);
- Reference apartment (adapted from EN 15265:2007);
- Residential building case study.

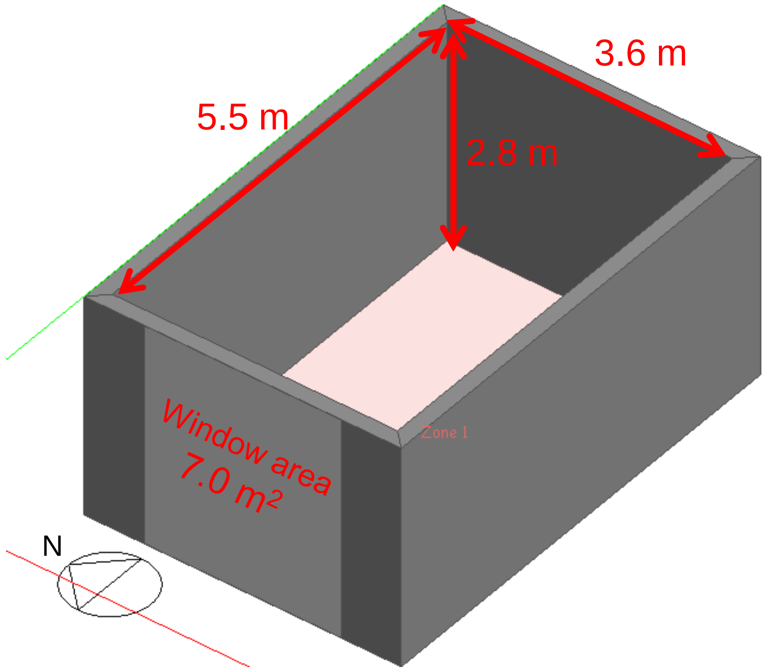
P. SANTOS; R. MARTINS; H. GERVÁSIO; L. SIMÕES DA SILVA, *"Assessment of building operational energy at early stages of design – A monthly quasi-steady-state approach"*, ***Energy and Buildings*** *(ISSN: 0378-7788)*, vol. 79, pp. 58–73, 2014.

EN 15265 (2007), Energy performance of buildings - Calculation of energy needs for space heating and cooling using dynamic methods - General criteria and validation procedures. CEN - European Committee for Standardization.

Reference compartment (EN 15265:2007)

This standard prescribes a series of 12 test-cases for a compartment room.

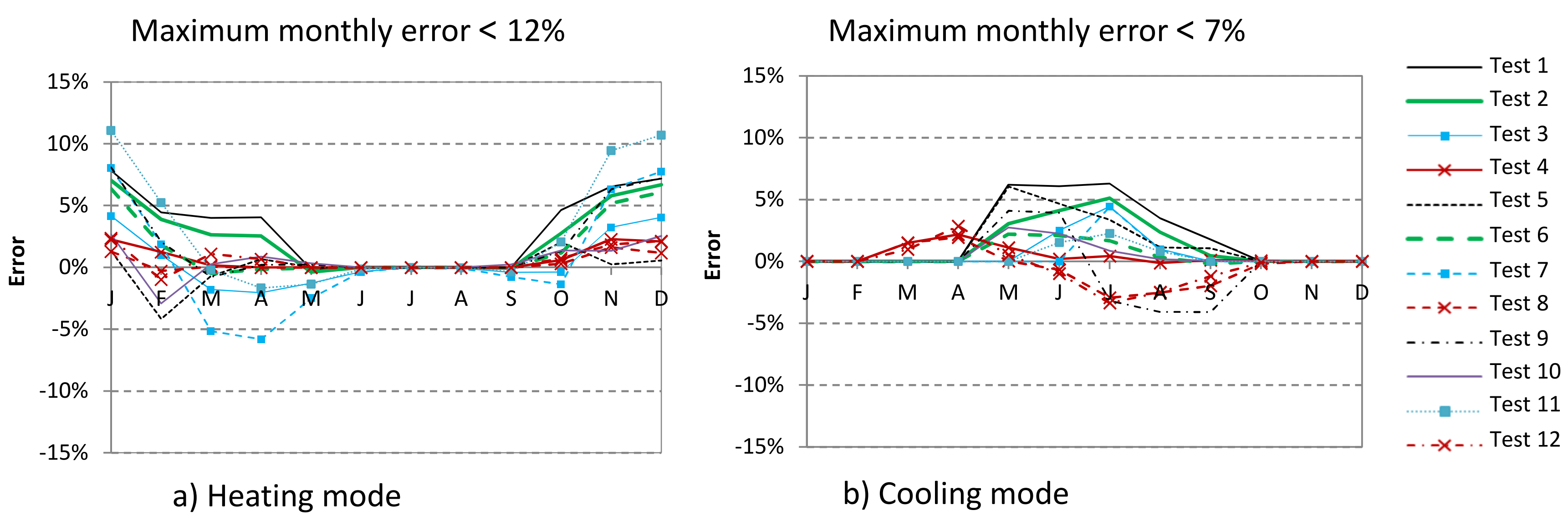
(Informative)	**Test 1** Reference Case	
	Test 2 Higher Thermal Inertia	
	Test 3 No Internal Gains	
	Test 4 No Solar Protection	
Intermittent HVAC (Normative)	**Test 5** = Test1 +	**HVAC only 8h00-18h00 from Monday to Friday**
	Test 6 = Test2 +	
	Test 7 = Test3 +	
	Test 8 = Test4 +	
Intermittent HVAC + External Roof (Normative)	**Test 9** = Test5 +	**External Roof**
	Test 10 = Test6 +	
	Test 11 = Test7 +	
	Test 12 = Test8 +	



