bSol : A straightforward approach to optimize building comfort and energy consumption in early design process.

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ABSTRACT

The software bSol addresses to the professionals (engineers and architects) eager to optimize the parameters of a building project according to the local environment. It allows, hour per hour over a whole year, to determine the thermal response of a building located under specific climatic conditions (including local horizon): the solar gains are taken into account in a very efficient way.

Moreover, this software offers a sensitivity study by varying eight constructive parameters, (thermal protection, size of the glazed openings, choice of the glazings, attenuation of the blinds, ventilation with/without recovery of heat, thermal inertia).

In addition, bSol gives a very good idea of the comfort obtained inside the building.

KEYWORDS

Early design, comfort, thermal loads, heat capacity, sustainable buildings.

INTRODUCTION

bSol is a tool developped for the professionals (engineers and architects) that can easily be used in an early design process in a very quick and efficient way without the need of deep building simulation knowledge.

The bSol software can handle up to 2 zones (rooms or a group of rooms having the same inside temperature) in thermal contact with each other.

To analyse a building area bSol assesses the thermal gains and losses in an hourly manner, in the frame of a model with one node, thus determining, hour after hour, the evolution of the inside temperature.

To have comfort conditions, variable parameters can be activated (lowering mobile solar protections, increasing ventilation in order to cool the room). As a last resort, a technical installation (heating, cooling) intervenes to guarantee the comfortable temperature inside.

The sum of all the interventions performed by the technical installation over a certain time period indicates precisely the energy (for heating or cooling) needed to guarantee thermal comfort. The maximum energy value provided by the technical installation in one hour determines the necessary peak power (for heating or cooling).

THEORETICAL BASES

Thermal balance

Generally speaking, for the area considered, the sum of the various thermal power losses (towards outside, towards various elements of the ground, towards various rooms having a constant temperature as well as towards another area) equals the sum of thermal gains (solar gains through glazing, destocking of heat accumulated in the structures, internal gains generated by people and/or electrical devices, and gains from the technical installation (positive for heating and negative for cooling)). This thermal balance is represented by the following equation:

$$H_e\left(\theta_i(t)-\theta_e(t)\right) + \sum_k H_{Gk}\left(\theta_i(t)-\theta_{Gk}(t)\right) + \sum_k H_{0k}\left(\theta_i(t)-\theta_{0k}\right) + H_{in}\left(\theta_i(t)-\theta_{in}(t)\right) = \sum_k g_{Sk}(t)\,F_F\,g_k\,A_{Wk}\,G_k(t) - C\,\frac{d\theta_i(t)}{dt} + SRE_0\left(P_{iP}(t)+P_{iE}(t)\right) + SRE\;P_{HC}(t) \quad (1)$$

Where the various specific thermal losses H are given by:

$$H_e = \left(\sum_{(j)_e} A_j U_j + \sum_{(j)_e} L_j \psi_j + \sum_{(j)_e} \chi_j\right) + c_a\,\rho_a\,(1-\eta)\,\dot{V}_e \quad (2)$$

$$H_{Gk} = \left(\sum_{(j)_{Gk}} A_j U_j + \sum_{(j)_{Gk}} L_j \psi_j + \sum_{(j)_{Gk}} \chi_j\right) \quad (3)$$

$$H_{0k} = \left(\sum_{(j)_{0k}} A_j U_j + \sum_{(j)_{0k}} L_j \psi_j + \sum_{(j)_{0k}} \chi_j\right) \quad (4)$$

$$H_{in} = \left(\sum_{(j)_{in}} A_j U_j + \sum_{(j)_{in}} L_j \psi_j + \sum_{(j)_{in}} \chi_j\right) + c_a\,\rho_a\,\dot{V}_{in} \quad (5)$$

Meteorological data

Outside temperature

For the outside temperature, bSol uses hourly data (from January 1st to December 31st). For a given geographic area, these values can – for instance – be extracted from the METEONORM database.

