DRAFT

Energy Efficiency, Thermal and Visual Comfort Study

of an Integrated Automation Solution

(Shading, Lighting and HVAC Systems)

in a Commercial Building located at Rio de Janeiro - Brazil

Final Report V.3.6

2016, February - São Paulo - Brazil

Performed by

Sustentech
Desenvolvimento Sustentável

Cooperating companies in this project

somfy

CCN AUTOMAÇÃO

PHILIPS

uniflex

INTRODUCTION

Commercial buildings consume a significant part of the energy generated worldwide, and most of this consumption is intended for operation of HVAC and lighting.

The increasingly frequent use of glass facades that bring aesthetic freedom and modernity to commercial buildings projects brings a dual challenge: how to maintain thermal and visual comfort of the occupants while reducing the energy consumption.

The reduction of this consumption will guide the new criteria for the use of energy, the legislation, the environmental certifications and the technologies employed in buildings.

This study was developed for a commercial building located in the city of Rio de Janeiro - Brazil, with a facade with large exposure to the sun and expressive glass area and aims to evaluate the reduction in energy consumption as well the improvement in thermal and lighting comfort level associated with HVAC and lighting systems.

Results were obtained by simulating strategies of automation (integration and control) with different materials for solar protection and different types of glasses.

Regarding the automation strategies, were evaluated three progressive levels of integration between the internal shading (interior roller blinds), lighting and HVAC automation.

Finally, the study highlights the importance of considering the jointly specification of glasses and automated internal shading for commercial building facades, in order to achieve more energy efficiency and comfort for the occupants. It also unequivocally shows the HVAC energy reduction consumption when using automated internal shading and the additional benefits when integrating it to lighting and HVAC automation.

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1. SUMMARY

The study is based on an envelope of an existing building located in the city of Rio de Janeiro, Brazil and aims to:

- Analyze the energy reduction consumption based on different levels of integration between shading, lighting and HVAC automation (Energy efficiency study);
- Validate the thermal and visual comfort of automated internal shading – interior roller blinds (Thermal and visual comfort studies).

In addition to the different levels of integration were also assessed in the study two types of shading fabric (with and without aluminum coating) and seven types of glass, shown in Table 1.

Glass #	1	2	3	4	5	6	7
Glass Type	Coated Insula ted	Coated Insula ted	Coated Lamina ted	Coated Lamina ted	Coated Lamina ted	Coated Lamina ted	Non Coated Single Pane
SHGC (g value)	0,27	0,30	0,30	0,33	0,36	0,40	0,87
Visible Light transmittance (Tv)	0,37	0,41	0,19	0,22	0,31	0,38	0,90

Table 1 - Glass specification

Computer simulations have been developed in co-simulation environment using EnergyPlus + Dialux + EES - Engineering Equation Solver.

The simulations models were based on the technologies of following companies:

- Somfy (shading motorization and automation);
- Uniflex (Shading manufacturer – interior roller blind);
- Philips (lighting and automation);
- CCN (HVAC automation and system integration).

ENERGY EFFICIENCY STUDY

The energy efficiency study consists of simulations scenarios with different levels of automation integration.

The automation integration scenarios are below described:

- Integration Level 1 (IL1): Automation of shading driven by Somfy system. No lighting automation;

- Integration Level 2 (IL2): Integration of Somfy automation system and Philips automation system by means of presence detectors;
- Integration Level 3 (IL3): Integration of Somfy system, Philips and CCN solutions, which will follow the Level 2 model and change the HVAC set-point temperature from 23°C to 27°C when the room is unoccupied.

Baseline scenarios with distinct façade arrangement were defined: one without shading and other with manual operated internal shading. Both baseline models have:

- Fluorescent lighting with normal performance and manual controlled;
- HVAC with fixed set point;

The climate files which were used in energy simulation, have the TMY format (Test Meteorological Year) and were developed by the Brazilian National Institute for Space Research (INPE).

The Table 2, and Table 3 show, for each level, the minimum and maximum energy savings compared to baseline models. This range includes the various simulation scenarios based on the selected glass and shading fabric.

Figure 1 shows, for the different types of glass, the energy consumption of baseline models and for each integration level considering two types of shading fabric.

