MULTIPLE-VIEW PERFORMANCE ASSESSMENT OF AN OFFICE BUILDING

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ABSTRACT

This paper presents the multiple-view performance assessment of an existing office building undertaken with an integrated application. It includes the assessment of the energy consumption, room acoustics, occupant comfort, and the environmental impacts (fuel, materials, transport, and processes) . The simulation results have been compared with in-situ measurements monitored in the building during the post-occupancy phase to analyse the conformity of the results.

Keywords: Integrated performance simulation; Energy consumption, Life cycle impact assessment, Room acoustics, Building design

INTRODUCTION

One of the major concerns of the scientific community is to resolve specific problems the building industry is confronted with. Preservation of non-renewable resources, occupant comfort and environmental impact limitation are the new issues of modern architecture. The necessity for an efficient construction industry has brought forward new architectural concepts whose performance assessment requires a multiple-view analysis.

To meet this challenge, a data model of the building was developed independently of any simulation tool. Then, to demonstrate the feasibility of the proposed approach, the model was implemented in ESP-r [5] whose capability was extended at the same time to include two new views that are: (1) Room acoustics, in which the reverberation time is assessed with different methods (Sabine [20], Eyring [6] and Millington [15]) based on the diffuse-sound field theory and which takes into account the absorption of the boundaries, occupants, furniture, and the enclosed air; (2) a Life Cycle Impact Assessment (LCIA), in which the environmental effects of the building are appraised, including all the phases of the building life (construction, maintenance and elimination). These developments are presented by the author in an other paper presented at this conference.

CASE STUDY ANALYSIS

The headquarters of Energie Ouest Suisse (EOS), one of the major electricity producing companies in Switzerland, was selected as a case study.

The EOS building is a four-story office building, constructed between 1994-1995 in the city centre of Lausanne in the south-western part of Switzerland on the Geneva lake shore (Latitude 46.32 N, Longitude 64.48 E, altitude 492 m). It is situated on a sloping site with a south-west orientation and consists of two building blocks linked by an entrance platform on the ground floor as shown in Figure 1. The building comprises about 10 office rooms per floor (400 m² per floor) which correspond to a total gross area of 5900 m². The majority of the office rooms are located along the main building facade.

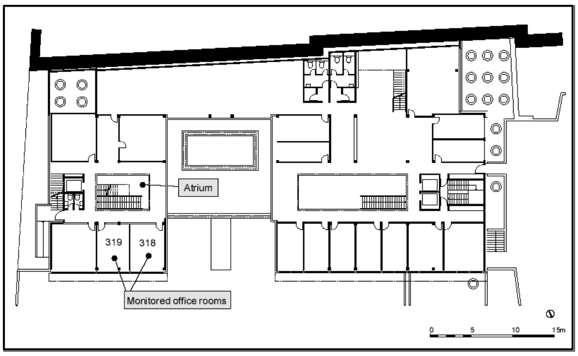

Figure 1 Plans of the EOS building

External light shelves are installed above a row of windows for office rooms located on the south facade as shown in Figure 2.

Figure 2 Wiew of the EOS building

The design of the light shelves was carefully studied before building construction, with the aim of optimising their geometry (slanting angle) and their photometry (type of material and specularity) by means of scale model simulation [3]. Finally, a central atrium is located behind the office rooms and provides them with daylight from the back. A complementary architectural description of the EOS building can be found in [1].

Typical office

Each office room is occupied by one person, and has a width of 5.7 m, a depth of 5.2 m and a height of 2.6 m. The floor is made of a 24 cm height plenum with a fitted carpet and the ceiling has a roughcast finish applied directly to the concrete slab in order to improve the thermal inertia. The partitions are made of steel sheeted plasterboard with a 5 cm mineral wool insulation. The office room is provided with daylight mainly from the facade openings, which have a glazing area of 4.4 m². In addition, an opening of 1.2 m² is located on the back side of the room and provides daylight to the room through the central atrium. The glazing ratio of an office room is equal to 0.19: the main part of the glazing area is located on the main facade (4.4 m^2).

Constructions

The EOS building is made of a concrete envelope. The roof is insulated with cellular glass and the ventilated facade with glass wool. The constructions composition are listed in Table 1.

The EOS building has super-insulated glazing systems for the facade. They are made of double clear float panes filled with Krypton, with two low-emissivity (14%) coating films tight inside the gas gap.

The internal windows (between the office and the atrium) consist of double clear float glass filled with air. The glazed area of the back wall corresponds to a small window fraction (0.09). Table 2 summarises the window's performance.