Ground temperature in contact with a structural element

The ground temperature in contact with a structural element located at a given depth below the ground level is analytically determined with the equation of heat conduction:

$$c\rho \frac{\partial \theta}{\partial t} = div(\lambda \; grad(\theta)) \qquad (6)$$

in which c, ρ et λ represent the specific heat, density and the thermal conductivity of the ground. The following assumptions are made:

- the ground is homogenous (constant thermal conductivity, specific heat and density)
- the structural element in contact with the ground is homogenous as for its U value and large (no edge effect)
- the ground temperature - on the surface can be considered as a harmonic function over a year (1st component of the development in Fourier series of the outside temperature)
- the inside temperature in contact with the ground is constant throughout the year

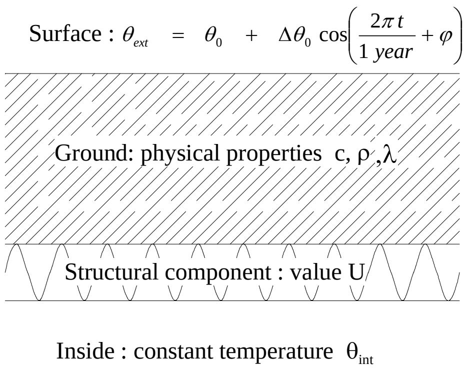

Figure 1 Contact between ground and a structural element

The ground temperature determined in this way takes into account the area thermal losses - towards the ground.

Sun radiation

The incidental radiation G_k on a window which is arbitrarily oriented k is calculated by bSol on the basis of rough time data of global radiances G_h and diffuse radiations D_h on a horizontal level, without any effect of horizon.

$$G_k = B_k + D_k^{sky} + D_k^{reflected} \qquad (7)$$

$$B_k = (G_h - D_h)\frac{\cos\vartheta}{\sin\eta} \qquad (8)$$

An isotropic model for the diffuse sky radiation, D^{sky}, is used. The effects of the horizon act simultaneously on the direct radiation B_k (horizon), on the diffused radiation D through sky view factors, on the ground factor of surface k (r_{Dk} and r_{Rk}) and of an horizontal surface (r_{Dh} and r_{Rh}).

$$D_k^{sky} = r_{Dk}\, D_h \qquad (9)$$

$$D_k^{reflected} = r_{Rk}\, \rho \frac{(G_h - D_h) + r_{Dh} D_h}{1 - \rho r_{Rh}} \qquad (10)$$

(sun above horizon)

$$D_k^{reflected} = r_{Rk}\, \rho \frac{r_{Dh} D_h}{1 - \rho r_{Rh}} \qquad (11)$$

(sun below horizon)

$$r_{Dk} + r_{Rk} = 1 \qquad (12)$$

$$\rho = \rho_0 + \delta_\rho \exp\left(-0.038(\overline{\theta}_e + 3\,^0C)\right) \qquad (13)$$
$$for \quad \overline{\vartheta}_e > -3\,^0C$$

Heat capacity

A structural element in contact with the inside climate can accumulate heat during certain hours of the day (solar supply through the glazing, heat produced by people or electrical devices, etc) and gives it back to the room when the temperature of the room falls. bSol handles these phenomena by admitting that :

- the temperature on the interior surface of the considered element varies according to the relation:

$$\theta_i(t) = \theta_{0i} + \Delta\theta \cos\left(\frac{2\pi t}{1\,day} + \phi\right) \qquad (14)$$

- the heat flow on the other face of the structural element is null (adiabatic plan). This happens in many situations, for example when the higher face of a concrete flagstone is insulated, when an outside wall in masonry has a peripheral insulation. The median plan of an interior wall can also be considered as an adiabatic plan: any interior partition must be cut out in two half-thicknesses, each one belonging to one of the rooms contiguous to the partition.
- the heat Q_k^{sto} stored in a structural element k is considered as the daily total heat flow entering the considered element.
- the heat capacity of the element is the quotient of accumulated heat divided by two times of the temperature variation amplitude.

$$C_k = \frac{Q_k^{sto}}{2\,\Delta\theta} \qquad (15)$$

- the heat capacity C associated with the inside node is considered as the sum of all the heat capacities of each element in contact with the inside air, the heat capacity of the air itself is neglected:

$$C = \sum_{(k)_i} C_k \quad (16)$$

From a practical point of view, bSol allows three alternatives:

1. the layer of storage k is directly in contact with the air of the room.

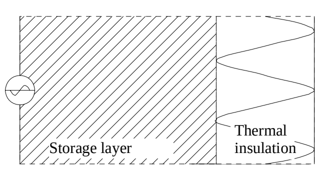

Figure 2 Direct contact with air

2. the layer of storage is in contact with the air of the room through a thermal resistance, such as woodwork, wallpaper, carpet, whose heat capacity can be neglected.

