An Introduction to the Development of the French Energy Regulation Indicators and Their Calculation Methods

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Abstract

We present the calculation strategy of the new Bbio indicator of the French energy regulation of new building (RT2012) that aims at assessing the quality of the bioclimatic design of low-energy building. It is a weighted sum of three needs: heating, cooling and lighting. The thermal model for assessing the heating and the cooling needs is strongly inspired from the simple hourly computation of NF EN ISO 13790. We show the thermal model is in the level A of the CEN validation procedure of dynamic thermal computation. The lighting efficiency is evaluated dynamically by computing artificial needs using a day light factor and the luminous flux penetrating inside.

Keywords – energy; French regulation; standard; low-energy building; model; lighting; RT2012; COMETH; dynamic calculation.

1. Introduction

The French new energy performance of new building regulation - aka RT2012 – is partially enforced in France since 2011 for office, teaching and housing buildings. It is mandatory for all new construction from 2013.

This new regulation aims to reach low energy consumption for all new buildings. This energy consumption has to be evaluated is some way. France has chosen to base this evaluation on the theoretical computation of the building energy needs before it is actually built. As such, the RT2012 is part of the set of regulations concerning new building construction. The theoretical calculation is specified in a set of algorithmic rules which is part of an official French executive order. These rules describe the behavior of all the models and solvers adopted in the French regulation. They allow the computation of the indicators required by the RT2012 such as

- the overall heating, cooling and lighting needs associated to the $Bbio$ indicator measured in points;
- the overall consumption of heating, cooling, domestic hot water, lighting and auxiliary systems (fans, pumps…) in primary energy (denoted Cep);
- the summer comfort.

The needs calculation is referred to as the Th-B calculation. The system consumption calculation is referred to as the Th-C calculation. The summer comfort is referred to as the Th-E calculation. Therefore, the whole set of computation is referred to as the « Th-BCE rules ». These rules are implemented in a computing kernel edited by CSTB which is named COre for Modeling Energy and THermal comfort - aka COMETH.

In this paper, we present the Th-B calculation. Th-B (as well as Th-C) is strongly inspired by the so-called simple hourly model of NF EN ISO 13790 [1] for evaluating energy needs, and custom simplified lighting model. In the previous regulation, such a dynamic computation only existed for system consumption *(*Cep calculation). The Th-B mode evaluates the energy and lighting needs and converts those in points to create the $Bbio$ indicator. In section 2.a, we go into the details of the lighting model. In section 2.b, we present the energy model and its validation in section 3.

2. Thermal and Lighting Model

France has chosen to use coupled models at an hourly time step for all usages. In particular, the heating/cooling needs model and lighting model are coupled through

- the recoverable losses of the lighting system (bulb losses and regulation auxiliaries);
- the regulation of solar protection which is concurrent to thermal and lighting comfort.

This enables to check whether a choice a priori interesting from a thermal point of view is as interesting for a more global point view.

a. Lighting Model

Natural daylighting in a room affects in opposite directions the energy consumption. It leads to use or not:

- Artificial daylighting which dissipates heat in the room because of increasing electric consumption;
- Solar protections which decrease solar gains and thus reduce heat emission in the room.

In order to estimate window impact on building energetic consumption, it is useful to calculate how long artificial lighting is working, especially in building well insulated where heat needs are low. Thus the aim is to estimate room artificial daylighting autonomy and not a proper evaluation of visual comfort.

The calculation procedure is as follows:

- Diffuse horizontal and direct normal radiations are given by meteorological data for the eight geographical zones of France for each hour of year. Appropriate meteorological data based on measurements from the last 15 years were calculated with ISO 15927-4 [2]. Then regressions, for light efficiency are used in order to calculate outside illuminance;
- Illuminances on the window are calculated thanks to its azimuth and tilt. Diffuse, direct and reflected by the ground parts are distinguished;
- Empirical formulation [3] gives solar protection position on the window depends on illuminance;
- Daylight factor is required to calculate internal natural daylight;
- This work is done for each window;
- Then a relation, built on experimental data [3] and literature [4], [5], establishes is artificial lighting on or off. Consumption can be obtained with this value and artificial lighting power.

Our purpose is to explain how internal illuminance is calculated.