Construction	Material	Thickness [cm]
Roof	Vegetal layer (outside)	17
	Drainage layer	8
	Waterproofing	1
	Cellular glass	16
	Reinforced concrete	22
	Roughcast (intside)	1
Facade	Granite tile (outside)	2
	Ventilated air gap	5
	Glass wool	15
	Reinforced concrete	20
	Roughcast (intside)	1
Partition	PVC coating	0.001
	Steel sheet	0.6
	Plaster board	1.25
	Glass wool	5
	Plaster board	1.25
	Steel sheet	0.6
	PVC coating	0.001
Floor	Fitted carpet	1
	Chipboard	4
	Air gap + support. bar	24
	Reinforced concrete	22
	Roughcast	1

Table 1 Composition of the EOS constructions.

The windows have a PVC frame and aluminium spacer. An external fabric blind is used as a movable shading system for the facade window.

Properties	EOS glazing types	
	External (Facade)	Internal (back wall)
Layers thick [mm]	4/10/3/10/4	6/60/6
Visible transmit. [-]	0.62	0.78
Solar transmittance [-]	0.46	0.69
U-value [W/m²K]	0.77	2.85

Table 2 Properties of the EOS glazing systems.

Heating

The building is equipped with a central gas heating plant, which provides heat to the whole building. The heat is distributed through water radiators, located in each office. The set-point temperature is 20 [°C] during the occupied period, and an 18 [°C] setback is applied during off-hour periods on week days and during the week-end.

Ventilation/infiltration
There is no mechanical ventilation system in the office rooms. The building is naturally ventilated through transversal ventilation in the office and the openings located at the top of the central atrium. A large meeting space located in the core of the building is the only space equipped with a mechanical ventilation system which is used only when the meeting space is occupied.

Artificial lighting
There are no lighting fixtures on the office ceiling. Each desk is equipped with a floor luminary in direct-indirect lighting mode. Each luminary uses 4 compact fluorescent lamps (4 x TL36 W). Switching between luminaries is possible from the entrance door and from the work desk. There is no dimming function on the luminary either daylight responsive or user controlled.

The EOS office building was widly monitored during the European project 'Daylighting Design of European Building' [22] from the lighting and energy consuption viewpoints. Its proximity has permitted to extend the monitoring to domains that were not analysed previously.

COMPUTER MODEL

A detailed computer model of 21 interconnected thermal zones was set up, which represented the last two floors of the south-west core of the building as shown in Figure 3.

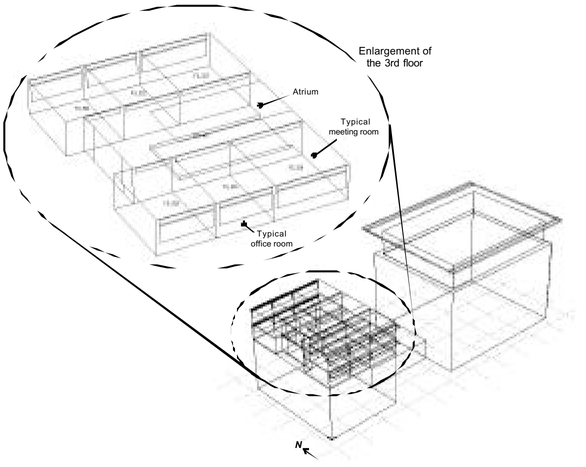

Figure 3 Computer model representation of EOS building.

A typical office situated on the third floor was selected for the daylight, room acoustic, thermal and visual comfort assessment, and was monitored for this purpose. The third and fourth floor underwent an energy and environmental impact assessment.

Once established, the computer model was used for energy, lighting, room acoustics, environmental impacts and occupant comfort analysis.

ENERGY CONSUMPTION

Thermal simulation was carried out on the basis of an hourly time step simulation using the Lausanne climate retrieved from Test Reference Years (TRY) generated with *Meteonorm* [19]. The annual energy consumption was assessed on the basis of the degree-day definition, for which the year was split into three different periods : winter, transient (spring and autumn) and summer. A typical week was selected for each period for its representativety of the climate throughout the period. This solution was necessary, because the control strategy (heating, infiltration, lighting, etc.) could not be simulated over the whole year with a single model.

As there was no dimming luminary, the artificial lighting simulation was performed with a fixed daylight profile, obtained from the daylight analysis. The daylighting profile, like the visual comfort analysis, was performed with the lighting module, which linked ESP-r and Radiance. An on/off control with a set point of 500 [lux] illuminance at the working place was assumed ([2], p A7-5 or [16], Annex B) from 7 a.m. to 6 p.m. during the weekdays and nil otherwise.