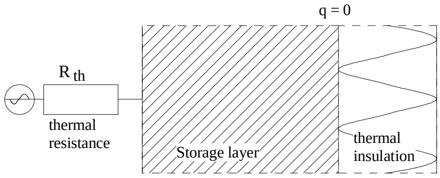

Figure 3 Contact through a thermal resistance

3. the layer of storage is covered with an overlap layer, such as roughcast, thick woodwork; in this case, the heat capacities of both layers are rigorously taken into account.

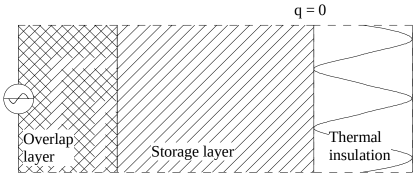

Figure 4 Contact through an overlap layer

Tuning elements

Heat evacuation through ventilation

As soon as the inside temperature exceeds the predefined point θ_V and the temperature of outside air is lower than the inside temperature of at least $\Delta\theta_V$, the flow of air renewal is increased till its upper value. It resumes its lower value as soon as one of the two conditions is no longer fulfilled.

Air exchange with the other zone

For the flow of air exchange between both areas, the higher value is taken into account each time the situation requires the heating of an area that is below the predefined heating value or the cooling of an area that is above the predefined value of air conditioning. In all the other cases the lower value of the flow is used.

Mobile solar protection

The effect of mobile solar protections is taken into account using a factor of solar transmission g_S. When the inside temperature reaches the predefined value θ_S and/or when the global radiance on the window considered goes above the predefined value g_S, the factor of solar transmission takes the value that characterises the lowered solar protection. Without these conditions the solar heat gain coefficient goes back to its value 1.

Technical installation

When the heating is activated and the inside temperature falls below the predefined value, the heating compensates, in one hour, the inside heat deficit, and this until the maximum deliverable heating power is used. In the case of a nocturnal lowering of temperature, the set value is restored in one hour, unless the available heating power is not sufficient.

In the same way, when air-conditioning is active and the temperature is higher than the predefined cooling temperature, the technical installation extracts, in one hour, the calorific excess, and this until the maximum available power is used.

Parameter variation

bSol proposes – in addition to determination of the energetic needs (heating and air-conditioning) – optimization assistance: the idea consists of varying successively each of the 8 different constructive parameters and quantifying the modifications of the response in energy and power.

- U_{opaque} : value U of the opaque elements of the building envelop
- $U_{glazing}$: value U of glazing
- U_{frame} : value U of the window frames
- η : efficiency of the heat recovery system
- S_{window} : windows area
- $g_{glazing}$: total energy profit of glazing
- g_{blind} : attenuation factor of the blinds
- C_{cal} : heat capacity

Principle applied for the parameters variation (surface of the windows excluded)

The parameter value is compared with an ideal value associated with this parameter. The parameter is then modified, in order to satisfy, on a logarithmic scale, the quarter of the variation which separates its initial value from the ideal value. This way of doing takes into account the fact that, if a structural element is very weak compared to the current ideal standard, it is very easy to improve it, whereas it is much more difficult to do it if the initial value is close to the ideal one.

For example for a glazing: if the initial value U is 2.9 W/m^{2}K, and the ideal value U of 0.6 W/m^{2}K, the value U after variation will be $\sqrt[4]{(2.9)^3(0.6)} \approx 2.0$ W/m^{2}K; if, on the other hand, the initial value U had been 1.1 W/m^{2}K, the value U after variation would have been ≈ 0.95 W/m^{2}K.

Table 1 Ideal values admitted for the different parameters

(U_{opaque})ideal	0.1 W/m^{2}K
$(U_{glazing})$ideal	0.6 W/m^{2}K
(U_{cadre})ideal	0.9 W/m^{2}K
$(1-\eta)$ideal	0.1
$(g_{glazing})$ideal	0.85
(g_{blind})ideal	0.15
(C_{cal})ideal	1.5 MJ/m^{2}K

Principle applied for the variation of the surface of the windows

Based on the orientation of each window of the project, the "dominant direction" is identified (for example South for a project in which there are large South windows and only reduced North openings).

In the dominant direction, the surface variation of the windows is calculated by increasing it until the remaining opaque wall surface in this direction will reach the quarter of its original value. In the opposite direction of the dominant direction, the variation of surfaces of windows is done by decreasing them by a quarter compared to their initial surface.