Natural lighting [lux] in a group of room is given by the next formula:

$$Ei_{\text{nat}} = \frac{1.8 \times Fl_{\text{Teq}}}{R_{A,At}^{gr} \times A_{\text{eclnat}} \times (1 - R^2)} \tag{1}$$

This formula is deducted from the daylight factor [13] regarded horizontal illuminance as twice vertical illuminance under a uniform sky.

Fl_{Teq} : all windows equivalent luminous flow letting into the room. It depends on illuminance nature and window characteristics [lux],

$R_{A,At}^{gr}$: total surface wall on useful surface rate,

A_{eclnat}: floor area of useful surface with access to natural light [m²],

R : light reflectance through walls of the group, average R for ceiling R=0.7 ; for wall R=0.5; for floor R=0.3.

Illumination flux through the window after taking into account any masks, Fl_{teq}, is the result of a formula depends on :

- Direct incident illuminance E_{dir};
- Diffuse incident illuminance E_{dif} ;
- Reflected on the ground incident illuminance: E_{ref} ;
- Inside room reflecting illuminance before to light the working desk. The coefficient 0.2 and 0.6 consider the attenuation of daylight due to the reflecting respectively on the floor and the ceiling for the axis transmitted solar illuminance, on the ceiling for the axis transmitted ground reflecting illuminance.

The formula becomes:

$$\frac{Fl_{\mathrm{teq}}}{A_{\mathrm{w}}} = (0.2 \times Tlii + Tlid).E_{\mathrm{dir}} + (Tlii + Tlid).E_{\mathrm{dif}} + (Tlid + 0.6 \times Tlii).E_{\mathrm{ref}} \qquad (2)$$

where:

- A_{w} is the window surface;
- Tli is the global transmission factor for solar illuminance. Under normal angle it becomes τ_v^{n-h}[6]. It is the sum of :
  - $Tlii$: axis transmission factor for solar illuminance. Under normal angle it becomes τ_v^{n-n}[6];
  - $Tlid$: all direction transmission factor for solar illuminance.
  - Tld : global transmission factor for diffuse illuminance. It can also be expressed Tl ou τ_v^{h-h}[6]. This factor is link to E_{dif}. It becomes in the formula $Tlii + Tlid$ because the $Tld = Tli$ hypothesis has been made.

In case of solar protection, the rate of the protected window Rp and the transmission factors ($Tlii$ and $Tlid$) of the windows with solar blinds must be taken into account.

The artificial lighting system is expected to provide an extra lighting flux if the natural one is below a given set point in lux. In the framework of $Bbio$ calculation, the system is conventional. This allows computing the “artificial lighting needs” Q_l in kWh/m².year.

b. Thermal Model

The thermal model is strongly inspired by [1] and a previous version of it has been sketched in [7] and [8]. It is based on the simplification of the heat transfer between indoor and external environment. A 5RC equivalent electric representation of the building components is used. The main underlying hypotheses are

- presence of heavy walls with homogeneous thermal properties;
- presence of light envelop element with homogenous thermal properties;
- heavy and light wall temperature should be close.

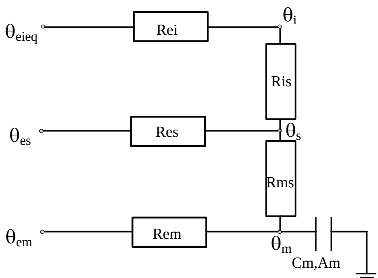

Figure 1 : 5RC network

The main advantage of the model is its ease of use. Inputs are easy to parameterize and it is convenient for taking into account phenomena such as variable solar protection or variable ventilation flow rate.

The building is described by three temperatures: the indoor temperature θ_{i}, the mass temperature θ_{m} of heavy walls and θ_s, being defined as

$$\theta_s = \frac{h_{ci}.\theta_i + h_{ri}.\theta_{rm}}{h_{ci} + h_{ri}}, \tag{3}$$

where θ_{rm} is the indoor mean radiant temperature, h_{ci} is the fixed convective transfert coefficient between envelope elements and indoor air, and h_{ri} is the radiative transfert coefficient between envelope elements . Heat exchanges with the outdoor environment are modeled by three phenomena each associated with one equivalent outdoor temperature, and one resistance:

- θ_{eieq}, the equivalent external air temperature;
- θ_{es}, the equivalent temperature for light external components (including solar and wind phenomena);
- θ_{em}, the solar equivalent temperature for heavy external components.