The annual energy consumption for heating, lighting and equipment in the EOS building are listed in Table 3.

Source	**Fuel**	**Delivered energy**	
		kWh/m² y	**MJ/ m² y**
Heating	Gas	75.1	270.3
Lighting	Electricity	2.7	9.7
Equipment	Electricity	8.4	30.1

Table 3 Energy consumption of the EOS building.

The heating energy consumption of the EOS building is good. This is not surprising when considering the solutions retained to reduce the heat loss through the shell and the absence of mechanical ventilation in most of the building. The heating energy consumption of the EOS building, averaged over the first three years of operation, is equal to 255 [MJ/m² y]) which corresponds to a difference of about 5% with the simulated results.

For practical reasons, it was not possible to monitor the specific annual electricity consumption of the lighting and the equipment separately and only the total electricity consumption was measured. The electricity delivered for the whole EOS building equals 11.8 [W/m²], while the simulation results estimation is about 11.1 [W/m²] (one quarter for the lighting and three quaters for the equipment). The closeness of these values is debatable.

It has been noticed that most of the occupants were relatively intensive computer users and the illuminance level at working place was generally lower than the 500 [lux] recommended for a work place in an office building. In fact, it was generally near 300 [lux] or even lower, for certain occupants. Thus, the simulation results for the lighting consumption, and correspondingly the total electricity consumption, should have been overestimated, which is not the case. It should be kept in mind that the electrical energy consumption includes the artificial lighting and the equipment. Therefore, if the lighting consumption is lower than estimated, the equipment electricity consumption should in reality be higher than simulated. This was confirmed during the post-occupancy visit, during which it was observed that several single office rooms had been equipped with a personal printer and/or a second computer. Furthermore several unexpected electrical devices such as battery chargers for mobile phones or music players that were not taken into account in the simulation, have also been observed. This supplementary consumption of electricity may have compensated the reduction of the artificial lighting consumption obtained in the simulation.

THERMAL COMFORT

The thermal comfort is expressed by the predicted percentage of dissatisfied (PPD) as defined in the ISO 7730 standard [12]. It was assessed in the typical office with the occupant clothing depending on the season and a metabolic rate that corresponds to a sedentary activity as listed in Table 4.

Season	Clothing [Clo]	Metabolic rate [Met]
Winter	1	1.2
Transient	0.85	1.2
Summer	0.5	1.2

Table 4 Clothing and metabolic rate used to assess the thermal comfort in the typical office.

The corresponding PPD in the typical office room during the occupancy period, for each typical seasonal day is given in Figure 4. During the winter and transient period, the thermal comfort is good. During the summer period, the occupant experiences overheating at the end of the day, when the sun is low on the horizon (west). The light shelf of the typical office room (facing South) does not stop direct sun radiation. The external fabric blind is not sufficiently efficient to stop the direct sun radiation and the upper part of the external window is not equipped with a shading system, which leads to unacceptable solar gains in the office. A post-occupancy evaluation of the EOS building confirmed that one third experience overheating *often* and one third *sometimes* during the summer period [21].

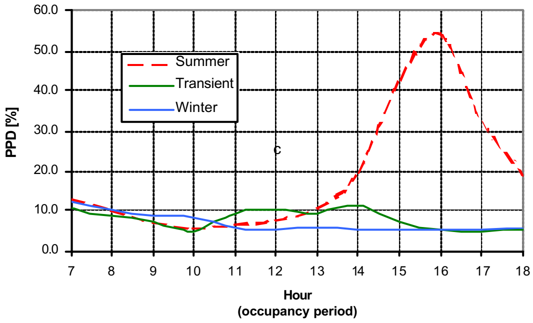

Figure 4 Thermal comfort assessment in a typical office for three typical seasonal days.

DAYLIGHTING

The daylighting profile, like the visual comfort analysis, was performed with the lighting module, which linkes ESP-r and Radiance [13].

The level and distribution of daylight factors (ratio between internal and external illuminance) has been used as an indicator of the impact of daylighting inside the building. A daylight factor profile is calculated for the representative office room. The profile is determined at the level of the work plane (0.8 m above the floor), perpendicularly to the window and in the middle of the room.

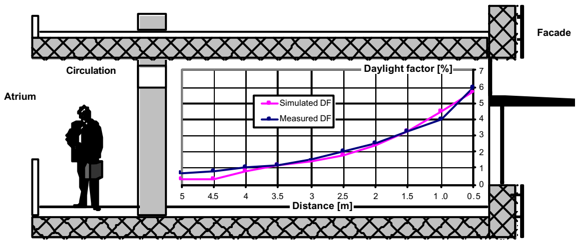

Figure 5 Measured and simulated daylight factors (DF) distribution in a typical office room.