For an intermediate orientation of window between the two preceding directions, the variation is calculated on the basis of one of the two preceding principles by using a projection factor (cosine of the angle located between the orientation of the window and the dominant direction).

SIMULATION

A bSol project

The main challenge with bSol was to develop a simple interface so that any engineer or architect can use it during the preliminary draft of a construction. A bSol project consists in the four following elements:

- the building : physical description of construction (volume, surface of the walls, thicknesses, materials, storage mass, description of heat recovery system, etc)
- the use of the building : operating temperatures (heating and/or cooling), internal gains, blinds management, ventilation, etc
- the weather data and local horizon : outside temperature, solar radiation, sun position (height and azimuth)
- the horizon : definition of the local horizon

Simulation results

Once the building, the operation, the weather and the horizon parameters have been defined, bSol makes the calculation and shows the results (Figure 5).

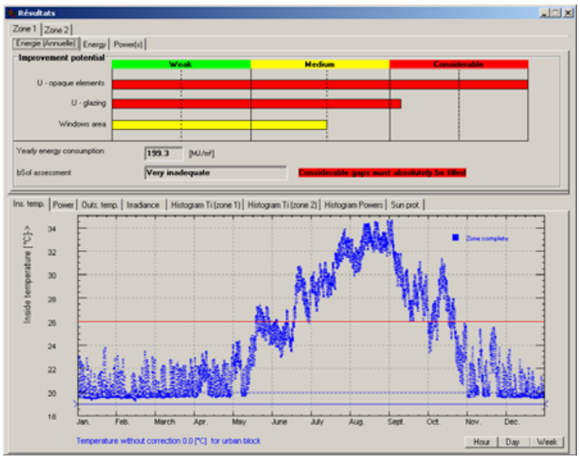

Figure 5 bSol results: main window

- The first part shows the projetct improvement potential from the energy point of view and the energy consumption (heating and/or cooling) for one year or one selected period of time.
- The lower part shows different charts, for example: the inside temperatures or the powers of heating and air-conditioning per hour over the year.

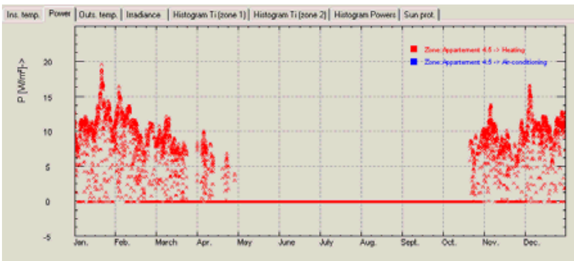

Figure 6 bSol results: power needs

Examples

a) Residential building – heating energy optimization

The aim of this example is to look at the impact that certain constructive modifications bring from an energy point of view. This example deals with a flat at the center of a residential building built during the 1960s.

Several constructive alternatives can optimize this apartment at the energy level (ie. insulation optimization, glazing quality, air recovery system). Some alternatives are more interesting from a financial or technical point of view. bSol shows the impact, in term of energy, of these various potential interventions.

In this particular example bSol confirms that important gaps must be corrected in order to optimize the energy consumption in this apartment (figure 7). It is strongly advised to put a particular effort on the ventilation and the glazings quality.

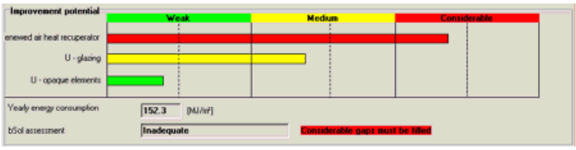

Figure 7 bSol results: improvement potential

Figure 8 shows detailed information on the potentials of improvement according to the eight parameters described previously.

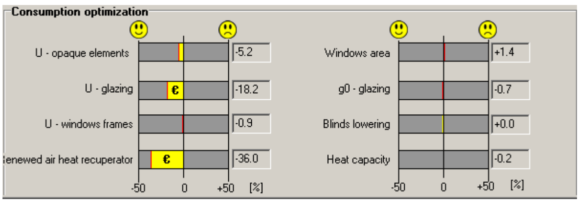

Figure 8 bSol results: main window

b) Office building – overheating issue

This example treats an office building with a northern face oriented 15 degrees west and entirely glazed. Despite a specific energy label this administrative building presents summer overheating: temperatures over 30°C were measured during the first year of operation.