θ_{e} being the outdoor air temperature, θ_{es}, θ_{eieq} and θ_{em} are calculated from θ_{e}, the direct solar radiation, the long wave sky radiation and wall and window characteristics as well as the air flow temperature and humidity. Each resistance is evaluated at each time step. Note that the air pressure is dynamically calculated following NF EN 15242 [9]; this is needed for evaluating θ_{eieq}.

In the Th-B mode, one requires the operative temperature θ_{op} defined as

$$\theta_{\mathrm{op}} = \frac{\theta_{\mathrm{i}} + \theta_{\mathrm{rm}}}{2} \tag{4}$$

to stay equal or above a temperature set point in winter and equal or below a temperature set point in summer if the unit is cooled down. Energy needs denoted ϕ will be computed assuming energy flow is half convective, half radiative. Therefore, half of it is injected on the air node, and the other half is dispatched on the θ_s and θ_m nodes. These energy flows are respectively denoted ϕ_i and ϕ_r. Once the boundary conditions are known (i.e. climatic data, internal gains from occupant, position of solar protections, recoverable losses for the lighting system, windows opening ratio and therefore all resistances and energy flows except ϕ), the 5RC network turns out to be an implicit equation that links θ_{op} and the ϕ's.

$$f(\theta_{\mathrm{op}}, \phi_i, \phi_r) = 0. \tag{5}$$

One can easily proves that this system is linear so that it behaves as

$$\theta_{op}(\phi_i, \phi_r) = A(t)\phi_i + B(t)\phi_r + \theta_{\mathrm{op,free}}(\mathrm{t}), \tag{6}$$

where $A(t), B(t)$ and $\theta_{\text{op,free}}(t)$ are real numbers varying at each time step**.** They are numerically computed by solving the 5RC network in three different configurations:

- $\phi_r = \phi_i = 0$. One finds the value for $\theta_{\text{op,free}}(\text{t})$,
- $\phi_r \neq 0, \phi_i = 0$. One finds the value for $B(t)$,
- $\phi_r = 0, \phi_i \neq 0$. One finds the value for $A(t)$.

As the Th-B mode assumes that the space is heated by a conventional system that emits equally in a convective and radiative way, we get $\phi_r = \phi_i = \phi/2$. If $\theta_{\text{op,free}}(t)$ happens to be below (resp. above) the temperature set point in winter (resp. summer), then ϕ is computed has

$$\phi(t) = 2 \times \frac{\theta_{\text{SetPoint}} - \theta_{\text{op,free}}(\text{t})}{A(t)+B(t)}, \quad (7)$$

Depending its sign, $\phi(t)$ contributes to the heating needs Q_h or to the cooling needs Q_c as follows:

$$\begin{cases} Q_h & = & \dfrac{\sum_t \text{Max}\,(0, \phi(t))}{A} \\ Q_c & = & \dfrac{\sum_t \text{Min}\,(0, \phi(t))}{A} \end{cases} \quad (8)$$

where A is the conditioned local surface. Q_h and Q_c are expressed in kWh/m²year.

3. Validation of the Thermal Model

We show the results of the European procedure [10] for validating dynamic methods for the calculation of the heating and cooling annual energy needs.

This method consists in comparing the heating and cooling needs calculated with COMETH to reference results. References are heating and cooling needs computed with seven European calculation models namely Consoclim, Clim2000, EPBD hourly, TRNSYS IDMEC, ESP IDMEC, HAUSER KST, CAPSOL. At first, four cases of validation, without any intermittence, are defined to calibrate the methods. In a second step, eight more realistic cases are used to validate the heating/cooling needs model.

a. Initial Test Case Description

The initial local, monozone, is a room in an office. Its length is 3.6 m, its depth 5.5 m and the local is 2.8 m high. The external wall including window glazing of 7 m² is facing west. The internal walls are supposed to be adiabatic. The internal gains (100% convective) and the ventilation are intermittent and depend on the occupancy, which is common in an office.

The local is located in Trappes, France. The weather (external temperature and solar radiations) is given in [10].

Once the initial case is described, three more test cases are defined. The case #2 differs from case #1 by other ceiling and roof characteristics and by a higher thermal inertia. The case #3 has no internal gains while the #4 has no solar protection.

b. Validation Tests Description

The last eight validation cases have intermittent boundary conditions, which allows for testing the response of the model to dynamic solicitations. For cases from #5 to #8, the intermittency of heating and cooling is added. The heating and cooling system could run between 8.00h and 18.00h, only during the weekdays. The rest of the week, they're off. The cases #9 to #12 incorporate the assumptions of cases #5 to #8 but a roof is added. Consequently it increases the solar gains and the thermal losses of the local.