These test-cases allow seeing the influence of certain key-parameters in the energy computation algorithm, such as: shading devices, thermal mass, intermittent or continuous HVAC systems, internal gains, etc.

Reference compartment (EN 15265:2007)

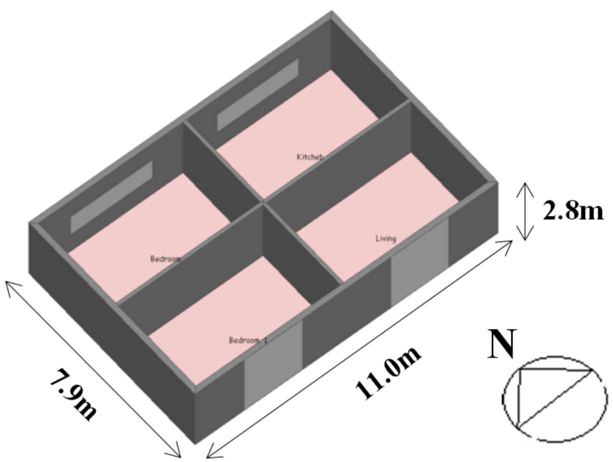
The precision of the algorithm depends on: the test-case, the month and the heating or cooling mode.



Monthly precision of the space heating/cooling algorithm: Twelve test-cases of EN 15265:2007.

Reference apartment (adapted from EN 15265:2007)

Since the monthly algorithm aims at the prediction of the energy needs of buildings instead of focusing only on one building compartment as prescribed in EN 15265 (2007), all calibrations were carried out with a new set of test cases based on the typical building characteristics (apartment) as illustrated here.



a) Building model (internal dimensions)

Element	U-value [W/m^2.K]	κ_m [J/m^2.K]
External wall	0.493	81297
Internal wall	-	9146
Roof	0.243	6697
Ground floor	-	63380

κ_m Areal heat capacity

b) Thermal properties of the envelope

Test case	GFR [%]	NGWR [%]	SGWR [%]	Shading devices
T1	35	36	54	ON
T2				OFF
T3	25	20	40	ON
T4				OFF
T5	15	12	24	ON
T6				OFF

GFR: glazing to floor ratio; NGWR: north-oriented glazed to wall ratio; SGWR: south-oriented glazed to wall ratio.