HVAC + Lighting Energy Savings (Baseline: Façade without Internal Shading)

	Glass 1	Glass 2	Glass 3	Glass 4	Glass 5	Glass 6	Glass 7
Glass SHGC	27%	30%	30%	33%	36%	40%	87%
Glass Tv	37%	41%	19%	22%	31%	38%	90%
Energy Savings (Shading without aluminum)	IL1: 2,5% IL2: 15,5% IL3: 16,7%	IL1: 2,6% IL2: 16,2% IL3: 17,4%	IL1: 4,1% IL2: 13,6% IL3: 14,7%	IL1: 4,3% IL2: 14,4% IL3: 15,6%	IL1: 4,5% IL2: 16,3% IL3: 17,5%	IL1: 4,9% IL2: 17,6% IL3: 18,8%	IL1: 10,5% IL2: 24,6% IL3: 25,7%
Energy Savings (Shading with aluminum)	IL1: 3,8% IL2: 17,2% IL3: 18,4%	IL1: 4,2% IL2: 18,2% IL3: 19,4%	IL1: 5,0% IL2: 14,5% IL3: 15,7%	IL1: 5,4% IL2: 15,6% IL3: 16,7%	IL1: 5,8% IL2: 17,7% IL3: 18,9%	IL1: 6,4% IL2: 19,2% IL3: 20,4%	IL1: 16,4% IL2: 30,8% IL3: 31,9%

Table 2 - Air conditioning + lighting energy savings (Baseline: façade without internal shading)

HVAC + Lighting Energy Savings (Baseline: Façade with Manually Controlled Internal Shading)

	Glass 1	Glass 2	Glass 3	Glass 4	Glass 5	Glass 6	Glass 7
Glass SHGC	27%	30%	30%	33%	36%	40%	87%
Glass Tv	37%	41%	19%	22%	31%	38%	90%
Energy Savings (Shading without aluminum)	IL1 2,0% IL2 15,6% IL3 16,9%	IL1 2,2% IL2 16,4% IL3 17,7%	IL1 2,5% IL2 12,3% IL3 13,5%	IL1 2,7% IL2 13,2% IL3 14,3%	IL1 2,9% IL2 15,2% IL3 16,4%	IL1 3,2% IL2 16,5% IL3 17,7%	IL1 8,8% IL2 24,6% IL3 25,8%
Energy Savings (Shading with aluminum)	IL1 2,0% IL2 15,6% IL3 16,9%	IL1 2,2% IL2 16,4% IL3 17,7%	IL1 2,5% IL2 12,3% IL3 13,5%	IL1 2,7% IL2 13,2% IL3 14,3%	IL1 2,9% IL2 15,2% IL3 16,4%	IL1 3,2% IL2 16,5% IL3 17,7%	IL1 8,8% IL2 24,6% IL3 25,8%

Table 3 HVAC + Lighting Energy Savings (Baseline: Façade with Manually Controlled Internal Shading)