Only the last eight cases are used to validate the thermal model. Results of cases #1 to #4 are only given for information.

c. Outcomes

In the following two graphs, the results of COMETH are compared to the CEN standard ones.

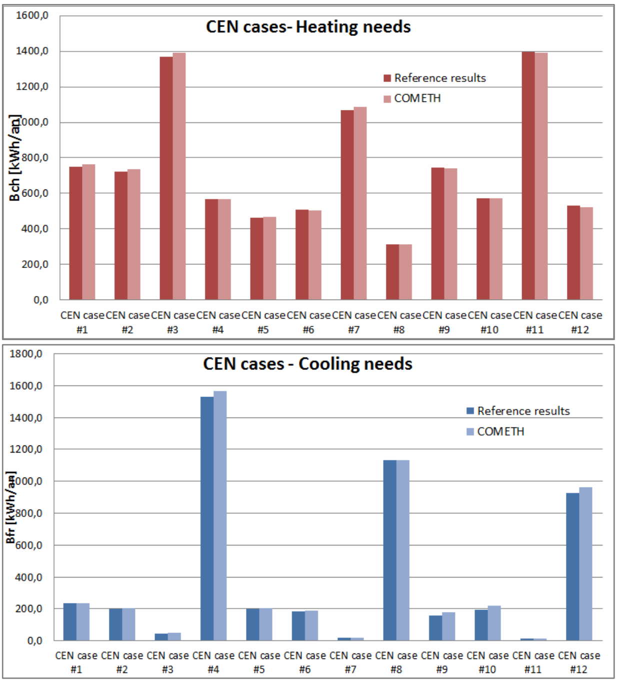

Figure 2: Heating and Cooling needs on all CEN configurations

The results for heating, Q_H, and cooling, Q_C, (expressed in kWh/year) are provided for the complete year and compared to reference values by calculating:

$$\begin{cases} rQ_H = \dfrac{|Q_H - Q_{H,réf}|}{Q_{TOT,réf}} \\ rQ_C = \dfrac{|Q_C - Q_{C,réf}|}{Q_{TOT,réf}} \end{cases} \quad (9)$$

which are represented in the following figure :

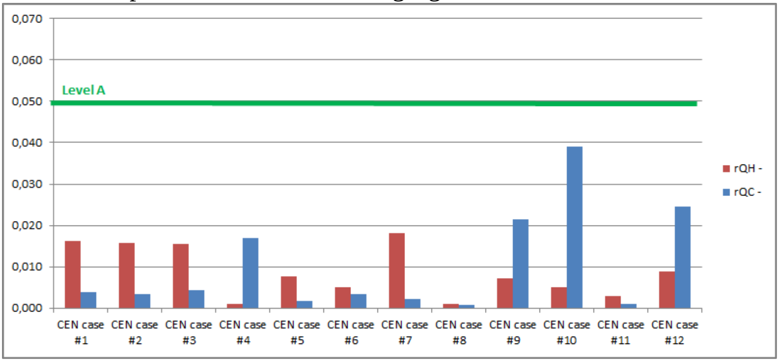

Figure 3: Validation criteria for COMETH

To reach the level A, the model must have all validation criteria under 0.05. This is the case for COMETH. Our model is adapted to evaluate the heating and cooling needs in the building. The eight validation cases of the CEN procedure allow to model different phenomena (intermittency of heating and cooling supply, solar gains, inertia, etc.) and to check that COMETH reproduces correctly all these dynamic phenomena.

4. The Bioclimatic Design in the RT2012

In RT2005, the model evaluated the quality of the building with the indicator « *Ubât* » which was the overall envelope thermal resistance.

The RT2012 goes further and defines the new indicator *Bbio* (for "Besoins Bioclimatiques i.e. Bioclimatic Needs") that evaluates the quality of the building without its HVAC, lighting or domestic hot water systems. It should not only take into account the thermal losses through the building envelope but also integrates notions of thermal inertia, air permeability and the internal geometry itself through contributions of natural lighting as presented in the previous sections.

