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Zumtobel Research

Study into the impact of a lighting and solar protection system on the energy consumption of an office building.

AJ INGENIERÍA José Luis Hernández, Barcelona | ES
CREVER the Applied Thermal Engineering Group, Barcelona | ES
URV Universität Rovira i Virgili in Tarragona, Tarragona | ES
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Views of the building. Top: before refurbishment. Bottom: after refurbishment

Background

AJ Ingeniería S.L.P. has been commissioned by LUXMATE to carry out a study into the influence of lighting control and solar protection Systems installed in the “Serveis Territorials del Department de Treball de la Generalitat de Catalunya” headquarters building, located in Barcelona.

This building has been recently refurbished and it is fitted with a LUXMATE artificial light control system which responds to the daylight entering through the windows.

In addition, the building also has motorised moveable slats on two of its façades which, depending on the position of the sun, close or open to avoid glare, at the same time avoiding over-heating caused by incoming solar radiation.

Building data

– Location: C/ Carrera 12 - 24, 08004 – Barcelona
– Use: headquarters of the “Serveis Territorials del Departament de Treball de la Generalitat de Catalunya”. Administration and public enquiry office
– Built surface area: 6 800 m²
– Project to comprehensively refurbish the building and its façade: AJ INGENIERIA, S.L.P.
– Architecture: Joan Francesc Serra Andreu, Architect
– Fittings: Juan Hernández Mayor, Dr. Ind. Eng.
– Cost of comprehensive refurbishment: 6 570 000 €
– Works completed: 2009

1 Purpose of this study

The purpose of the study is to determine the influence on a building's energy consumption of a lighting control system and solar protection system on glazed façades.

To do this, energy modelling of the building was carried out using the control systems installed in order to be able to evaluate on both an individual and joint basis their influence on the building's energy consumption in terms of lighting and air-conditioning.

The main aim of this study is to find synergies between the energy-saving resulting from these systems, not only in lighting consumption but also in other energy-consuming systems, such as air-conditioning.

When modelling a real building fitted with a LUXMATE lighting control system, one has a record of electrical consumption for lighting for a whole year with the installation in operation (May 2010 to May 2011), which can be compared with data taken from the simulation. Later sections will test the proximity of both sets of results, thus enhancing the reliability of the rest of the results obtained and analysed by the simulations, insofar as energy consumption is concerned.

2 The study's authors

This study has been carried out by AJ INGENIERÍA S.L.P., in association with CREVER (the Applied Thermal Engineering Group) of the URV (Rovira I Virgili University) of Tarragona, Spain.

CREVER was responsible for modelling the building using Design Builder and Energy Plus, under the supervision of and using data provided by AJ INGENIERÍA S.L.P.

AJ INGENIERÍA S.L.P. has also been responsible for drawing conclusions from the results obtained from the energy modelling carried out by CREVER.

For this they have used graphs and tables provided by the CREVER simulation.

Plant and energy engineers founded in 1979 in Barcelona, Spain, by Ángel González Toro and Juan Hernández Mayor.

More than 30 years creating final plans for special electrical and mechanical installations, and in protection against fire in residential, tertiary and industrial settings.

Report Author: José Luis Hernández Yuste, Industrial Engineer.
Supervision and Direction: Dr Juan Hernández Mayor, Industrial Engineer.

The Applied Thermal Engineering Research Group is a multi-disciplinary research group in the Rovira I Virgili University, Tarragona, focused on research into and the development of new renewable energy technologies and on the improvement of energy efficiency.

Report Author: Arturo Ordóñez García, Architect.
Supervision and Direction: Alberto Coronas Salcedo, CREVER Leader and Professor at the URV.

3 Study methodology

3.1 IT tools used

To achieve the stated objective an analysis process based on dynamic energy simulations was carried out, using the DesignBuilder programme, which includes the EnergyPlus calculation engine.

DesignBuilder
DesignBuilder was developed some seven years ago by the company of the same name, based in Gloucestershire, UK. From the outset, one of the main objectives of its developers was to create a user-friendly interface for EnergyPlus, which is completely integrated within its platform. Even so, independent modules, such as the SBEM Certification module and the CFD module are being added to it.

More information can be found at:
www.designbuilder.co.uk and www.sol-arq.com

EnergyPlus
EnergyPlus is a programme developed by the United States Department of Energy, through the Orlando Lawrence Berkeley National Laboratory. It includes various modules which work together to calculate the energy necessary to cool or heat a building, aiming at achieving optimal comfort and using a broad range of energy systems and resources. At the heart of the programme is a model of the building based on the fundamental principles of energy balance.

The software provides integrated simulation. This means that the three main parts of the simulation, that is, the building's zones, the air management system and the air-conditioning plant are resolved simultaneously (unlike in its predecessor programmes, DOE-2 and BLAST, in which these three parts were resolved sequentially, with no feedback of any kind).

To calculate the heat flows through the building's constructive elements, EnergyPlus uses a system of heat transfer functions based on a method known as state space, which makes it possible to analyse the dynamic processes involved including the effects of thermal mass.

It is also a very powerful tool for evaluating the thermal performance of buildings operating passively (that is, with no mechanical air-conditioning systems) since, as well as providing a fairly precise estimate of the effect of solar radiation, it also calculates external airflows using the AIRNET model.

EnergyPlus has been validated using a range of recognised industry-standard measures, such as ASHRAE Research Project 865, ANSI/ASHRAE Standard 140-2007 and IEA BESTest (Building Energy Simulation Test).

More information can be found at:
http://apps1.eere.energy.gov/buildings/energyplus

Slab
Slab is an EnergyPlus auxiliary tool to calculate the average monthly temperatures of the external surfaces (of buildings) in contact with the ground, using a three-dimensional heat transfer calculation engine. It uses the same hourly climate data as EnergyPlus, in epw. format.

For more information see the EnergyPlus Auxiliary Programs document at:
http://apps1.eere.energy.gov/buildings/energyplus/documentation.cfm

Weather Tool
Weather Tool is a program developed by Square One, based in the UK. Basically, it is a tool to display and analyse climate data using hourly data files in EnergyPlus .epw format, although it can also import data in other formats. It offers a broad range of display options including 2D and 3D graphs as well as wind charts and sunpaths.

More information can be found at:
http://ecotect.com/products/weathertool

3.2 Models

In order to analyse the effects on the building's energy consumption of lighting control and solar protection strategies, both together and independently, 5 scenarios have been chosen for modelling the building based on the layout and plant actually in it.

- Scenario 01: Original building, before refurbishment, without moveable slats or lighting control.
- Scenario 02: Current refurbished building without moveable slats or lighting control.
- Scenario 03: Current refurbished building with moveable slats but without lighting control.
- Scenario 04: Current refurbished building, without moveable slats but with lighting control.
- Scenario 05: Current refurbished building, with both moveable slats and lighting control.

For each of the scenarios an analysis will be made of energy consumption for lighting and air-conditioning. These analyses will not touch on energy consumption by miscellaneous equipment and lifts, as this is beyond the scope of this study.

These scenarios have been set in order to evaluate the impact of the main improvement strategies, working independently and jointly.

Thus, Scenario 02 enables an evaluation to be made of the effects of changes in the composition of the envelope and glazing after these have been refurbished.

Scenario 04 models the effects of using a lighting control system without using moveable slats; this scenario will be used to see the effect of an independent lighting control system.

Scenario 03, on the other hand, evaluates the impact of a moveable slat system without a lighting control system; this will make it possible to observe the effect of a moveable slat system working in isolation.

Finally, Scenario 05 enables an evaluation to be made of the effects of a moveable slat system and lighting control system working together.

It should be noted that in Scenarios 01, 02 and 04, modelling the building without an external slat solar protection system, a system of translucent blind-type curtains is included.

Regarding the lighting systems modelled, a light load (W/m^2) matching that actually in the building has been assumed. The same light load has even been assumed in Scenario 01 (before refurbishment), so that in this scenario the improvements brought about by the luminaires' and electronic equipment's improved energy efficiency have not been taken into account. The plant's assumed operating hours are those provided by the building user, detailed below.

Turning to the air-conditioning systems, all the simulations assume a mechanical model, that is, they assume the use of heating/cooling systems to maintain optimally comfortable conditions whenever the building is occupied, all year round. In this situation the most relevant information for evaluating and comparing the different scenarios' energy performance is that of energy consumption by the air-conditioning systems.

The air-conditioning system is the same in all scenarios, meaning that no consideration is made of improvements in the system's efficiency due to the enhanced energy performance of the HVAC system fitted. In this way it is possible to precisely gauge the impact of each improvement measure (lighting control or moveable slats) on a reference air-conditioning system that is the same in all scenarios.

4 Description of the building

4.1 Description of the building BEFORE refurbishment

4.1.1 Description of the building

The building consists of a ground floor, a mezzanine, 4 upper floors and two basement floors. Construction is grouped around two vertical communication shafts. The two basement floors are used for parking, with a total of 120 parking spaces. The ground floor, occupying the whole of the plot, and the upper floors, are used for offices. The building has a surface area of approximately 6000 m^2.

Construction is grouped around two vertical communication shafts, each of which has a staircase, two lifts per shaft, washrooms and vertical utility conduits.

4.1.2 Methods of construction

Structure
Reinforced concrete pillars and main beams.

Floor slabs
Waffle slab reinforced concrete with mortar pan forms, with 80 cm spacing. The slab is 22 cm + 4 cm compression layer.

External envelope
- Rear elevation: 1/4 walling, cavity with 3 cm expanded polystyrene insulation and external finish in brick perforated on one face. Carpentry is externally fitted.
- Main elevation: 1/4 walling with cavity filled with 3 cm expanded polystyrene insulation, 14 cm thick hollow brick wall and external natural sandstone cladding.

Internal partitioning
- Office walls made of 14 cm unfinished hollow brick.
- Washrooms: 9 cm hollow brick.
- Stair cases and lift casings: 14 cm unfinished hollow brick.

Roof
Sloped cellular concrete, average thickness 12 cm, waterproofed using asphalt roofing felt and thermally insulated using high-density extruded 30 mm polystyrene slabs, puncture-resistant water-draining coat and gravel layer 5 cm average depth.

External carpentry and glazing
External carpentry is aluminium without thermal break.
Clear Climalit 6-6-5 for external carpentry.
4-4 reinforced glass, with butyral internal lamination for external carpentry on the ground floor, mezzanine and entrance doors.

4.1.3 Fittings

Lighting
– Offices: 120 x 60 fittings recessed into the suspended ceiling with 4 No. 36 W fluorescent tubes. Novalux Model NLE 436/440. With blade-type diffuser with V-shape bridges. Magnetic ballast.
– Washrooms: Flush-fitting spotlights using 40 W E-14 lamps of the Guzzini 8011 type.
– Vestibules: Flush-fitting 50 W halogen lamp luminaires, of the Guzzini 8005 type.

Air-conditioning
Shared direct expansion units and heat pumps. External units on the roof and internal equipment located in the suspended ceilings of corridors and vestibules. 7 sets per floor.

4.2 Description of the building AFTER refurbishment

4.2.1 Description of the building

The building consists of a ground floor, a mezzanine, 4 standard floors and two basement floors. Construction is grouped around two vertical communication shafts. The two basement floors are used for parking, with a total of 120 parking spaces. The ground floor, occupying the whole of the plot, and the upper floors, are used for offices.

The surface areas of the above-ground levels are:

Ground floor	1 350 m^2
Mezzanine floor	700 m^2
First floor	950 m^2
Second floor	940 m^2
Third floor	950 m^2
Fourth floor	950 m^2
Total	**6 800 m^2**

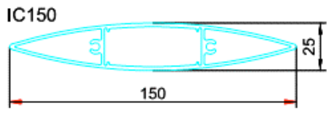
4.2.2 Methods of construction

Structure
The refurbishment did not affect the structure (reinforced concrete pillars and main beams).

Floor slabs
The refurbishment did not affect the floor slabs (Waffle slab reinforced concrete with mortar pan forms, with 80 cm spacings. The slab is 22 cm + 4 cm compression layer).