The daylighting factors were measured at 0.7 [m] from the floor under overcast skies according to the procedure recommended by the CIE [4].

The daylight factor profiles of the monitored room and the corresponding simulation results are given in Figure 5. As can be observed, the computer simulation results are consistent with the in-situ measurements.

Compared to an office room without the light shelf, a more uniform illuminance distribution is achieved in the EOS office room, and thus better luminance contrasts. The post-occupancy evaluation of the EOS building has confirmed the positive appreciation of the daylighting features of the building.

The DF of 0.5% in the rear of the office is comparable to the DF that would be obtained in the same office without the internal window. Therefore, this opening in the back wall does not contribute significantly to the illuminance in the rear of the office. This is due to the low glazing fraction of the back opening and to the presence of the circulation of the upper storey, which play the role of horizontal eaves and thus reduce the supply of daylight from the atrium (left of Figure 5).

VISUAL COMFORT

The visual comfort has been estimated in the typical single office room with the Guth Visual Comfort Probability (VCP) [8], which expresses the percentage of persons satisfied with the visual environment when looking from a location in a certain direction.

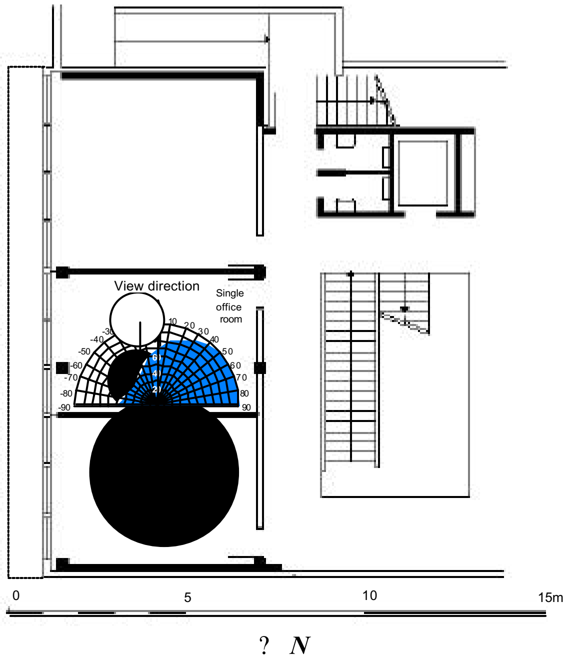

Figure 6 Guth Visual Comfort Probability (VCP) in a typical singe office room.

In the studied single office, the view position corresponds to the occupant seat, which is leaning with the back against the East partition. The VCP has been assessed with a view direction scanning from left (-90°) to right (90°) as shown in Figure 6. As can be seen, the VCP is below the recommended 70%, when the occupant looks in the direction of the facade, due to the glare sources generated by the openings. The more the view is oriented in the direction of the rear partition, the higher the VCP. A post-occupancy sounding out of opinion has confirmed that tendency. Some intense computer users (secretaries) have even partly obstructed the windows with an opaque screen to reduce the glare sources.

ROOM ACOUSTICS

The reverberation time profile was measured in a typical meeting room, according to the procedure recommended by the ISO [11]. Figure 7 shows the reverberation time profile monitored and calculated for the typical meeting office room (80 m^3). It also includes the recommended maximum and minimum reverberation time value extracted from [17]. As can be seen, the reverberation time is higher than the recommended value for frequencies between 250 et 1000 [Hz], which reduces the speech intelligibility as observed by the occupants.

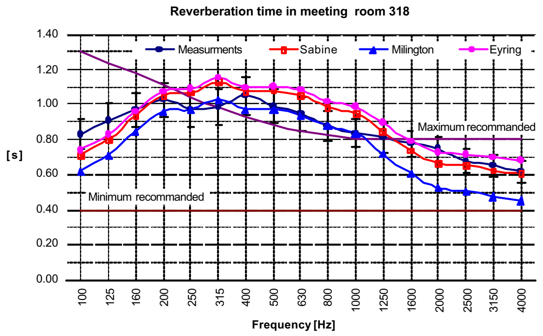

Figure 7 Monitored and calculated reverberation time profiles for the typical meeting room.