The *Bbio* is a weighted sum of the heating, cooling and lighting needs as defined in the previous section.

$$Bbio = 2 \times Q_h + 2 \times Q_c + 5 \times Q_l \quad (10)$$

The $Bbio$ indicator thus encourages a good quality of building while taking into account its integration in its environment. The required decrease of building energy consumption in France and in Europe demands buildings with low needs. This is achieved by a good conception that benefits as much as possible from the window natural lighting.

5. Example

a. Computation

A single house, located in Nantes, France, with a 142 m² conditioned surface is taken as an example to evaluate the $Bbio$ on a real building. The geometry and the energetic characteristics of building elements are described in the table below.

Table 1.characteristic of the house

	Area [m²]	U [W/m².K]
Vertical walls	143.2	0.17
Windows	35.4	1.14
Roof	142.0	0.15
Floor	135.4	0.17

The thermal bridges are 178 m long for a mean thermal bridging factor of 0.11 W/m.K. The inertia of this house is considered « light »[11]. The hygienic flow is 170 m^3/h while the infiltration rate is 41.6 m^3/h under 4 Pa. The conventions of the French Regulation being used, the occupancy is entirely conventional [14]. And the house is considered to be not cooled down by any active system. The outcomes of the annual simulation are

Table 2. Heating, cooling and lighting needs

	[kWh/ m²$SHON_{RT}$/yr]	[points]
Heating Needs	12.4	24.8
Cooling Needs	0	0
Lighting	1.4	7.1
		Bbio=31.9

The calculated $Bbio$ reaches 31.9 points which is a lower value than the required $Bbiomax$ for single house (59.7 points [12]). The main contributor to the $Bbio$ is, for this case, the heating needs but the part of the artificial lighting is not negligible.

6. Sensitivity on Bbio

The weight given to the artificial lighting in the Bbio indicator shows how central is this point during the conception of the building. Even if a window causes more thermal losses than an insulated wall, it brings more solar gains and natural lighting so that it reduces the consumption of artificial lighting.

In order to understand the central role of windows, we study the impact of the windows area on the heating needs on the one hand and on the other hand on lighting needs. In the graphic below, the area of the south facing window of the house described below is changed from 5.6 m² to 45.6 m².

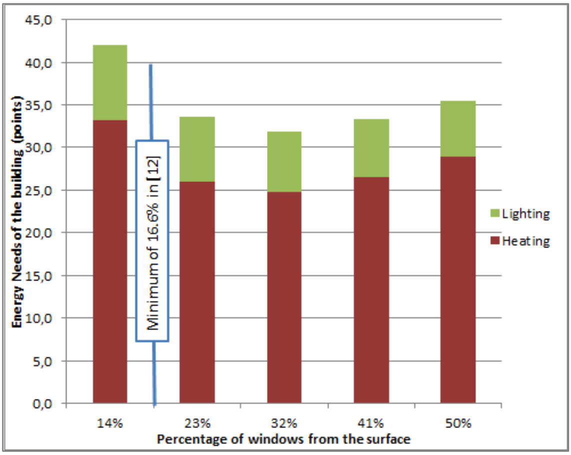

Figure 4: Impact of window area on Bbio

The bigger the window (facing south) become, the lower the consumption of artificial lighting is. The variation on heating needs is balanced between solar gains, internal gains (due to artificial lighting) and thermal losses.

Finally, it should be noted that the lighting needs of a residential building are not very high, contrary to the needs of other sectors as in the office sector. In this case, we can show that the lighting needs are often the most important ones.

7. Conclusion

In this paper, we presented COMETH. We showed that it also takes into account an artificial lighting procedure and thus assesses the bioclimatic design from a more global point a view than just heating and cooling. As the energy consumption of heating and cooling systems is going down, such global considerations are essential. Moreover, heating/cooling needs and lighting needs cannot be evaluated independently. Lighting recoverable losses play an essential role in the heating/cooling needs assessment, and control of solar protections does also depend on both the thermal and visual comfort.

We proved that COMETH thermal kernel is of level A considering the CEN classification. Note that there is no framework for testing the artificial lighting system consumption calculation. As said above, given the importance of this aspect, this might become relevant.

Note that COMETH is much more that a heating/cooling and lighting needs evaluation. We only presented this very specific aspect of COMETH which comes with much more functionalities such as HVAC and domestic hot water systems consumption and dynamic interaction with the building, solar systems models, renewable share calculation and summer comfort assessing. COMETH is also based on an innovative multi-platform IT technology that allows to plug-in innovative modules, systems and controls and to connect the kernel though an API.

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