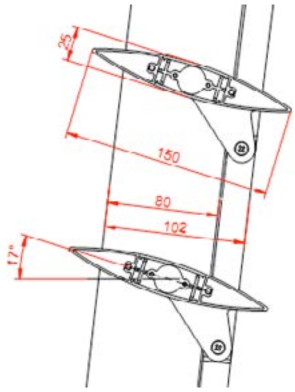
External envelope
– Rear elevation: The refurbishment did not affect the rear elevation (1/4 walling, cavity with 3 cm expanded polystyrene insulation and external finish in brick perforated on one face.).
– Main elevation: Modular spandrel panels between windows on main elevation (vertical section) made of:
 1. Alucobond Smoke Silver Metallic composite outer panel
 2. Water-repellent fibre panel
 3. Rockwool insulation (100 kg/m^3 -100 mm.)
 4. Promatect silicate fibre interior fire-resistant board

– Solar protection on the East, South and South-East (angle) façades: using a second skin of aluminium power-moveable slats which, in addition to enhancing the building's appearance, making it look distinctive, give it very significant energy savings and its users significant improvements in their quality of life. The slats have the following shape and size:

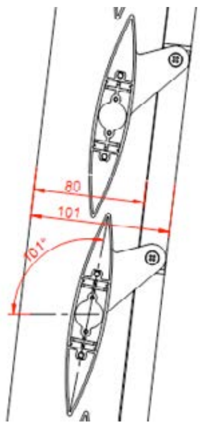


The slats are motorised, their movement being controlled by the LUXMATE control system to protect the façade from solar radiation and to protect the building's occupants from unwanted glare.

The fully open position of the slats is as shown:



The fully closed position is as shown below:



Internal partitioning

- Divisions between offices: 80 mm thick partitions made from an internal and external galvanised steel structure. 13 mm agglomerate panels. Internal insulation from mineral wool 50 mm thick and with a density of 30/40 kg/m^3.
- Washrooms: 9 cm hollow brick.
- Staircases and lift casings: Not affected by the refurbishment (unfinished perforated 14 cm brick).

Roof

Sloped cellular concrete, average thickness 12 cm, waterproofed using asphalt roofing felt and thermally insulated using high-density 50 mm extruded polystyrene slabs, puncture-resistant draining coat and gravel layer 5 cm average depth.

External carpentry and glazing

Aluminium carpentry with thermal break, REYNAERS model CS68 finished in RAL 9007

Glazing to Mezzanine and Floors 1 to 4:

- 6 mm transparent float / 15 mm gap / transparent silence 4+4 butyral lamination. Low emissivity.

Firefighters' access windows on floors 1 to 4:

- 6 mm transparent tempered float / 15 mm gap / 8 mm transparent tempered glass.

Glazing to ground floor, above curtain wall:

- External 6+6 non-coloured lamination / 16 mm gap / internal 6+6 non-coloured lamination with acoustic butyral. Low emissivity.

Ground floor windows, in the area of the angled access to the building are of the type:

- 6+6 non-coloured laminated with external tempering.

4.2.3 Fittings

Lighting

- Offices and open-plan areas: 60 x 60 fittings recessed into the suspended ceiling for 3 No. T16 24 W fluorescent tubes. LLEDÓ brand, model OD-3281, with double parabolic reflector in satinised aluminium with TRIDONIC digital adjustable ballast model EXCELL ONE4ALL.
- Washrooms: ZUMTOBEL downlights, model PANOS Q LM, 2 x 26 W and/or 2 x 18 W, with TRIDONIC digital adjustable ballast model EXCELL ONE4ALL.

LUXMATE lighting control

CONTROL BUS

A control system based on the LUXMATE field bus is installed, with every module in the installation connected to it. Bus topologies are completely flexible, thus facilitating cabling and module connections. Except for ring, every type of topology is possible, including star, tree, line etc.

The LUXMATE bus can be segmented, using galvanic separators, each segment being powered from a source permitting the connection of up to 100 modules per segment. If required, a second power source can be connected to each segment, supplying redundancy with automatic switch-over should a problem be detected in the primary power supply.

LUXMATE bus segmentation will be used to its maximum advantage to carry out functionally structured cabling throughout the entire installation, thus ensuring that any bus problems, such as short circuits, breaks in the bus line or lack of power in any one part of the installation do not affect the rest of it.

The topological freedom of the bus makes any future alterations or extensions to the installation both simple and economical.

The LUXMATE bus is immune to electromagnetic interference with no need to use shielded wiring for its cabling. Every LUXMATE module connected to the bus is fitted with a diode rectifier bridge, meaning that polarity can be disregarded when connections are made. In addition, every module can be hot-swapped, that is, with no need to cut the power to the bus segment before connecting or disconnecting modules.

The physical medium used for the bus wiring is totally standard twisted pair H 05 VV-U 2 x 0.75 or H 05 VV-U 2 x 1.5.

The LUXMATE bus works at a speed of 4 800 baud and variable bit frame rate with 16-bit cyclic redundancy checking (CRC) which automatically repeats the message in the event of transmission error.

All LUXMATE modules, both input and output, can have several channels and each channel has assigned to it an unambiguous address identifying it within each bus. LUXMATE system operation commands can be directed to one channel, all the channels in a group, all the channels in a room, or to every channel in the installation.

Addressing is simple and intuitive using a LUXMATE control unit connected to the system. These units, in addition to addressing all the system modules, can be used later if desired as control units for the installation. There is no requirement for complex programming consoles, personal computers or specialised software to carry out this addressing.

The LUXMATE system makes it possible to create and modify scenes in each of the rooms. These scenes consist of specific values for each of the output channels within the room, recorded on each module's EPROM memories. Depending on the type of module, it is possible to record up to a maximum of twenty different scenes which can be called later by a simple press on a control unit or system input device.

Within the system it is possible to set fade times for transitions from one scene to another. These times are totally user-configurable and when a user activates them, having decided to move from one scene to another within the room, the outputs gradually vary their values from their starting point in one scene to the correct value for the new scene. This process takes the time set for it, and it can be different for each target sequence or universal for all the sequences defined for the room in question.

LUMINAIRE CONTROL

The installation's fluorescent luminaires are controlled using the DALI communication system which supplies each luminaire with the correct value. This digital signal is used to adjust the luminaires with a minimum accuracy of 1–3 %.

Using this digital signal makes constant regulation possible, even with low light levels, without causing any flickering; the ballast can send lamp errors to the system.

Every LUXMATE module with a DALI luminaire control output has an output monitoring system so that error codes can be sent to the system in the event of malfunction, such as for example short circuits in the DALI line, open line, or lamp failures sent by the fluorescents' digital ballasts.

Every luminaire connected to the DALI line can be controlled on a completely individual basis. The cable used is totally standard twisted pair H 05 VV-U 2 x 0.75 or H 05 VV-U 2 x 1.5.

BLIND POSITION AND SLAT ANGLE CONTROL

The specific low voltage direct current modules have several independent outputs, each of which is assigned its own LUXMATE address.

Every channel can control both the vertical position of the blind and the angle of the slats from just one output. Control of the blinds can be carried out through the system or using push-buttons directly connected to the module.

RADIO-OPERATED REMOTE CONTROLS
The LUXMATE system has radio-frequency LM-RFR push-button receivers for cordless EnOcean push-button controllers (non-battery RFR push-button technology). This ensures maximum flexibility of planning and reduces installation time.

These controllers can be used to easily activate pre-set scenes and their rocker switches are used to switch the lights on and adjust their brightness, simply by pressing T+ (brighter) or T+ (dimmer).

CONTROLLERS
The LUXMATE system has a broad range of wall-mounted control units with various functions including switching on and off, and calling and adjusting pre-set scenes.

OUTDOOR LIGHT SENSOR
The LUXMATE system has a general whole-installation sensor fitted to the highest part of the building. This sensor contains a total of eight photo-electric cells and an infra-red sensor. The sensor constantly collects data on direct and diffused light in both the horizontal and the vertical planes for each of the cardinal compass points; its infra-red sensor gathers data on the general state of the sky.

All the data captured by the sensor are sent over the LUXMATE bus to the rest of the system for processing and use.

DAYLIGHT PROCESSOR
LUXMATE installations carry out their centralised processing using as many processors as are necessary, each of them capable of controlling three field buses in such a way that each field bus is totally independent from the other two. Each field bus has a maximum of 500 outputs, making a total of 1 500.

The connection between the processor and the field buses is via RS 232 communication ports provided for this purpose as part of the processor. A communications interface is connected to each of them enabling communication between the processor and the field components.

The processor has a modem enabling telephone access for remote system support.

The daylight processor has the following functions:

Daylight-responsive regulation
In those parts of the building with sufficient natural light, the luminaires are adjusted according to the amount of available light, with positive outcomes on both user comfort and significant energy savings.

The role of the light processor is to adjust the lighting values of each of the system outputs according to the variations in daylight measured by the roof-mounted sensor.

The LUXMATE control system enables the creation of a characteristic control curve for each of the adjustable outputs, which it uses to calculate at any given moment the output value needed to maintain constant light levels in the area, regardless of the normal variations in natural daylight.

Each luminaire can have different control curves recorded for each of the possible LUXMATE system scenes, so that when one of these scenes is chosen in a zone the system automatically calculates the output values using the control curve for that scene.

The user can vary luminaire output at any time even when they are under automatic system control; it is possible to set the length of time taken to return to fully automatic operation after manual adjustments have been made.

Each area under daylight-responsive regulation has an indoors light sensor fitted, to measure the amount of daylight entering the room taking into account items that block light, such as blinds of various kinds.

Using this indoors sensor means that a third point on the control curve needs to be set, to take account of local variations in the amount of light entering the area.

Slat automation
The LUXMATE control system is able to use its daylight processor to completely automate all the system's slat outputs. Automation can be for individual outputs or for groups of outputs within each area.

For each group of external blinds, their orientation compared to North is established along with both the horizontal and vertical angles from which the window receives direct sunlight. The external light value to trigger slat operation is also established.

When the position of the sun is such that it shines directly on the window, and the outdoors sensor values are over the defined lighting threshold, the system automatically positions the slats so that they are perpendicular to the sun's radiation, with angle adjustments to follow the movements of the sun.

The system takes account of the building's geometry and of other buildings or any neighbouring object shading the automatically operated slats.

Since the position of the sun is a real annoyance early in the day even though there may not be enough light to trigger the threshold, the system has a correction factor to compensate for this, thus operating the blinds.

The system also has a capability for pre-setting closure times based on opening hours, or non-working days or holiday periods. It is possible to define if users can carry out manual system overrides during these closure periods.

Time-based management
The daylight processor has the functionality to programme events by times of day, non-working days or holiday periods. These events can be for any part of the installation, several rooms, a single room or individual or groups of outputs. It is also possible to specify what type of output an event is programmed for.

Energy consumption management
The system has input into it the number of luminaires connected to LUXMATE system output and the power of each of them. These data are used to create records of the times the luminaire has been in use, the power used and the energy consumed.

This application means that maintenance technicians have reliable information about the ageing of each of the system's component parts and accurate data about energy usage in each of the system zones.

User management
The daylight processor carries out all user administration and control tasks, it being possible to define user names, passwords and work areas for each user, in addition to their access rights for the various LUXMATE control programs and their ability to carry out system actions.

Communications with external systems
The daylight processor communicates with other systems using the BMS communications standard over the TCP/IP protocol or using a RS232 serial port.

It is possible to use this communications capability to allow any external system to operate the LUXMATE control system, including switching on or off and adjusting any connected luminaire, and verifying the condition of any luminaire or the status of any part of the installation.

GRAPHICAL INTERFACE
The LUXMATE control system has a graphical installation display facility, showing the status of all the system outputs.

The LUXMATE graphical display system shows system error logs. Within these logs, depending on user rights, it is possible to mark alarms as already known by the systems operator and/or print them.

The system is not limited to giving general alarm codes; instead, it states if the fault is due to a general module fault, to a communications error, to an error in the component controlled by the module, and so on.

CONTROLLED ZONES

The controlled zones and their operating definitions in terms of their usage and the needs to be covered by them are shown below.

The control system has a graphical installation supervision terminal showing a real-time display of the status of the system outputs. It is also possible to send system commands to the outputs and view or print module or lamp fault reports.

Corridors and communal areas

General control of light switching to suit the building's defined hours of operation is carried out here.

In those areas where natural light is a factor, there is continuous adjustment of the luminaires within a radius of approximately 5 metres.

Outside the building's normal working hours at least one third of the luminaires in the security and surveillance areas remain lit.

Reception

This area has a touch control screen fitted flush to the wall, enabling total control. It displays a summary representation of every component controlled and its location in the building.

In those areas where natural light is a factor, there is continuous adjustment of the luminaires within a radius of approximately 5 metres.

General control of light switching to suit the building's defined hours of operation is carried out here.

Washrooms and changing rooms

The lights in these areas will be switched on and off using presence detectors.

Toilet cubicle lights will be switched on and off using conventional wall-mounted press-buttons

Offices and meeting rooms

These areas will be switched on and off using radio-operated remote controls fitted on the walls.

In those areas where natural light is a factor, there is continuous adjustment of the luminaires within a radius of approximately 5 metres.

Slats are automatically controlled in such a way that when there is direct sunlight on the window their angle is continuously adjusted to suit the position of the sun, thus avoiding light coming straight in, but enabling diffused light to enter. The system calculates the adjusted luminaire output to go with each slat position, maintaining in this way the assigned light level for the area.