c) Main variables of the test cases

Reference building used to calibrate the correction factors

Research Fund
for Coal & Steel

LVS3

Research Fund
for Coal & Steel

LVS³

Residential building case study

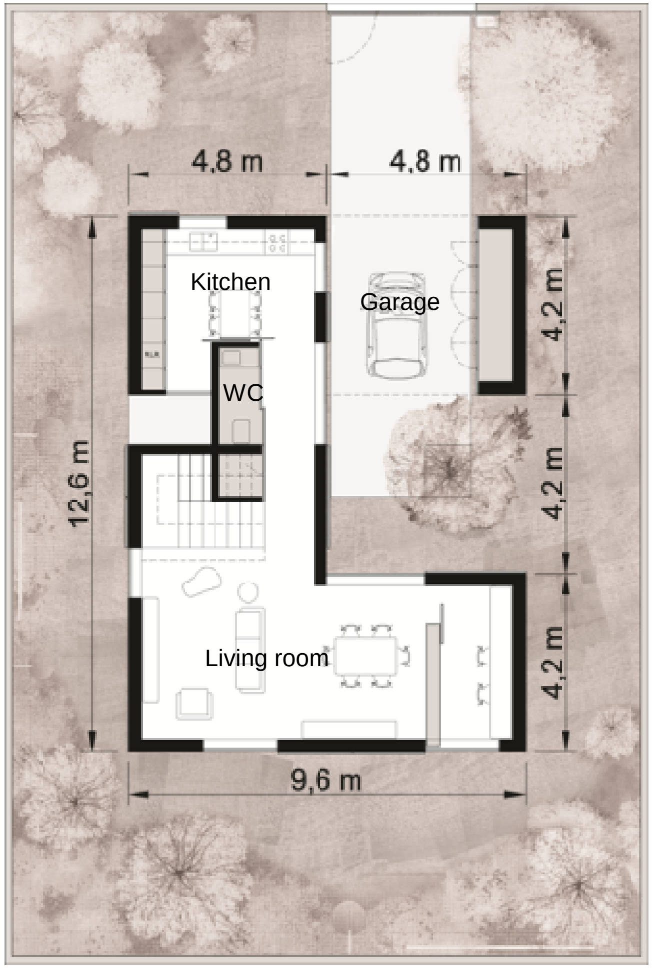
Two storey lightweight steel framed (LSF) residential building located in Coimbra.

South-West view

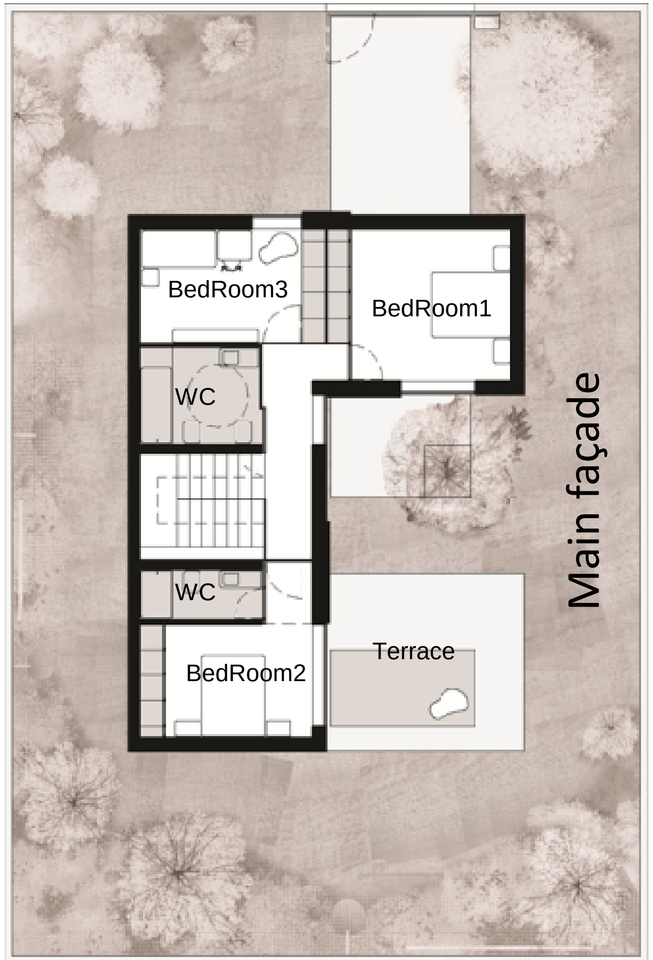
North-West view

Residential building case study

Ground-floor level



First-floor level



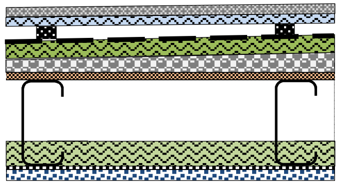
N

Building's floors layout

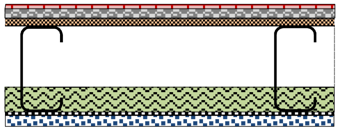
Residential building case study

Opaque envelope:

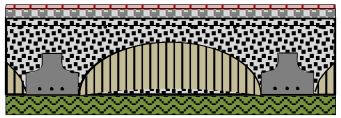
Roof floor



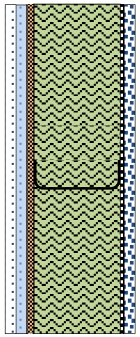
Interior floor



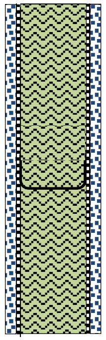
Ground floor



Exterior wall



Interior wall



Thermal properties:

Element	U-value [W/m².K]	κ_m [J/m².K]
Roof slab	0.37	13435
Interior floor	-	61062
Ground floor	0.60	65957
Exterior wall	0.29	13391
Interior wall	-	26782

Glazed envelope:

Thermal properties:

Materials	U-value [W/m².K]	SHGC
PVC frame and double pane (8+6 mm, with air gap of 14 mm)	2.60	0.78

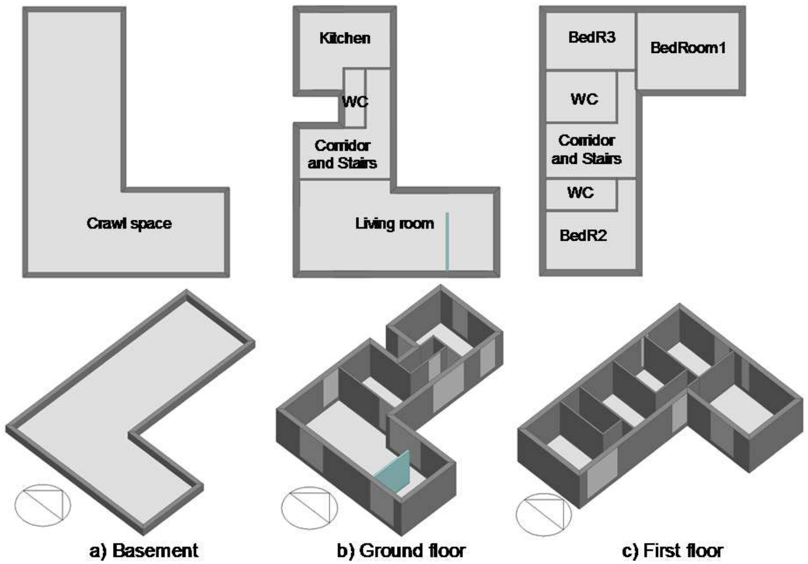
SHGC – Solar heat gain coefficient

Residential building case study

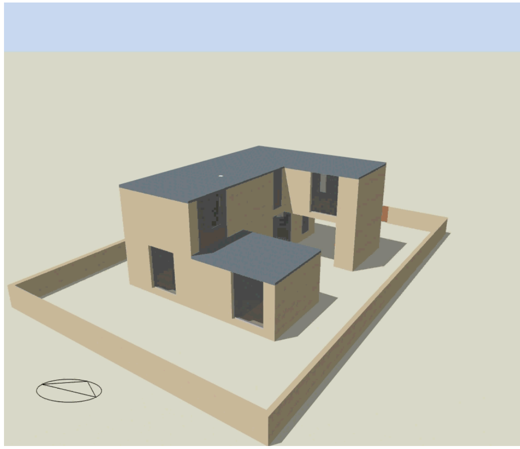
The reference results for this building were obtained from advanced dynamic simulations.