Among the three methods proposed to assess the reverberation time, Sabine's method has predicted the best results. This is not surprising as this equation is the most suited for an average surface-absorption coefficient $\overline{7}^{Sab} < 0.2$, which is the case in the single office room ($\overline{7}^{Sab}$? 0.14) and in the meeting room ($\overline{7}^{Sab}$? 0.13). This would not be the case if the ceiling was covered with an acoustic absorbent, which may be necessary in the meeting room to achieve the recommended reverberation time.

LIFE CYCLE IMPACT ASSESSMENT

The life cycle impact assessment (LCIA) of the building considers the environmental effects generated by the building during its whole life span.

The environmental effects due to building operation (heating, lighting and equipment) are determined as a function of the building energy consumption. The impact factors of the different energy sources were multiplied by the annual energy consumption of each energy source to give the annual environmental effects.

The environmental effects of a building include all the phases of its life span, from building construction to disposal. The LCIA takes into account: (1) the construction materials required for construction and replacement, (2) the energy consumption during operation, (3) the material disposal, (4) the corresponding material transport, (5) processes (construction, maintenance, etc.), and (6) the materials lost during assemblage and transportat phases.

The impact factors used for this study are mainly extracted from [18], which is based on the CML methodology [10].

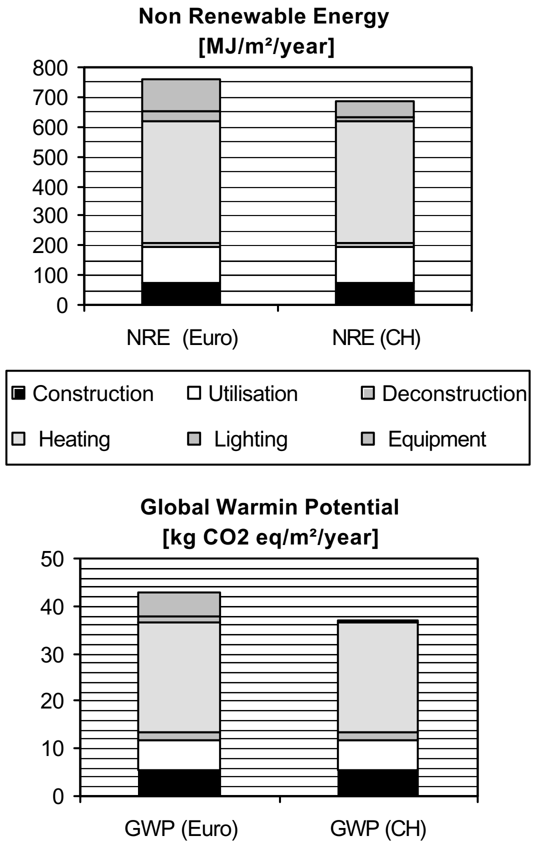

Figure 8 Environnemental profile of the EOS building.

Finally, the environmental effects generated during building operation have been summed with the contribution of the building itself (life span of 80 years) and normalised per gross floor area and year, which leads to the environmental profile shown in Figure 8.

The environmental effects generated by the electricity consumption (lighting and equipment) is lower with Swiss current because it is generated by an hydraulic power plant. On the other hand, the contribution of the gas consumption used to heat the building is almost similar for Europe and Switzerland.

The LCIA of a building cannot be monitored. The only possibility to analyse the validity of the results is to compare them with published data, which are rare. Nevertheless, the results have shown good accordance with other studies, such as [7,9,14]. However, in the author's opinion, it is currently preferable to use the LCIA to compare variants obtained by the same application using a comprehensive description of the building phases.

CONCLUSIONS

This paper has presented the multiple-view appraisal of an office building. The study was performed with the integrated application ESP-r. Its original capabilities have been extended in order to support a room acoustic and life cycle impact assessment over the whole building life. The integrated approach has several advantages compared to a stand-alone or inter-operable approach. First, as only one model is needed to run a multiple-view simulation, data management is simplified. Changes can be made more easily and are better managed, and modifications need only be implemented once. Second, it may support an interactive data exchange between views during the simulation process itself. No exchange file format is required. Finally, the user is required to master only one program's interface, which eases the learning process.

The simulated energy consumption, occupant comfort and room acoustics performance are in agreement with in-situ monitoring.

The LCIA has posed the most problems due to difficulties encountered with the gathering the required information. The availability of the environmental impact factors for construction materials, transport and material disposal is good. On the other hand, it was more difficult to obtain the materials' loss rate during transport and assembly, and the material elimination rate. The information was obtained from manufactures, consultants, or informal sources for which a great variability has been observed depending on the sources.

This case study has demonstrated the feasibility of an integrated approach when performing a multiple-view appraisal of a building performance with a single application.

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