General switching control is carried out as a function of the building's established hours of operation.

Press room
This area has a wall-mounted controller providing control over the activation, de-activation and regulation of outputs, in addition to a facility to store the current configuration of five different scenes, to be called up later.

Manual control of slats and the projection screen depending on the scene selected by means of the wall control or touch screen.

The area is controlled by means of audio-visual device controllers; for this integration to take place the system needs to be connected to external systems.

Control points listing

Following table shows a list of all controlled inputs and outputs of the lighting and blind control system

LUXMATE	DALI	Actuators			Operation panels						Sum of actuators		Details		Illumination			Input devices					Sensors		Operation panels		Touchscreens	Radio operation		Blinds	Screens	Daylight control modules	Special devices	Automation devices								Software	
Description	DALI Actuators	DALI lines	Relayoutputs	Blind outputs	Switch input on/off	Switching/dimming input	Presence detectors	Blind control inputs	Operation panels CG/SG	Touchscreens	Addresses total	Input devices total	DALI lines daylight dependent	Daylight sensors internal	LM-DALIS	LM-3DLIS	LM-4RUKS	LM-SWE	LM-SCE	LM-4ILS	LM-SJED	LM-RV	LSD	DPTO	EGBV-BOX	LM-CS	LM-CP	LITENET-RFR	H5001-A230	LM-4JSP	LM-2LSE	LM-TLX	LM-SI03	LRA-1500	Addresses total	LM-TLM	LM-PCSIR	LM-BV	LM-BVS35	LM-BK	PC2LAN	LRA-BMS	LMW-1GO
Ground floor															**2**																							**1**		**1**			
Entrance and shared areas	505	15								1	15	1	8			5											1								15								
Meeting rooms (3)	120	22							3		22	3	22									1				3									22								
Archive and miscellaneous			6		6						6	6					2		2																6								
Washrooms (4)			12		8		4				12	12					3	2	2					4											12								
Changing rooms (2)			2				2				2	2					1	1						2											2								
Mezzanine															**8**													**4**										**1**		**1**			
Meeting rooms (7)	112	28		8				7			36	7	28	8						2			8						7	2					36								
Office	16	2		4				2			6	2	2	4						1			4						2	1					6								
Large meeting room (1)	96	12		6					2		18	2	12	6						2		1	6			2				2					18								
Open-plan office and waiting area	98	24		3				4			27	4	14	3						1			3						4	1					27								
Board room	58	29		3					1	1	32	2	29	3						1			3			1	1			1	1		1		32								
Corridors and communal areas	138	6					4				6	4	6			2		2						4											6								
Washrooms (4)			8		4		4				8	8					2	2	2					4											8								
1st Floor															**5**													**4**										**1**		**1**			
Meeting rooms/offices (16)	226	71		20				16			91	16	71	20						5			20						16	5					91								
Large office room	50	14		3				4			17	4	14	3						1			3						4	1					17								
Corridors and communal areas	202	9		2			4				11	4	9	2		3		2		1			2	4						1					11								
Washrooms (6)			11		6		5				11	11					3	3	3					5											11								
2nd Floor															**8**													**4**										**1**		**1**			
Meeting rooms/offices (3)	40	14		3				4			17	4	14	3						1			3						4	1					17								
Open plan and shared areas	333	108		16				15			124	15	62	16						4			16						15	4					124								
Storerooms and office	72	5						3			5	3	3																3						5								
Lift vestibules	24	2					2				2	2	2			1		1						2											2								
Washrooms (7)			12		6		6				12	12					3	3	3					6											12								
3rd Floor															**8**													**4**										**1**		**1**			
Meeting rooms/offices (6)	138	42		14				7			56	7	42	14						4			14						7	4					56								
Open plan and shared area	281	99		13				15			112	15	99	13						4			13						15	4					112								
Office	6	1						1			1	1	1																1						1								
Lift vestibules	24	2					2				2	2	2			1		1						2											2								
Washrooms (7)			12		6		6				12	12					3	3	3					6											12								
4th Floor															**8**													**4**										**1**		**1**			
Meeting rooms/offices (12)	213	75		22				16			97	16	75	22						6			22						16	6					97								
Open plan and shared area	204	88		5				10			93	10	88	5						2			5						10	2					93								
Office	6	1						1			1	1	1																1						1								
Lift vestibules	22	2					2				2	2	2			1		1						2											2								
Washrooms (8)			15		8		6				15	14					4	4	3					6											15								
LUXMATE System																									1									1		1	3		3		1	1	1
Total:	**2984**	**671**	**78**	**122**	**44**		**47**	**105**	**6**	**2**	**871**	**204**	**606**	**122**	**39**	**13**	**21**	**25**	**18**	**35**		**2**	**122**	**47**	**1**	**6**	**2**	**20**	**105**	**35**	**1**		**1**	**1**	**871**	**1**	**3**	**6**	**3**	**6**	**1**	**1**	**1**

Air-conditioning system

The air-conditioning system uses water as the heat-carrying medium to four tubes, since the building's geometry and orientation mean that as different parts of the building face different ways it is possible to meet needs when there is simultaneous and momentary heat inversion.

Cold water is produced using an air-cooled condenser located on the roof and hot water is produced using natural gas powered boilers. This water is forced round the system using circulation pumps and an insulated pipe network, to its terminal units.

In most offices the terminal units are 4-tube fancoils with cooling and heating elements.

Air is brought in from outdoors using conditioner units that treat and filter the incoming air to then pass it through the fancoils at a temperature close to that of indoor comfort.

Every zone has the regulation air changes as per the current Thermal Installations in Buildings Regulations, using conditioners and rotary enthalpy heat air recuperators which transfer energy from treated extracted air to incoming external air.

5 Input data

5.1 Climate data

The building is located in Barcelona, Spain (Latitude 41.28°, Longitude 2.07, Altitude 6.0 metres above mean sea level).

For modelling purposes a dataset of climate data for Barcelona obtained from ASHRAE's International Weather for Energy Calculations (IWEC) has been used. The dataset contains hour-by-hour information for one full year, of parameters including dry bulb temperature, dew-point, relative humidity, solar radiation (global horizontal, normal direct and diffuse horizontal) and wind (direction and speed).

Annex 1 contains charts showing annual-hourly data for the main parameters included in this dataset.

In order to verify the reliability of the climate dataset, a comparison has been made of average solar radiation and temperatures as recorded by a weather station located close to the building's location.

The charts below enable a comparison to be made of average values (source: METEOCAT) with the equivalent values in the IWEC climate dataset. It will be appreciated that there is an adequate correspondence between the data measured and the dataset values, especially for solar radiation.

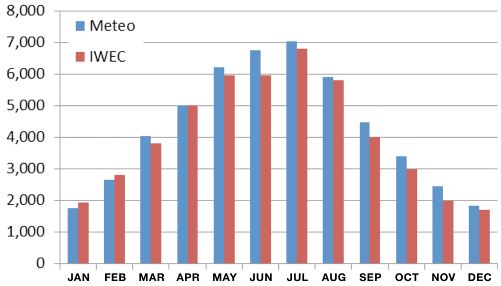


Figure 1: Global horizontal solar radiation (Wh/m²).

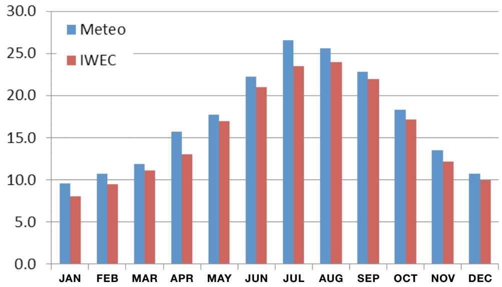


Figure 2: Average monthly temperature (Wh/m²).

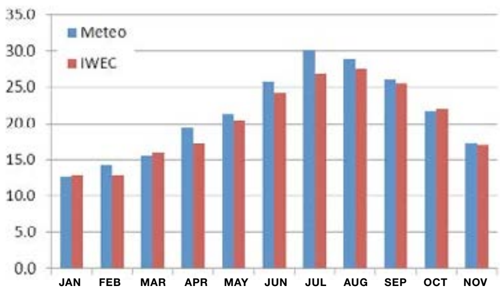


Figure 3: Average maximum monthly temperature (Wh/m²).

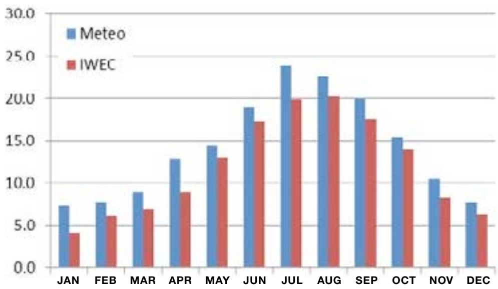


Figure 4: Average minimum monthly temperature (Wh/m²).

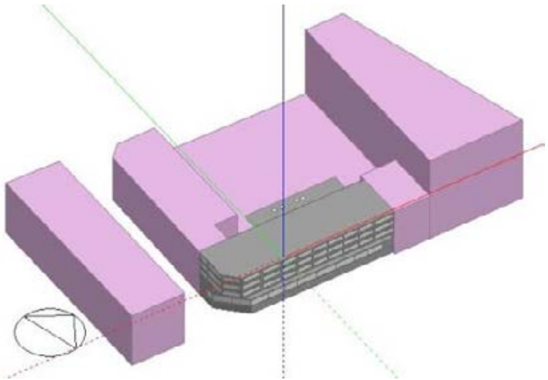


Figure 5: 3D representation of complete building.

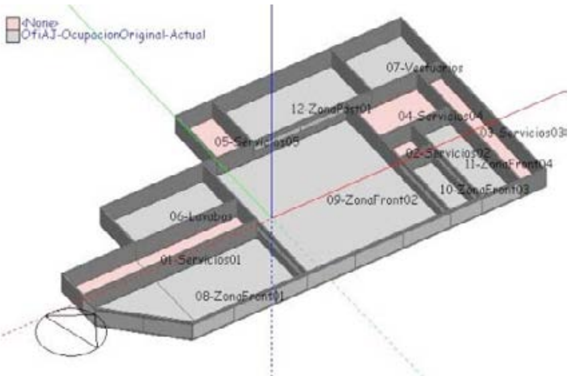


Figure 6: 3D representation of ground floor.

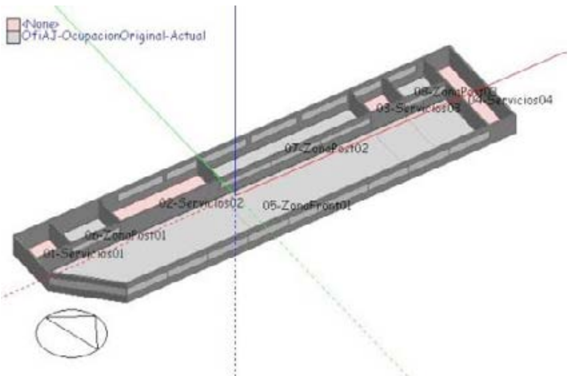


Figure 7: 3D representation of mezzanine.

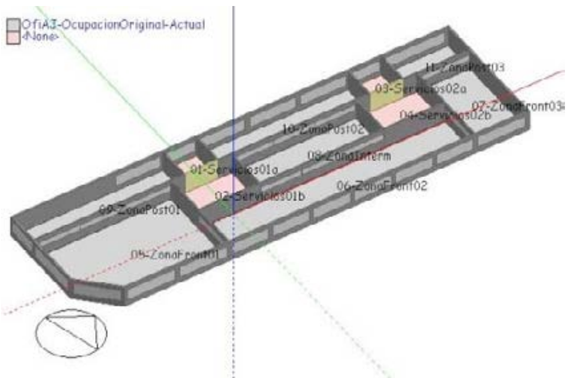


Figure 8: 3D representation of floors 1 to 4.

5.2 The building's geometry and zoning

The building has eight floors, consisting of two underground levels principally used for parking, the ground floor, a mezzanine floor and four upper floors. The underground floors and the ground floor all occupy the whole of the plot. The mezzanine and upper floors form an elongated shape with its longitudinal axis running north-south (meaning that the most extensive façades face East and West).

The simulation model has been designed to respect as closely as possible the geometry of the real building, albeit with some adjustments made to optimise the analysis process. The most important adjustments include the following:

a) The second and third floors have been modelled using just one nominal type, using a zone multiplier of 2 to obtain results for both floors.

b) A simplified internal zoning model has been chosen, with the aim of differentiating work zones from service areas and of differentiating the different thermal conditions related to the locations of these spaces.

c) The model's configuration has been designed in such a way that all the zones are convex, a necessary condition for DesignBuilder's complete internal and external solar distribution option to be used. With this option it is possible to model in greater detail the distribution of solar radiation entering spaces, an important aspect considering the objectives of this study.