Tools: DesignBuilder SOFTWARE EnergyPlus

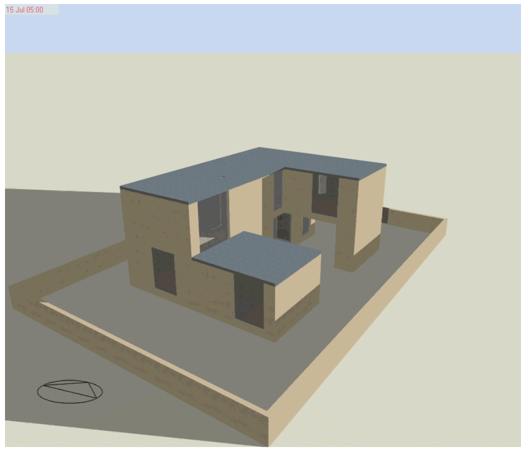
The model was assembled using 10 thermal zones



Layout of the floors



Orbit view of the DsB model

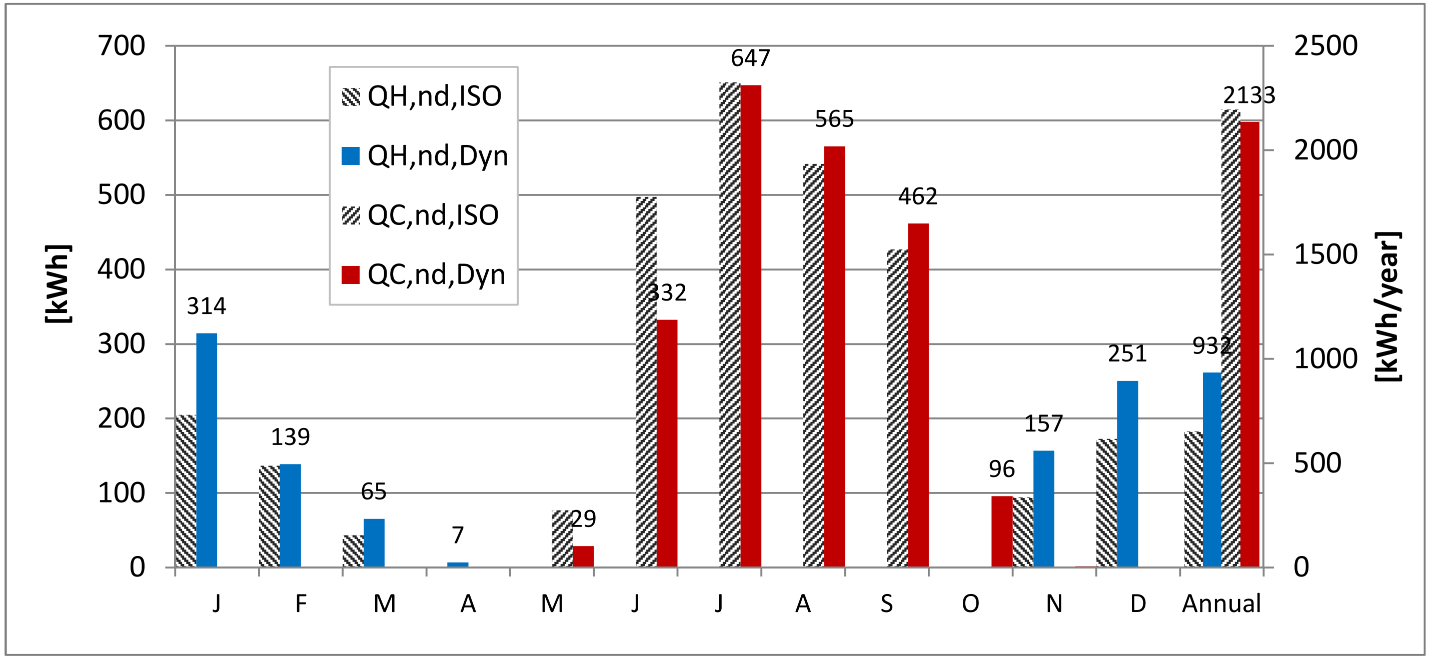


Shading evolution at 10 Aug.

Residential building case study

Obtained results:

Average error: -7.2%



Building energy need for space cooling and heating: dynamic simulations (Dyn) *versus* monthly algorithm (ISO)

3) Final remarks

- The assessment of embodied and operational energy is essential to perform a life cycle analysis.
- To accurately predict the operational energy of a building it is not an easy task since it depends on so many parameters.
- A simplified algorithm was implemented to quantify the energy need for space heating/cooling and for the quantification of DHW production, having as reference some international standards.
- The precision of the monthly quasi-steady-state method provided by ISO 13790 was verified by comparison with some advanced dynamic simulations.
- The comparison of the results enables to conclude that the accuracy of this approach is very reasonable (mean error < 10%).