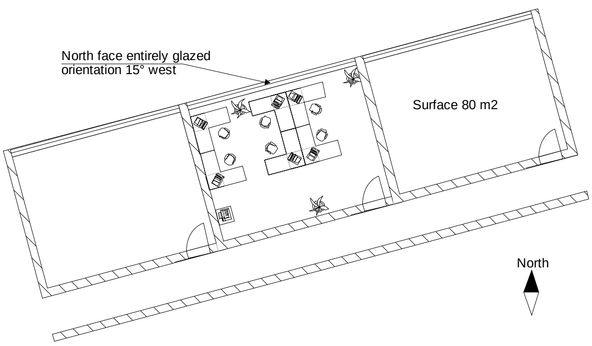

Figure 9 Office room plan

A typical office room was introduced and simulated with bSol in order to visualize the overheating problems. Figure 10 shows the simulation results: overheating already appears at the beginning of May and gets worse during the summer months.

Figure 10 Hourly inside temperatures from May to September without solar protections

A second simulation test (figure 11) was carried out by adding mobile solar protections on the northern face of the building. The installation and correct use of these blinds eliminate overheating problems.

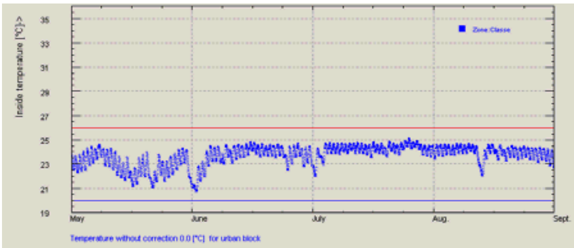

Figure 11 Hourly inside temperatures from May to September without solar protections

This real example shows the utility of the bSol software; costs could have been reduced easily if the simulation had been done in the early design process.

CONCLUSION

bSol is a simple but thorough tool for complete energy planning; it takes into account complex dynamic phenomena. It can be used by engineers and architects alike. bSol :

- is light and easy to use: it was designed for non-specialists in data processing
- is user friendly: a calculation for a unit (house, office, whole building) is carried out in less than one working hour
- determines the energy response of an object - heating and air-conditioning - by carrying out the time assessments of all the heat fluxes
- uses the local weather data (outside temperature, solar radiation)

- considers the effects of horizon which obstruct the solar radiation
- performs its analysis by taking into account the thermal inertia of the building, i.e. the effects of mass in which heat can be temporarily stored
- can simultaneously consider two different areas of the same object interacting thermically one with the other (for example winter garden and house)
- offers a time management of the internal gains
- takes into account the blinds which can sometimes be raised in order for the solar radiation to enter the building, sometimes be lowered to avoid overheating
- gives a good perception of the thermal comfort encountered inside the simulated area
- studies, in addition to the configuration of reference, a whole series of configurations of construction and thus offers a synthetic view of the choices to optimize the energy aspect of a construction.

bSol is profiled thus like an instrument of integral energy planning (energy and power, heating and air-conditioning) in the early design process.

NOMENCLATURE

Table 2 index terms

INDEX	TERMS
0	Constant temperature
C	Cooling
D	Diffuse
e	Exterior / outside
E	Electrical devices
F	Window frame
G	Ground
H	Heating
h	Horizontal plan
i	Interior / inside
in	Other zone
j, k	Sum index
k	Any orientation plan
P	People
R	Reflected
S	Solar protection
W	Windows
V	Ventilation

Table 3 symbols description

SYMBOLS	UNITS	TERMS
V	m^3/s	Flow of air exchange
A	m^2	Surface area
L	m	Length
B	W/m^2	Direct radiation
C	J/K	Heat capacity
c_a	J/kgK	Air specific heat
H	W/K	Specific heat losses
D	W/m^2	Diffuse radiation
F	-	Reduction factor
g	-	Radiation transmission factor
G	W/m^2	Global radiation
P	W/m^2	Heating or cooling specific power per SRE
Q^{sto}	J	Daily stored heat
r	-	View factor
SRE	m^2	Energy reference area
SRE_0	m^2	Energy reference area with high correction
U	W/m^2K	Overall heat transfer coefficient
ψ	W/mK	Linear heat transmission coefficient
χ	W/K	Punctual heat transmission coefficient
Δθ	^0C	Amplitude of the daily temperature variation
α	-	Sun azimuth
η	-	Heat recovery effectivness
η	-	Elevation angle
θ	^0C	Temperature
θ	-	Incidence angle
ρ_a	kg/m^3	Air mass density
ρ	-	Ground albedo

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