On the other hand, additional blocks have been included representing neighbouring buildings in order to take account of the shadows cast by them onto the building under analysis.

Figures 5 to 8 show images taken from the 3D models used in the simulations, including the complete building, the ground floor, the mezzanine and the first through to fourth floors.

5.3 Opaque envelope components

The following table shows a summary for the opaque envelope components as assigned to the model of the building as it was originally and is now. This includes transmittance values and heat capacities. Annex 2 contains a detailed listing for each of these components.

	Original building	**Current building**
East and south façades	Wall 01 U (W/m^2-K) = 0.675 k-m (KJ/m^2-K) = 57.4	Wall 04 U (W/m^2-K) = 0.272 k-m (KJ/m^2-K) = 14.2
South-east (angle) façade	Wall 01 U (W/m^2-K) = 0.675 k-m (KJ/m^2-K) = 57.4	Wall 05 U (W/m^2-K) = 0.201 k-m (KJ/m^2-K) = 57.4
West façade	Wall 02 U (W/m^2-K) = 0.682 k-m (KJ/m^2-K) = 57.4	Wall 02 U (W/m^2-K) = 0.682 k-m (KJ/m^2-K) = 57.4
North façade (party wall)	Wall 03 U (W/m^2-K) = 1.167 k-m (KJ/m^2-K) = 56.5	Wall 03 U (W/m^2-K) = 1.167 k-m (KJ/m^2-K) = 56.5
Partitions (interior walls)	Partition 01 U (W/m^2-K) = 1.730 k-m (KJ/m^2-K) = 104.6	Partition 01 U (W/m^2-K) = 1.730 k-m (KJ/m^2-K) = 104.6
Upper roof (4^{th} floor)	Roof 01 U (W/m^2-K) = 0.547 k-m (KJ/m^2-K) = 158.0	Roof 02 U (W/m^2-K) = 0.530 k-m (KJ/m^2-K) = 158.0
Lower roof (ground floor)	Roof 03 U (W/m^2-K) = 0.545 k-m (KJ/m^2-K) = 158.0	Roof 03 U (W/m^2-K) = 0.545 k-m (KJ/m^2-K) = 158.0
Interior floors	k-m (KJ/m^2-K) = 180.4	k-m (KJ/m^2-K) = 0.0

U = total thermal transmittance
k-m = internal heat capacity

Figure 9: Envelope components considered.

5.4 Glazing

The following tables show the detailed and global properties of said glazing, before and after refurbishment:

Sheet, Glass/gas	Thickness (m)	Conductiv. (W/m-K)	Source
1 (Ext) Clear glass	0.006	0.900	EnergyPlus database
2 Air chamber	0.006		BS EN 673 / EnergyPlus
3 (Int) Clear glass	0.006	0.900	EnergyPlus database
3.094 W/m²-K Total transmittance (U)			
0.700 Total solar heat gain (SGHC)			
0.604 Direct solar transmission			
0.781 Light transmission			

Figure 10: Properties of glazing in original building.

Sheet, Glass/gas	Thickness (m)	Conductiv. (W/m-K)	Source
1 (Ext) Generic reflective glass	0.006	0.900	EnergyPlus database
2 Air chamber	0.013		BS EN 673 / EnergyPlus
3 (Int) Generic clear glass	0.010	0.900	EnergyPlus database
2.639 W/m²-K Total transmittance (U)			
0.691 Total solar heat gain (SGHC)			
0.577 Direct solar transmission			
0.763 Light transmission			

Figure 11: Properties of glazing in current building.

5.5 Shading devices

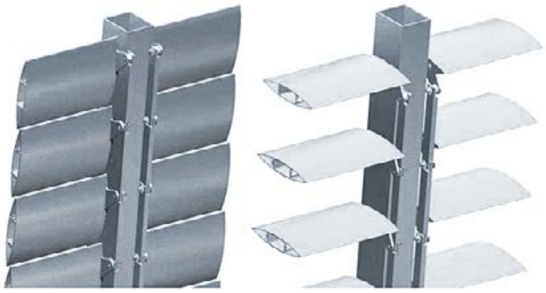


Figure 12: Commercial images of the moving slat system, showing the slats in their open and closed positions.

The simulation models have used two types of shading device. The first consists of a system of automatically moved slats located to the exterior of the glazing. Their position varies automatically between minimum and maximum openings (and back again), with the aim of blocking direct solar radiation on the glass. To model this control method the EnergyPlus WindowProperty: ShadingControl > BlockBeamSolar object has been used.

Figure 12 shows commercial images of the moving slat system, while Figure 13 shows the geometric parameters used for the simulation models. In this regard it must be noted that DesignBuilder-EnergyPlus is only capable of modelling flat slats. It is assumed that the slats have a conductivity of 0.1 W/m-K and that both the front and rear faces have solar and visible reflectance indices of 0.6 and emissivities of 0.4.

The moveable slat system has been used in modelling Scenarios 03 and 05. Nonetheless, to make it match the characteristics of the actual building, it has only been assigned to the windows of floors 1 to 4 on their East, South-east (angled) and South façades. In this last case only the windows adjacent to the South-east façade have been considered.

The second shading device consists of an internal translucent blind, with solar transmittance and reflectance of 0.2. As a control, it has been assumed that this device is in use when its corresponding window has incident solar radiation of 75 W/m^2 or greater. (When incident solar radiation falls below 75 W/m^2 the blind is assumed to be folded back). The internal blinds have been assigned to those windows without moveable slats in the models of Scenarios 03 and 05, as well as on all the windows when Scenarios 01, 02 and 04 are modelled.

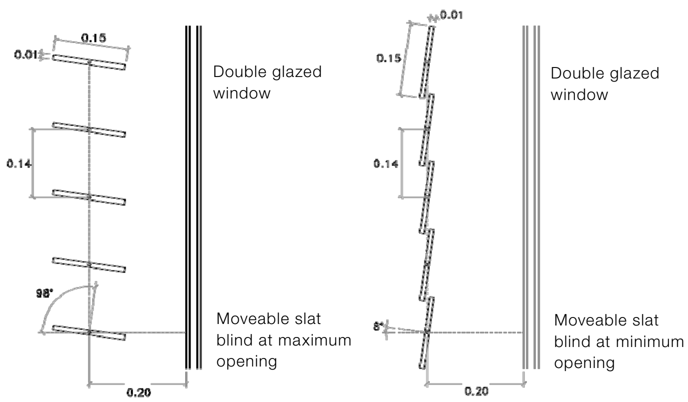


Figure 13: Geometry of moving slat blind system used in simulation models.

5.6 Internal gain from building occupants

Figure 14 shows the input data for building occupancy, while Figure 15 shows the scheduling values used for this. These parameters are used to calculate internal heat gain from people, using the following formula:

Gain from persons (W) = Floor area x Occupation density x Metabolic rate x Metabolic factor x Scheduling factor

Density values have been established and standardised from available information about the building's use. Metabolic rate depends on the type of activity (the greater the activity, the greater the metabolic rate), while the metabolic factor makes it possible to take account of the physical constitution of the occupants, with men at 1.00, women at 0.85 and children at 0.75.

Type of space	Density (pers/m²)	Metabolic rate (W/pers)	Metabolic factor	Gain (W/m²)	Scheduling
Work areas	0.150	120	0.90	16.2	Occupation
Service areas	0.030	120	0.90	3.2	Occupation

Figure 14: Occupation related input data.

As expressed in the formula, occupation scheduling makes it possible to set the periods when the spaces are occupied (when the value is other than zero), as well as modifying the associated heat gains over time, using an agreed model of building use. In those periods, for example, when the scheduling value is 0.80, the rate of gain from occupants is reduced to 80 %.

Mon to Thu	Fri	Sat and Sun
00:00 - 08:00 = 0.05	00:00 - 08:00 = 0.00	00:00 - 24:00 = 0.00
08:00 - 09:00 = 0.80	08:00 - 09:00 = 0.80	
09:00 - 13:00 = 1.00	09:00 - 13:00 = 1.00	
13:00 - 14:00 = 0.80	13:00 - 14:00 = 0.80	
14:00 - 16:00 = 1.00	14:00 - 16:00 = 1.00	
16:00 - 20:00 = 0.20	16:00 - 24:00 = 0.00	
20:00 - 24:00 = 0.05		

Figure 15: Occupancy scheduling: 1 January to 31 December.

5.7 Internal gain from devices and equipment

Figure 16 shows the input data related to the use of devices and equipment within the building, while Figure 17 shows the scheduling values used for them. These data are used to calculate the energy consumption and corresponding heat gain, using the following formula:

Consumption/gain by equipment (W) = Floor area x Gain rate x scheduling value.

Type of space	Gain (W/m²)	Equipment type	Loss F	Latent F	Radiant F	Sensible F	Scheduling
Work areas	12.0	Electrical	0.00	0.00	0.20	0.80	Equipment
Service areas	3.0	Electrical	0.00	0.00	0.20	0.80	Equipment

Loss F. = Loss fraction (heat expelled to outside), Latent F. = Latent fraction, Radiant F. = Radiant fraction, Sensible F = Sensible fraction

Figure 16: Input data for devices and equipment.

NB: When, as in this case, the loss fraction is taken as zero, it is assumed that the energy consumed is the same as the heat gained within the space. The heat gained is shared out into its latent, radiant and convective fractions as per the corresponding values.

As expressed in the formula, equipment scheduling makes it possible to set the periods when devices and equipment are in use (if the value is other than zero), as well as modifying the associated heat gains over time and associated energy usage, using an agreed model of building use. In those periods, for example, when the programming value is 0.80, the rate of energy use and heat gain by devices and equipment is reduced to 80 %.

Mon to Thu	Fri	Sat and Sun
00:00 - 08:00 = 0.05	00:00 - 08:00 = 0.05	00:00 - 24:00 = 0.05
08:00 - 09:00 = 0.80	08:00 - 09:00 = 0.80	
09:00 - 13:00 = 1.00	09:00 - 13:00 = 1.00	
13:00 - 14:00 = 0.80	13:00 - 14:00 = 0.80	
14:00 - 16:00 = 1.00	14:00 - 16:00 = 1.00	
16:00 - 20:00 = 0.20	16:00 - 24:00 = 0.05	
20:00 - 24:00 = 0.05		

Figure 17: Device and equipment scheduling: 1 January to 31 December.

5.8 Internal gain from lighting

The input data related to the use of artificial lighting in the building are shown in Figure 18, while its scheduling values appear in Figure 19. These data are used to calculate the energy consumption and corresponding heat gain, using the following formula:

Consumption/gain from lighting (W) = Floor area x (minimum light level/100) x lighting energy (W/m²-100 lux) x scheduling value

Type of space	Min light (lux)	Light energy (W/m²-100 lux)	Gain (W/m²)	Ret. F	Radiant F	Visible F	Conv. F	Scheduling
Work areas	500	4.20	21.00	0.00	0.37	0.18	0.45	Lighting
Service areas	200	4.20	8.40	0.00	0.37	0.18	0.45	Lighting

Ret. F = Return fraction (heat extracted), Rad. F = Radiant fraction, Visible F = Visible fraction, Conv. F = Convective fraction

Figure 18: Input data for artificial lighting.

Mon to Thu	Fri	Sat and Sun
00:00 - 08:00 = 0.05	00:00 - 08:00 = 0.05	00:00 - 24:00 = 0.05
08:00 - 09:00 = 0.80	08:00 - 09:00 = 0.80	
09:00 - 13:00 = 1.00	09:00 - 13:00 = 1.00	
13:00 - 14:00 = 0.80	13:00 - 14:00 = 0.80	
14:00 - 16:00 = 1.00	14:00 - 16:00 = 1.00	
16:00 - 20:00 = 0.20	16:00 - 24:00 = 0.05	
20:00 - 24:00 = 0.05		

Figure 19: Lighting scheduling: 1 January to 31 December.

It is, nonetheless, important to clarify that in addition to these parameters, a light sensor has been modelled in the work areas for Scenarios 03 and 05, able to gradually increase or decrease the lighting intensity depending on natural light availability. It is assumed that luminaires can attenuate their output down to 3 % of maximum and, when they reach this level, go out completely.

In Scenario 05, working together with a system of automatically moving slats, the light level control is intended to represent as realistically as possible the real building's solar and light control system, within the limitations of the modelling software used.

5.9 HVAC system

The air-conditioning systems have been modelled using DesignBuilder's Compact HVAC option, which enables the inclusion, through EnergyPlus template objects, of generic systems with self-dimensioning particular components.

In this case a four tube fancoil system has been specified, with a hot water circuit supplied by a gas boiler with a nominal output of 0.89, and a cold water circuit supplied by a cooling device with a reference COP of 3.67. Both circuits are considered to be simultaneously available when the building is occupied and for the whole year, as shown in the scheduling chart in Figure 20. The temperature setpoint for cooling is 25 °C and that for heating is 21 °C.

Mon to Thu	**Fri**	**Sat and Sun**
00:00 - 08:00 = 0.00	00:00 - 08:00 = 0.00	00:00 - 24:00 = 0.00
08:00 - 20:00 = 1.00	08:00 - 16:00 = 1.00	
20:00 - 24:00 = 0.00	16:00 - 24:00 = 0.00	

Figure 20: Heating and cooling schedule: 1 January to 31 December.

The mechanical ventilation that forms part of the air-conditioning system has been configured to use return air while always guaranteeing a minimum fresh air rate of, in this case, 12.5 l/s per person. The scheduling shown in Figure 21 has been assigned to the mechanical ventilation system, so that the level of fanned fresh air varies depending on the occupation level (a value of 1 represents maximum fresh air, while the decimal values represent partial ventilation rates).

Mon to Thu	**Fri**	**Sat and Sun**
00:00 - 08:00 = 0.00	00:00 - 08:00 = 0.00	00:00 - 24:00 = 0.00
08:00 - 09:00 = 0.80	08:00 - 09:00 = 0.80	
09:00 - 13:00 = 1.00	09:00 - 13:00 = 1.00	
13:00 - 14:00 = 0.80	13:00 - 14:00 = 0.80	
14:00 - 16:00 = 1.00	14:00 - 16:00 = 1.00	
16:00 - 20:00 = 0.20	16:00 - 24:00 = 0.00	
20:00 - 24:00 = 0.00		

Figure 21: Mechanical ventilation schedule: 1 January to 31 December.

This section presents a synthesis of the results from the simulations. For each of the scenarios a simulation over one year using the input data shown in the previous section has been run.

6.1 Total energy usage

The first results are those showing a comparative table of energy usage (Figure 22), expressed in kWh/m². These include energy used for lighting, heating (boiler), mechanical ventilation, air-conditioning pumps and cooling (cooling unit). The table also shows the degree of improvement provided by Scenarios 02 to 05 compared to Scenario 01, expressed as percentage reduction in overall energy usage. Figure 23 is a graphical representation of Figure 22.

	Lighting	Heating	Ventilation	Pumps	Cooling	Total	Improvement
01. Original, no slats, no control	46.7	12.2	7.9	8.1	36.3	111.2	Ref.
02. Current, no slats, no control	46.7	9.2	8.0	8.9	40.3	113.1	-1.7 %
03. Current, slats, no control	46.7	10.9	6.3	7.4	33.3	104.6	6.0 %
04. Current, no slats, control	27.4	12.5	6.5	7.5	32.6	86.5	22.2 %
05. Current, slats, control	27.7	15.3	5.2	6.5	27.6	82.3	26.0 %

Figure 22: Comparative table showing the building's air-conditioning and lighting-related energy consumption (kWh/m²).

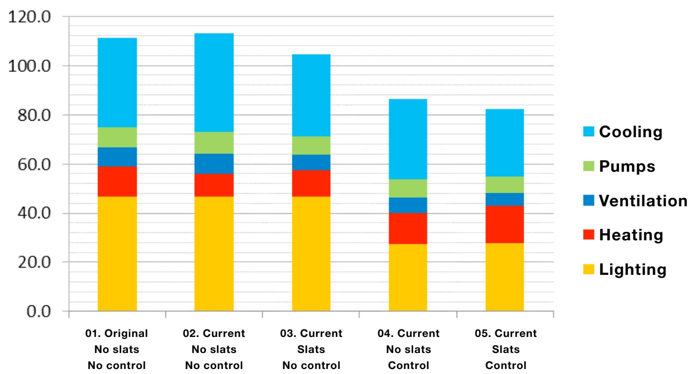


Figure 23: Comparative chart showing the building's air-conditioning and lighting-related energy consumption (kWh/m²).

It will be noted that in Scenario 02 (current building, no slats, no control) total energy consumption is 1.7 % higher than in Scenario 01 (original building before refurbishment). This is due to the installation on the main façade of envelope closures with improved insulation (lower transmission coefficient) but lower thermal mass.

Given that the building is located in Barcelona and given its use and internal loads (occupation, illumination and equipment), the energy usage for cooling is much higher than that for heating. The fact that the type of closure replaced in the main façade had greater thermal mass than the new closure means that the total consumption of the refurbished building is slightly higher than that of the old building. It can be seen that the refurbished building has lower heating energy requirements than the original building due to the closure on its front façade having a lower transmission coefficient (better insulation), although the energy consumption for cooling is greater in the refurbished building than in the old one due to the original closure in the main façade having greater thermal mass. Since the building's energy simulation is dynamic, the value of the thermal mass has a considerable influence on the results obtained.

Taking Scenario 02 (current, no slats, no control) as a reference point the improvements from slats and lighting control are shown. In this way the improvement exclusively produced by the systems is shown.

	Lighting	**Heating**	**Ventilation**	**Pumps**	**Cooling**	**Total**	**Total Improvement**	**Total Improvement**
01. Original, no slats, no control	46.7	12.2	7.9	8.1	36.3	111.2	1.9	1.68 %
02. Current, no slats, no control	46.7	9.2	8.0	8.9	40.3	113.1	Ref.	Ref.
03. Current, slats, no control	46.7	10.9	6.3	7.4	33.3	104.6	8.5	7.52 %
04. Current, no slats, control	27.4	12.5	6.5	7.5	32.6	86.5	26.6	23.52 %
05. Current, slats, control	27.7	15.3	5.2	6.5	27.6	82.3	30.8	27.23 %

Figure 24: Energy consumption: comparative table (kWh/m^2).

6.2 The building's thermal balances

To better quantify this, a thermal balance for the building has been made taking account of gains through the opaque envelope (incorporating gains and losses through walls, floors and roofs), through internal sources (people and equipment), through infiltration, through glazing (including solar gain and through-window conduction), through lighting, heating and cooling, with the following conditions in place:

1. Values represent the sum of heat gains and losses throughout the year. Some values imply gains only, as is the case with lighting, and others losses only, as is the case with cooling. For the opaque closures, nonetheless, there are both gains and losses. This means that taking the year as a whole, even if the result is a loss of heat through the closures, there are also periods when the results show gains.

2. Cooling and heating gains represent the energy that the air-conditioning system both extracts and gives to the space, to maintain comfortable conditions. The main differences regarding the corresponding energy consumption are that for this calculation the efficiency of the equipment does not enter into the equation and the loads associated with the treatment of external ventilation air are not taken into account either.

3. In a perfect thermal balance the total values in the right-hand column should tend to zero. Since we are dealing with dynamic calculations, however, in which such aspects as thermal inertia are involved, there will always be residual values in this case.

	Closures	Internal Gain	Infiltration	Glazing	Lighting	Heating	Cooling	Total
01. Original, no slats, no control	-38.5	52.1	-9.4	25.5	46.7	1.9	-75.4	3.0
02. Current, no slats, no control	-31.3	52.2	-9.5	25.0	46.7	1.3	-81.5	2.9
03. Current, slats, no control	-29.5	52.2	-9.2	12.4	46.7	1.5	-71.6	2.6
04. Current, no slats, control	-28.0	52.4	-9.2	26.0	27.4	1.9	-68.0	2.3
05. Current, slats, control	-27.0	52.3	-8.9	13.1	27.7	2.2	-57.5	1.9

Figure 25: Comparative table: the building's thermal balances (kWh/m²).

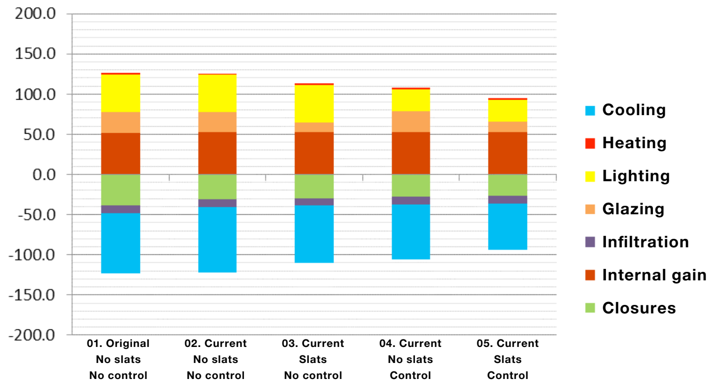


Figure 26: Comparative chart: the building's thermal balances (kWh/m²).

In Figures 27 and 28 the data for heat gains and losses due to cooling, heating and lighting have been isolated out from the above data. This allows us to establish a clearer relationship between thermal balances and their associated energy usage, most especially in terms of percentage improvements.

NB: To calculate the total values in the table in Figure 27, negative values (heat losses) associated with cooling have been inverted.

	Cooling	Heating	Lighting	Total	Total improvement
01. Original, no slats, no control	-75.4	1.9	46.7	124.1	4.17 %
02. Current, no slats, no control	-81.5	1.3	46.7	129.5	Ref.
03. Current, slats, no control	-71.6	1.5	46.7	119.8	7.49 %
04. Current, no slats, control	-68.0	1.9	27.4	97.3	24.86 %
05. Current, slats, control	-57.5	2.2	27.7	87.4	32.51 %

Figure 27: Comparative table of the building's partial thermal balances (kWh/m²).

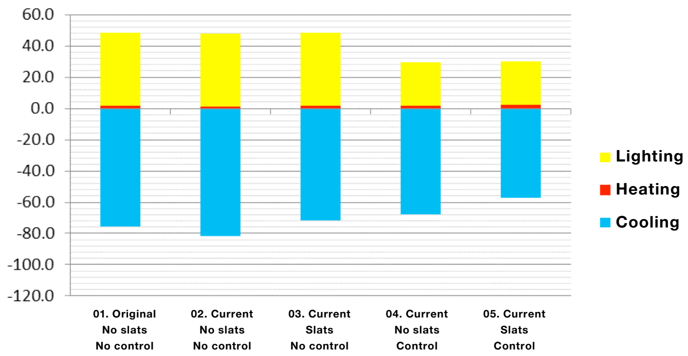


Figure 28: Comparative chart of the building's partial thermal balances (kWh/m²).

Analysis of Scenario 02 results

It can be appreciated the consumption for cooling is greater in Scenario 02 (refurbished building, no slats, no lighting control) than in Scenario 01 (building pre-refurbishment), with respective figures of 75.4 and 81.5 kWh/m². Heating, on the other hand, reduces from 1.9 kWh/m² pre-refurbishment to 1.3 kWh/m² post-refurbishment.

Analysis of Scenario 03 results

When considering the results of Scenario 03 (refurbished building with slats but no lighting control) it will be appreciated that energy consumption for cooling decreases substantially compared to Scenario 02, falling from 81.5 to 71.6 kWh/m², due to having fitted the moveable solar protection slats. Nonetheless, heating consumption noticeably increases, rising from 1.3 to 1.5 kWh/m², since while the moveable slats allow diffused sunlight to come in, they stop direct sunlight from doing so (to avoid glare) and there is, therefore, less free heat gain in winter, which creates a noticeable increase in demand for heating compared to Scenario 02. It will also be noted that lighting consumption remains steady in all of Scenarios 01, 02 and 03, since the lighting system modelled does not have lighting control and the luminaires are lit all the time the building is occupied and used, regardless of the natural daylight coming into the building.

There is a 3.5 % improvement in energy consumption compared to the original building and a 7.5 % improvement compared to the refurbished building with neither slats nor lighting control.

Analysis of Scenario 04 Results

Turning to the results for the Scenario 04 model (refurbished building with lighting control but no slats) and comparing them with the Scenario 02 results (refurbished building with neither slats nor lighting control) it can be observed that there is a significant improvement in whole-building energy usage, due in its greatest part to the reduction in energy for lighting, falling from 46.7 to 27.4 kWh/m^2. Energy usage for cooling also falls noticeably, from 81.5 kWh/m^2 to 68 kWh/m^2, from which it can be deduced that the fall in energy usage for lighting has a substantial positive impact on reduced energy requirements for cooling. The reduction in energy usage for lighting has a negative effect, however, on the building's heating energy use, which increases from 1.3 to 1.9 kWh/m^2, although the differences in the amounts of energy used for cooling/lighting compared to heating, mean that this negative effect does not have any significant impact when it comes to calculating whole-building energy consumption.

The building's improvement in energy consumption is 21.6 % compared to the original building and 24.8 % compared to the refurbished building without slats or lighting control.

Analysis of Scenario 05 results

Comparing the results obtained from Scenario 05 (refurbished building with both slats and lighting control, incorporating all the actions undertaken as part of the comprehensive refurbishment of the building) with Scenario 04 (refurbished building with lighting control but no slats), it is observed that energy usage for cooling falls from 68 to 57.5 kWh/m^2, due to the protection given by the moveable slats on the façade from solar gain, even though energy consumption for lighting and heating increases noticeably due to the fact that while the moveable slats allow diffused solar radiation into the building, they prevent the entry of direct solar radiation (to avoid glare) and, therefore, there is less free solar gain in winter, leading to a marked increase in heating requirements. This increase is not very significant in the overall calculation of the building's energy usage, with an improvement of 29.6 % compared to the building before it was refurbished and an improvement of 32.5 % in comparison with the refurbished building with neither slats nor lighting control.

From these results it is possible to draw conclusions about energy improvements resulting from fitting the solar protection and lighting control systems, considering them both separately and jointly.

Considerations relative to the building

The results obtained and commented on above all refer to the BUILDING (that is, the entire, whole building), including all its façades, floors and internal spaces. It needs to be stated that the solar protection system is only fitted on the East and South-east (angled) façades, and not on the West-facing rear façade. It is also the case that there is no slat solar protection system anywhere on the ground or mezzanine floors, meaning that the results for improved energy usage would have been even greater had slats been fitted to the rear, West façade and to the ground floor and mezzanine.

To quantify the effect of a slat solar control system, a simulation has been carried out at the ZONE level of one representative zone with both slat and lighting control systems. The simulation was carried out in such a way that other zones without the control systems had no influence on the improvement results obtained in this zone. This simulation is carried out in the next section.

6.3 One representative ZONE's thermal balances with moveable slats

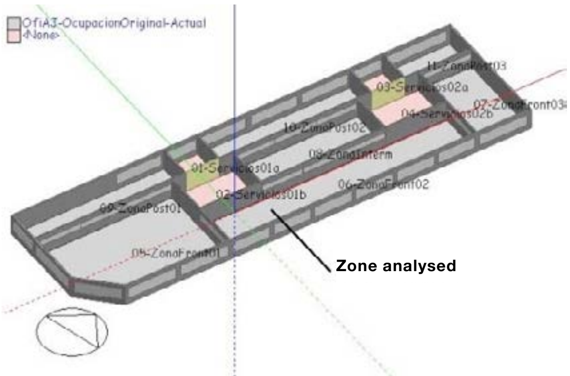


Figure 29: The zone analysed in this section.

As mentioned in the Input Data section, the moveable slat system was not installed at every window in the building, but only on those first to fourth floor windows on the East, South-east and South façades (for the South façade only those windows adjacent to the South-east façade are considered.) This means that only 42.2 % of the total occupied surface area of the building has the moveable slat system. This, added to the fact that the ground floor has a very different exposure to solar radiation than the other floors, due to its geometry, makes it difficult to measure the true impact of the moveable slat system when data are presented at the whole building level.

To come closer to this aspect of the building's performance, this section presents the thermal balances calculated for one representative zone using the moveable slat system. The zone in question is Frontal Zone 02 on the second floor (See Figure 29).

NB: All the conditions made in the previous section apply for these data.

	Cooling	Heating	Lighting	Total	Total Improvement
01. Original, no slats, no control	-98	1.1	47.8	146.9	6.85 %
02. Current, no slats, no control	-109.5	0.3	47.8	157.7	Ref.
03. Current, slats, no control	-80.6	0.6	47.8	129.0	18.20 %
04. Current, no slats, control	-89.3	0.7	20.8	110.7	29.80 %
05. Current, slats, control	-60.9	1.0	22.1	84.0	46.73 %

Figure 30: Comparative table of overall thermal balances for Frontal Zone 02 (kWh/m²).

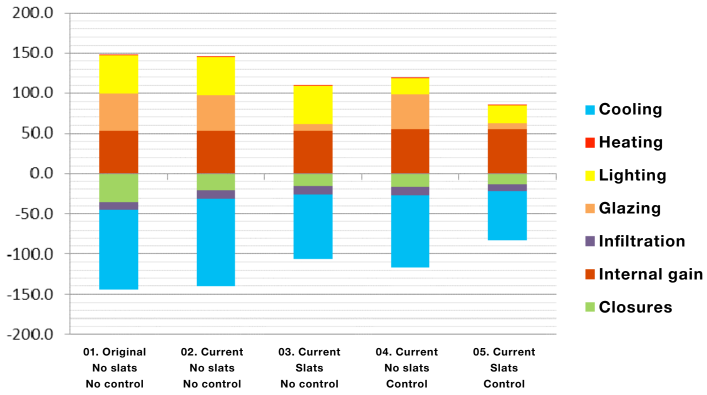


Figure 31: Comparative chart of overall thermal balances for Frontal Zone 02 (kWh/m²).

	Cooling	Heating	Lighting	Total	Improvement
01. Original, no slats, no control	-98.0	1.1	47.8	146.9	Ref.
02. Current, no slats, no control	-109.5	0.3	47.8	157.7	-7.4 %
03. Current, slats, no control	-80.6	0.6	47.8	129.0	12.2 %
04. Current, no slats, control	-89.3	0.7	20.8	110.7	24.6 %
05. Current, slats, control	-60.9	1.0	22.1	84.0	42.8 %

Figure 32: Comparative table of partial thermal balances for Frontal Zone 02 (kWh/m²).

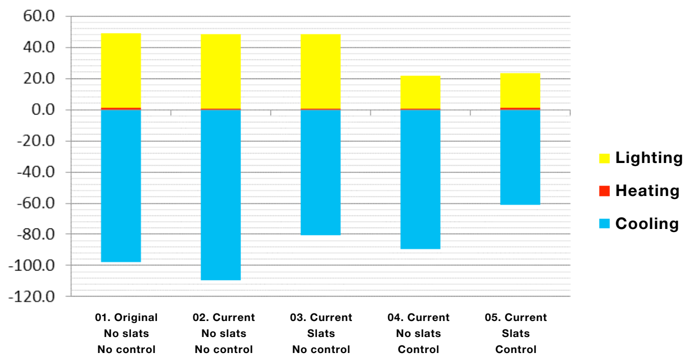


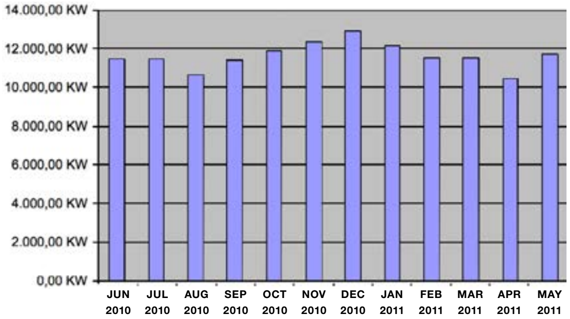
Figure 33: Comparative chart of partial thermal balances for Frontal Zone 02 (kWh/m²).

It can be seen that the improvement results in terms of ZONE level energy usage increase considerably compared to the BUILDING level energy usage, achieving improvements of 42.8 % compared to the original building before refurbishment and 46.7 % compared to the refurbished building without slats or lighting control.

6.4 Comparison of measured and modelled energy usage for lighting

Since real measured data are available for the energy used for lighting for one complete year in the current building (Scenario 05), it is possible to make a comparison between these data and those obtained in the simulations.

The electrical consumption data for lighting taken from the LUXMATE LRA Module for the period June 2010 to May 2011 are shown below:



Building	SERVEIS TERRITORIALS DE TREBALL
Location	C/ Carrera 12-24. BARCELONA
Start Date	01-Jun-2010
End Date	31-May-2011
DALI Luminaire	2 x 36 W
Number Luminaires:	1 137
Power installed (W)	81 864
June 2010	11 450.26 KW
July 2010	11 462.26 KW
August 2010	10 657.44 KW
September 2010	11 370.64 KW
October 2010	11 878.58 KW
November 2010	12 315.18 KW
December 2010	12 910.79 KW
January 2011	12 134.43 KW
February 2011	11 539.17 KW
March 2011	11 522.12 KW
April 2011	10 443.91 KW
May 2011	11 714.40 KW
Total	139 399.18 KW

The table in Figure 34 and the chart in Figure 35 show this comparative analysis. A good level of correspondence between the measured data and those obtained from the simulations can be observed. Even though the differences start to become significant in the early and late months, the rest show a fairly close match. Taking annual energy usage, on the other hand, the difference is only 3.5 %.

This comparison offers us a good reliability level in the models developed, especially insofar as the operation of the moveable slat and lighting control systems is concerned. Regarding the other energy consumption parameters, such as those to do with heating and cooling, no comparison was possible due to the lack of differentiated measured data.

	Measured	**Simulation**	**Difference**
Jan	2.33	2.77	-19.1 %
Feb	2.21	2.23	-0.6 %
Mar	2.21	2.15	2.7 %
Apr	2.00	2.15	-7.3 %
May	2.25	2.21	1.8 %
Jun	2.20	2.02	8.1 %
Jul	2.20	2.10	4.5 %
Aug	2.05	2.05	0.0 %
Sep	2.18	2.17	0.7 %
Oct	2.28	2.58	-13.2 %
Nov	2.36	2.52	-6.8 %
Dec	2.48	2.75	-11.1 %
Total	26.76	27.71	-3.5 %

Figure 34: Table comparing measured and simulated energy consumption for lighting in Scenario 05 (kWh/m²).

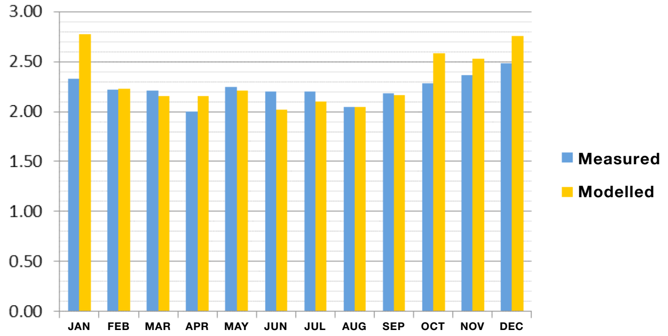


Figure 35: Chart comparing measured and simulated energy consumption for lighting in Scenario 05 (kWh/m²).

The differences, albeit small, between actual energy usage by the installation and the figures yielded by the model may be due to the following factors:

1. The building's hours of operation used in the model may differ to a certain extent from its actual operating hours.

2. The climate data used in the model are taken from an IWEC (Ashrae) database, which differ to an extent from the real climate data for the period June 2010 to May 2011, the period for which we have real data for lighting power usage. Since real climate data from a weather station located close to the building studied is available, provided by the "Servei Meteorològic de Catalunya – METEOCAT", a comparison has been made between both sets of data (as explained in section 5.1 of this study). The comparison follows:

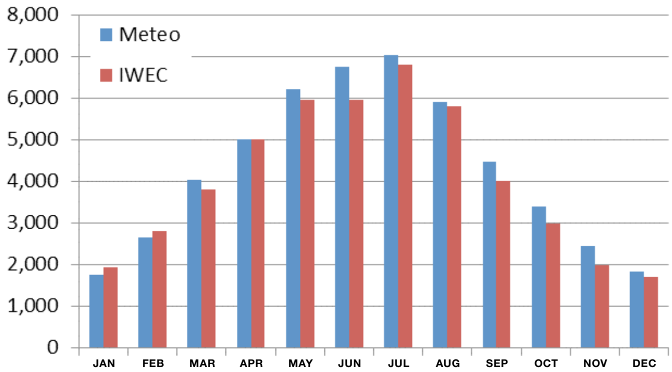


Figure 36: Comparison of global horizontal solar radiation (Wh/m²).

3. The simulation does not take account of the light passing through the interior partitions separating outer rooms from inner ones; this leads to differences between the installation's real energy usage data for lighting and the results from the model.

7 Conclusion

This section will present the Study's conclusions.

This study has been carried out using the example of a recently refurbished building fitted with a Luxmate lighting control and external slat system, for which real data are available for electrical power consumption from May 2010 to May 2011. Real data for the air-conditioning system are not, however, available since it has not been possible to take readings from the network analysers fitted to the electrical panels.

This study has quantified the influence of a lighting regulation and external slat solar protection system on the building's energy consumption, not only in terms of power used for lighting but also as regards the building's energy usage for air-conditioning.

7.1 BUILDING scenarios

Different Scenarios have been modelled in order to quantify the improvements in energy usage from the lighting control and external slat systems fitted, both individually and together. The scenarios are listed below:

– Scenario 01: Original building, before refurbishment, without moveable slats or lighting control.
– Scenario 02: Current refurbished building without moveable slats or lighting control.
– Scenario 03: Current refurbished building with moveable slats but without lighting control.
– Scenario 04: Current refurbished building, without moveable slats but with lighting control.
– Scenario 05: Current refurbished building, with both moveable slats and lighting control.

The simulation was carried out on both the BUILDING and ZONE levels. In the first case (BUILDING level), the model was of every zone and floor of the building, arriving at results for energy consumption arising from the lighting system and from the air-conditioning system for each of the Scenarios, summarised below:

	Cooling	**Cooling Improv.**	**Heating**	**Heating Improv.**	**Lighting**	**Lighting Improv.**	**Total**	**Total Improv.**	**Total Improv.**
01. Original, no slats, no control	-75.4	7.48 %	1.9	-46.15 %	46.7	0.00 %	124.1	5.4	4.17 %
02. Current, no slats, no control	-81.5	Ref.	1.3	Ref.	46.7	Ref.	129.5	Ref.	Ref.
03. Current, slats, no control	-71.6	12.15 %	1.5	-15.38 %	46.7	0 %	119.8	9.7	7.49 %
04. Current, no slats, control	-68.0	16.56 %	1.9	-46.15 %	27.4	41.33 %	97.3	32.2	24.86 %
05. Current, slats, control	-57.5	29.45 %	2.2	-69.23 %	27.7	40.69 %	87.4	42.1	32.51 %

Figure 37: Comparative table showing the building's partial thermal balances (kWh/m²).

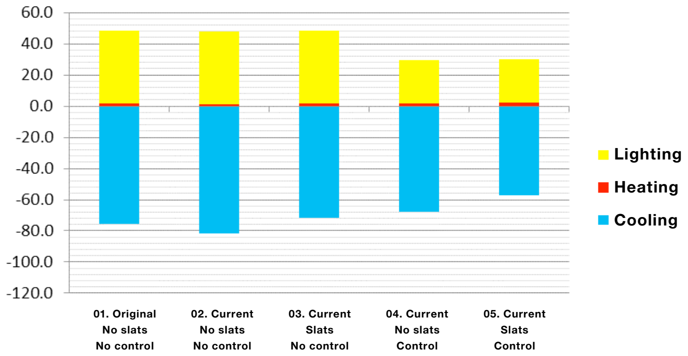


Figure 38: Chart comparing the building's partial thermal balances (kWh/m²).

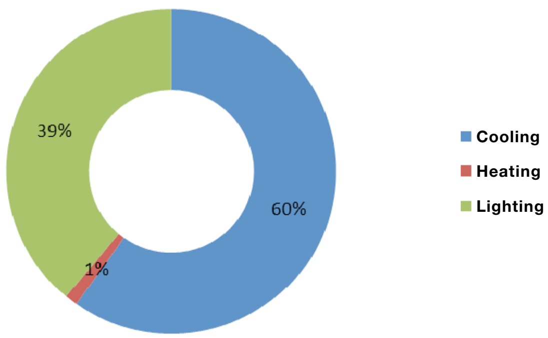
It must be pointed out that both the rear elevation (facing West) and the main façades of the ground and mezzanine floors (facing East) do not have a moveable slat system over their glazing; this means that the results obtained show the influence both of zones with solar protection and zones with no solar protection at all. Nonetheless, the improvements gained in Scenarios 03, 04 and 05 are significant.

7.1.1 BUILDING LEVEL analysis of Scenario 03 (current building, with slats but no lighting control)

Taking the Scenario 02 (Current building, no slats, no control) results as a reference, it is appreciated that Scenario 03 (external slats only) yields a 7.5 % reduction in overall air-con + lighting costs.

This Scenario 03 enables energy savings due solely to having fitted a moveable slat system fitted on glazed areas of the façade.

Energy consumption is divided up among cooling, heating and lighting as follows:



Breaking this overall percentage saving down into the different types of energy consumption:

- Cooling: A 12.14 % reduction in energy used for cooling is achieved, compared to Scenario 02. The impact on the cooling system of having solely the slats can be clearly seen, due to the fact that the slats clearly have an effect of reducing direct solar radiation through the façade's glazed surfaces. It must be noted that results are at the Building level and, therefore, include parts of the building without solar protection slats (rear, West-facing elevation and main, East-facing elevations on ground and mezzanine floors).

- Heating: In this situation the energy used for heating increases by 15.4 % compared to the same building without the system of external slats on the windows. The fact that the external slats provide protection against the entry of direct solar radiation through the windows has a clear influence on the heating system since such radiation is free heating gain working in favour of the heating system. Nonetheless, since the relative load of heating compared to that for lighting and cooling is not very representative given the placement and characteristics of the building, this 15.4 % increase does not have much impact on the calculation of the building's overall energy consumption. Moreover, this numerical calculation of energy usage does not take into account the aspects of improved comfort for the building's users due to the fact that preventing the entry of direct solar radiation through the windows avoids unwanted glare and excessive overheating of bodies close to the external windows, even in winter.

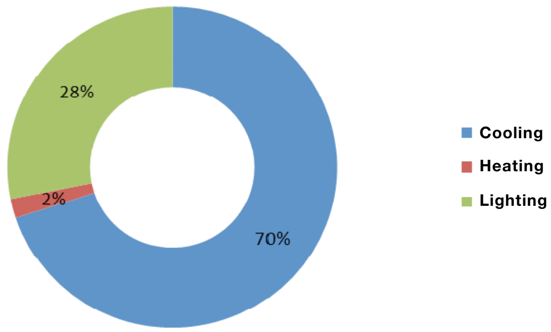
- Lighting: This remains unchanged since neither Scenario 02 nor Scenario 03 have lighting control and so lighting remains at 100 % the whole time the building is in use, regardless of the incidence of natural light through the windows.

7.1.2 BUILDING LEVEL analysis of Scenario 04 (current building, with lighting control but no slats)

With Scenario 04 (lighting control fitted, but no slats) a 24.9 % reduction compared to Scenario 02 is observed.

This Scenario 04 provides energy savings resulting from fitting a lighting control system without other measures.

Energy consumption is divided up among cooling, heating and lighting as follows:



Breaking this overall percentage saving down into the different types of energy consumption:

– Cooling: In this case a 16.56 % reduction in cooling energy usage is achieved, compared to Scenario 02, due solely to the reduction in internal gain through lighting to be combated by the air-conditioning system, given that there is a light regulation system in place which modulates the intensity of the luminaires depending on how much natural daylight enters through the building's glazed façades.

– Heating: In this instance there is a 46.15 % increase in consumption by the heating system compared to the same building without lighting control. This is due to the fact that internal gain from lighting, which acts in favour of the heating system in winter, is reduced, and the heating system, therefore, has to combat this reduction. Nonetheless, since the effect of consumption for heating compared to that for lighting and cooling is not very representative given the location and characteristics of the building, this 46.15 % has little impact on the calculation of the building's overall energy consumption.

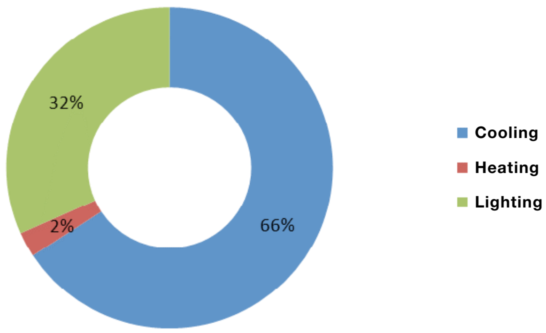
– Lighting: The impact of installing a lighting control system is that the lighting system's energy use falls by 41.32 % compared to the same building without lighting control.

7.1.3 BUILDING LEVEL analysis of Scenario 05 (current building with both slats and lighting control)

With Scenario 05 (lighting control and moveable slats on glazed surfaces of the elevation) a 32.51 % reduction compared to Scenario 02 is observed.

This Scenario 05 provides energy savings due to the combination of fitting a lighting control system and a moveable slat system to glazed surfaces of the elevation.

Energy consumption is divided up among cooling, heating and lighting as follows:



Breaking this overall percentage saving down into the different types of energy consumption:

- Cooling: in this instance there is a 29.44 % reduction in energy consumption for cooling compared to Scenario 02, due to a combination of fitting both a lighting control system and a moveable slat system to the glazed surfaces of the façade.

- Heating: in this instance consumption by the heating system increases by 69.23 % compared to the same building with neither lighting control nor external moveable slats. This is due to reduced internal gain from lighting, which works in favour of the heating system in winter and also to reduced free gain from the entry of direct solar radiation through the windows, since both these losses have to be combated by the heating system. Nonetheless, this increase has little impact on the calculation of the building's overall energy consumption due to the low weight of the heating compared to the cooling and lighting.

- Lighting: in this instance energy consumption by the lighting system falls by 40.68 % compared to the same building without lighting control or external slats. This percentage is somewhat lower than that in Scenario 04 (41.32 %) since, as has been stated, the fact of external slats preventing the entry of direct solar radiation through the façade's windows also affects the entry of natural light from outside with a consequent slight increase in the luminaires' intensity.

7.2 Single ZONE scenarios

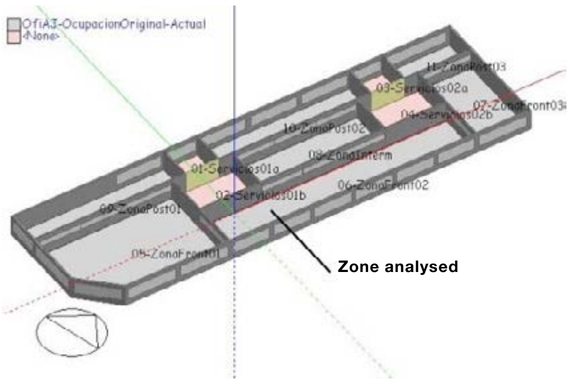


Figure 39: The zone analysed in this section.

When the simulation is carried out at the ZONE level, the results are quite different. Modelling has been carried out for a single zone of the building fitted with a moveable slat system on its façade. To be specific, modelling has taken place of the zone shown in the drawing as "Frontal Zone 02", which has an East-facing elevation.

Modelling just this zone of the building makes it possible to more precisely quantify the impact of a moveable slat system on the façade, since the results are not impacted by the energy balances of building zones without this system, such as the ground floor and mezzanine spaces and the spaces adjacent to the rear, West-facing façade.

The results achieved for the zone analysed are shown below:

	Cooling	Cooling Improv.	Heating	Heating Improv.	Lighting	Lighting Improv.	Total	Total Improv.	Total improv.
01. Original, no slats, no control	-98	10.50 %	1.1	-266.67 %	47.8	0.00 %	146.9	10.8	6.85 %
02. Current, no slats, no control	-109.5	Ref.	0.3	Ref.	47.8	Ref.	157.7	Ref.	Ref.
03. Current, slats, no control	-80.6	26.39 %	0.6	-100.00 %	47.8	0 %	129.0	28.7	18.20 %
04. Current, no slats, control	-89.3	18.45 %	0.7	-133.33 %	20.8	56.49 %	110.7	47.0	29.80 %
05. Current, slats, control	-60.9	44.38 %	1.0	-233.33 %	22.1	53.77 %	84.0	73.7	46.73 %

Figure 40: Comparative table showing partial thermal balances for Frontal Zone 02 (kWh/m²).

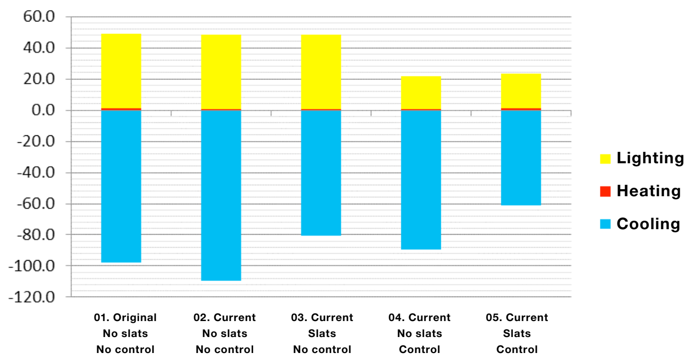


Figure 41: Comparative chart showing partial thermal balances for Frontal Zone 02 (kWh/m²).

The next chart, below, shows a comparison of the improvements achieved in each of the Scenarios modelled between the BUILDING and ZONE levels, compared to Scenario 02 (current building, no slats, no lighting control).

7.2.1 ZONE LEVEL analysis of Scenario 03 (current building, no slats, no control)

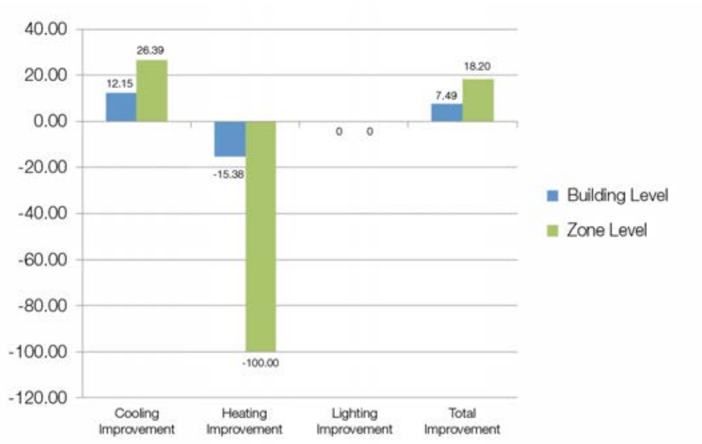


Figure 42: Comparative improvements chart, Scenario 03, BUILDING vs. ZONE level.

7.2.2 ZONE LEVEL analysis of Scenario 04 (current building, no slats, with control)

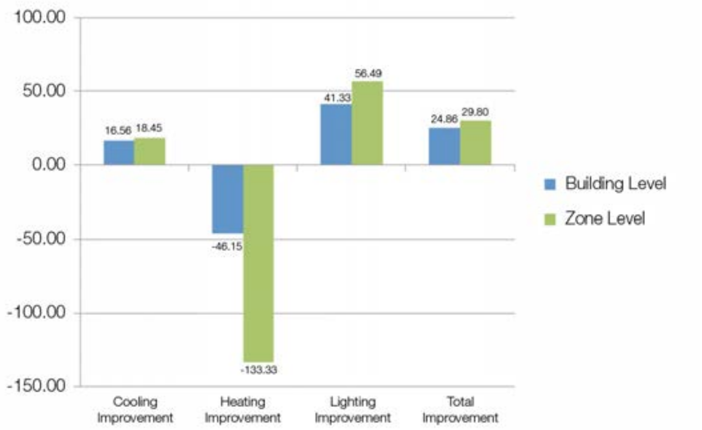


Figure 43: Comparative improvements chart, Scenario 04, BUILDING vs. ZONE level.

7.2.3 ZONE LEVEL analysis of Scenario 05 (current building with slats and control)

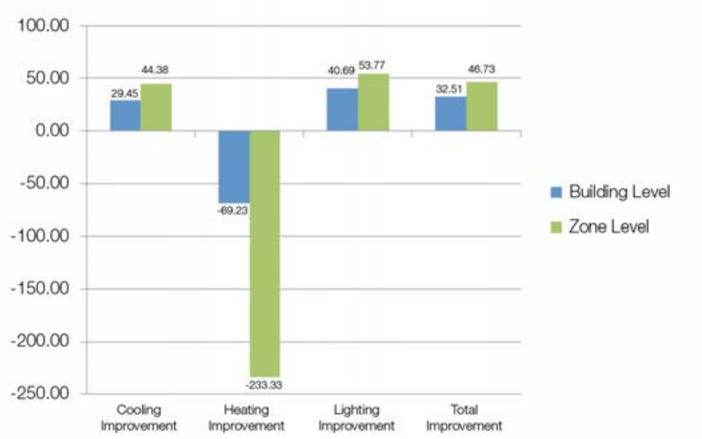


Figure 44: Comparative improvements chart, Scenario 05, BUILDING vs. ZONE level.

7.3 Final conclusions

It can be seen in the comparisons above that overall energy-saving improvements are substantially greater in the case of ZONE level modelling, since, as has been mentioned, other building zones without moveable slats installed on the façade have no influence.

In the specific case of the cooling system, it must be borne in mind that at the ZONE level a space with an East-facing façade has been modelled. Were the simulation to be carried out at ZONE level for a space with a West-facing elevation protected by moveable slats, the cooling system energy saving would be even greater since the incident solar radiation in summer in a location such as Barcelona is greater in a West orientation (afternoon sun) than in an Eastern orientation (morning sun). Nonetheless, the building studied here does not have solar protection slats on its West elevation.

From these results and comparisons made above, one can conclude that in a climate such as Barcelona's, and an office building with high internal loadings from equipment, lighting and occupancy, the loadings are nearly always positive, for which reason the cooling system has to combat them all year round and, therefore, the heating system is of little import insofar as the building's overall energy consumption is concerned.

For this reason a solar protection moveable slat system on the glazed elevations is totally advisable on buildings located in areas with similar climatic conditions as Barcelona and with similar uses to the building modelled, since significant energy savings can be made with the cooling system, as has been shown above.

These savings are (Scenario 03) 18.20 % compared to the total building energy consumption for one ZONE and 7.49 % for the whole BUILDING.

Regarding lighting, if we refer to one East-facing ZONE, the saving from lighting control alone is 56.49 % of power used for lighting and for the whole of our BUILDING it is 41.33 %.

Lighting control, on its own, would be responsible for a saving of 29.80 % of energy used (air-con and lighting) at the ZONE level and 24.86 % of energy used (air-con and lighting) for the BUILDING, and this is why lighting control is so important.

If we now consider moveable slats and lighting control in combination, it turns out that lighting control alone saves 53.77 % of energy used on lighting in the ZONE and 40.69 % in the BUILDING. And the improvements in energy usage (air-con and lighting) when we include both moveable slats and lighting control are 43.73 % in the ZONE and 32.51 % in the BUILDING, and this is why slats and lighting control in combination are highly beneficial for energy-saving at the whole-building level.

Finally, it should be stated that simulated energy consumption for lighting has been compared with data taken from the system in operation with results that are very close, as can be seen in the following table:

	Measured	**Simulation**	**Difference**
Jan	2.33	2.77	-19.1 %
Feb	2.21	2.23	-0.6 %
Mar	2.21	2.15	2.7 %
Apr	2.00	2.15	-7.3 %
May	2.25	2.21	1.8 %
Jun	2.20	2.02	8.1 %
Jul	2.20	2.10	4.5 %
Aug	2.05	2.05	0.0 %
Sep	2.18	2.17	0.7 %
Oct	2.28	2.58	-13.2 %
Nov	2.36	2.52	-6.8 %
Dec	2.48	2.75	-11.1 %
Total	26.76	27.71	-3.5 %

Figure 45: Comparative table showing measured and modelled energy consumption for lighting in Scenario 05 (kWh/m^2).

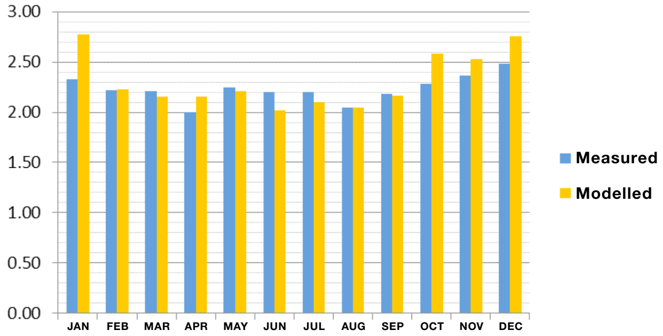


Figure 46: Comparative chart showing measured and modelled energy consumption for lighting in Scenario 05 (kWh/m^2).

The closeness between the simulated and real energy consumptions for lighting give a high degree of reliability to this Study.

UNIVERSITAT ROVIRA I VIRGILI
DEPARTAMENT D'ENGINYERIA MECÀNICA

Alberto Coronas, catedrático del area de Máquinas y Motores Térmicos del Departamento de Ingeniería Mecánica de la Universidad Rovira i Virgili

Hace Constar

Que el Estudio " Análisis del impacto energético de las medidas de control solar y lumínico aplicadas en el edificio SCDT de la Generalitat de Catalunya" ha sido realizado por Arturo Ordoñez Garcia bajo mi supervisión y con la colaboración de Jose Luis Hernandez de la empresa AJ Enginyeria.

Y para que así conste, firmo este documento en Tarragona a 30d e Noviembre de 2011

Barcelona, January 2012

THE INDUSTRIAL ENGINEER

Juan Hernández Mayor
Dr. Ingeniero Industrial
N° Col. 3 687

ZUMTOBEL

United Kingdom
Zumtobel Lighting Ltd.
Chiltern Park
Chiltern Hill, Chalfont St. Peter
Buckinghamshire SL9 9FG
T +44/(0)1388 420 042
lightcentreuk@zumtobelgroup.com
zumtobel.co.uk

USA and Canada
Zumtobel Lighting Inc.
3300 Route 9W
Highland, NY 12528
T +1/(0)845/691 6262
F +1/(0)845/691 6289
zli.us@zumtobel.com
zumtobel.us

Australia and New Zealand
Zumtobel Lighting Pty Ltd
333 Pacific Highway
North Sydney, NSW 2060
T +61/(2)8913 5000
F +61/(2)8913 5001
info@zumtobel.com.au
zumtobel.com.au

China
Zumtobel Lighting China
Shanghai office
Room 101,
No 192 YIHONG Technology Park
Tianlin Road, Xuhui District
Shanghai City, 200233, P.R. China
T +86/(21) 6375 6262
F +86/(21) 6375 6285
sales.cn@zumtobel.com
zumtobel.cn

Hong Kong
Zumtobel Lighting Hong Kong
Unit 4301, Level 43,
Tower 1, Metroplaza,
223 Hing Fong Road,
Kwai Chung, N.T.
T +852/2578 4303
F +852/2887 0247
info.hk@zumtobel.com

India
Zumtobel Lighting GmbH
Vipul Trade Centre, 406, 4th Floor
Sohna Road, Sector 48,
Gurgaon 122002, Haryana, India
T +91/124 4206885 6886
info.in@zumtobel.com

Singapore
Zumtobel Lighting Singapore
158 Kallang Way # 06-01/02
Singapore 349245
T +65 6844 5800
F +65 6745 7707
info.sg@zumtobel.com

United Arab Emirates
Zumtobel Lighting GmbH
4B Street, Al Quoz Industrial Area
Dubai, United Arab Emirates
T +971/4 340 4646
F +971/4 299 3531
info@zumtobel.ae
zumtobel.ae

Romania
Zumtobel Lighting Romania SRL
Radu Greceanu Street, no. 2,
Ground Floor, sector 1
012225 Bucharest
T +40 31225 38 01
F +40 31225 38 04
welcome.ro@zumtobel.com
zumtobel.com

Hungary
ZG Lighting Hungary Kft.
Váci út 49
1134 Budapest
T +36/(1) 450 2490
F +36/(1) 350 0829
welcome@zumtobel.hu
zumtobel.hu

Croatia
ZG Lighting d.o.o.
Radnička cesta 80
10000 Zagreb
T +385/(1) 64 04 080
F +385/(1) 64 04 090
welcome@zumtobel.hr

Bosnia and Herzegovina
ZG Lighting d.o.o.
Topal Osman Pase 18
71000 Sarajevo
M+387 61 172 240
welcome.ba@zumtobel.com

Serbia
ZG Lighting d.o.o.
Beton hala – Karađorđeva 2-4
11000 Belgrade
M+381 69 54 44 802
welcome@zumtobel.rs

Czech Republic
ZG Lighting Czech Republic s.r.o.
Jankovcova 2
Praha 7
170 00 Praha
T +420 266 782 200
F +420 266 782 201
welcome@zumtobel.cz
zumtobel.cz

Slovak Republic
ZG Lighting Slovakia s.r.o.
Vlčie Hrdlo 1,
824 12 Bratislava
welcome@zumtobel.sk
zumtobel.sk

Poland
ZG Lighting Polska Sp. z o.o.
Wołoska 9a
Platinium Business Park III
02-583 Warszawa
T +48 22 856 74 31
zgpolska@zumtobelgroup.com
zumtobel.pl

Slovenia
ZG Lighting d.o.o
Štukljeva cesta 46
1000 Ljubljana
T +386/(1) 5609 820
F +386/(1) 5609 866
si.welcome@zumtobelgroup.com
zumtobel.si

Russia
Zumtobel Lighting GmbH
Official Representative Office
Skakovaya Str. 17
Bld. No 1, Office 1104
125040 Moscow
T +7/(495) 945 36 33
F +7/(495) 945 16 94
info-russia@zumtobel.com
zumtobel.ru

Norway
Zumtobel Belysning
Strømsveien 344
1081 Oslo
T +47 22 82 07 00
info.no@zumtobel.com
zumtobel.no

Sweden
Zumtobel Belysning
Birger Jarlsgatan 57
113 56 Stockholm
T +46 8 26 26 50
info.se@zumtobel.com
zumtobel.se

Denmark
Zumtobel Belysning
Stamholmen 155, 5. sal
2650 Hvidovre
T +45 35 43 70 00
info.dk@zumtobel.com
zumtobel.dk

Headquarters
Zumtobel Lighting GmbH
Schweizer Strasse 30
Postfach 72
6851 Dornbirn, AUSTRIA
T +43/(0)5572/390-0
info@zumtobel.info

ZG Licht Mitte-Ost GmbH
Grevenmarschstrasse 74-78
32657 Lemgo, GERMANY
T +49/(0)5261 212-0
F +49/(0)5261 212-7777
info@zumtobel.de

zumtobel.com

zumtobel.com/lightingmanagement