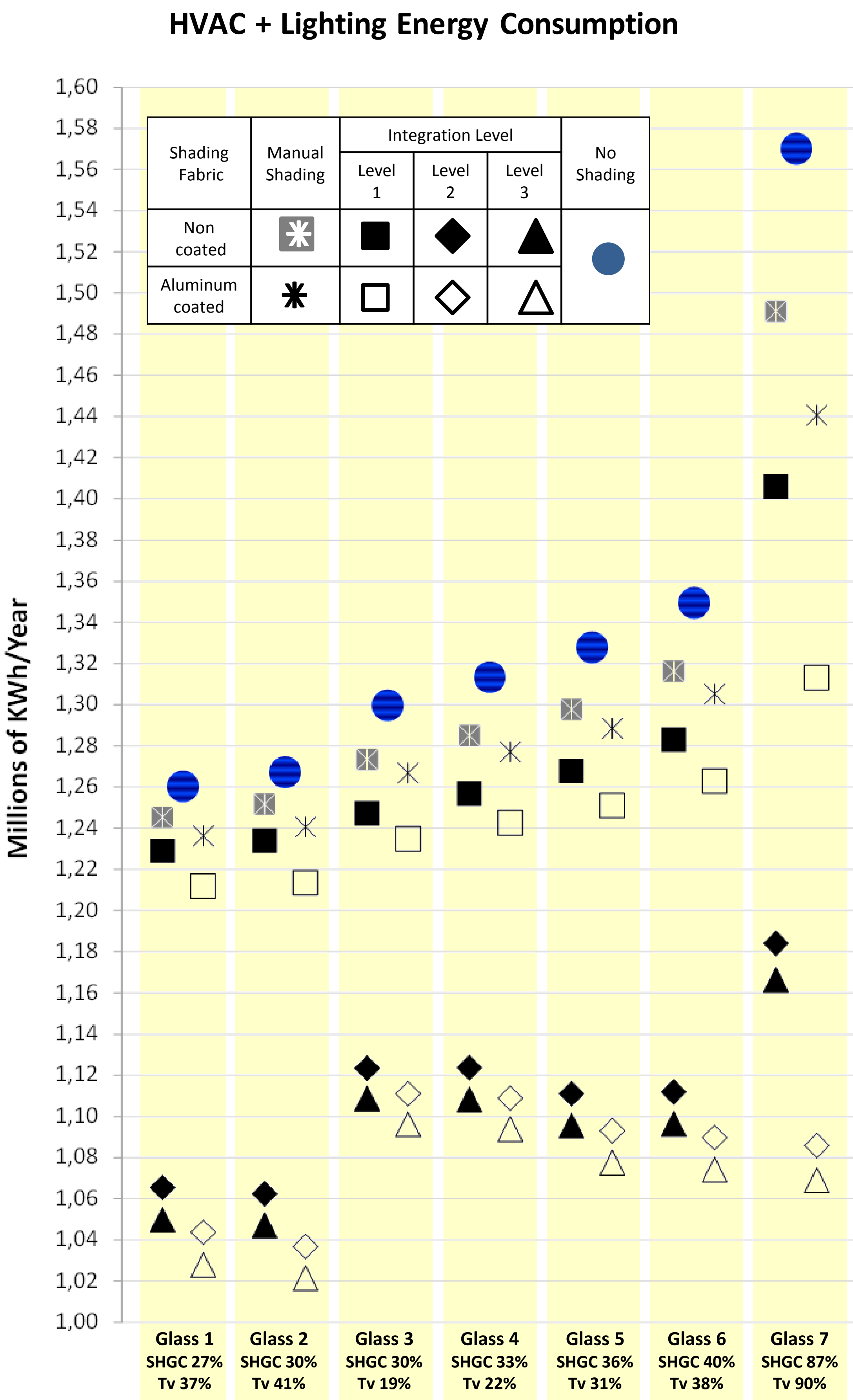

Figure 1 HVAC + Lighting Energy Consumption

Conclusions of energy efficiency study:

- The use of automated internal shading (IL1) reduces the HVAC energy consumption between 2,0% to 16,4% and therefore allows the specification of a broader options of glasses with higher SHGC value without impairing the energy consumption;
- The performance of internal shading with aluminum coated fabric increases when combined with glasses with higher SHGC value and should certainly be considered if higher OPEX are desired;
- The adoption of automated internal shading in retrofit of commercial buildings could allow the maintenance of the original glass with high SHGC values;
- The lighting automation integrated with internal shading automation (IL2) has a significant impact on energy consumption reduction, between 12,3% to 30,8% . This reduction is higher with glasses with higher transmittance of visible light (Tv) which enhances the harvesting of natural light into the workplace;
- The major savings in energy consumption is achieved when all systems are integrated (IL3), between 13,5% to 31,9%.

THERMAL COMFORT STUDY

The study evaluates the influence of the automated shading on occupant thermal comfort along the façade perimeter.

The thermal comfort is measured by reduction of thermal discomfort in degrees hour above 25°C in operating temperature.

The Table 4 and Table 5 show the achieved reduction and represent the various simulation scenarios based on the selected glass and shading fabric.

The Figure 2 shows, for the different types of glass, the thermal discomfort for baseline models and each integration level considering two types of shading fabric.

Thermal Discomfort Reduction (Baseline: Façade without Internal Shading)

	Glass 1	Glass 2	Glass 3	Glass 4	Glass 5	Glass 6	Glass 7
Glass SHGC	27%	30%	30%	33%	36%	40%	87%
Glass Tv	37%	41%	19%	22%	31%	38%	90%
Thermal Discomfort Reduction (Shading without aluminum)	53,8% IL1	52,0% IL1	69,5% IL1	68,0% IL1	65,9% IL1	63,6% IL1	59,5% IL1
Thermal Discomfort Reduction (Shading with aluminum)	80,2% IL1	81,6% IL1	79,7% IL1	79,3% IL1	79,1% IL1	78,3% IL1	86,1% IL1

Table 4 Thermal Discomfort Reduction (Baseline Façade without Shading)

Thermal Discomfort Reduction (Baseline: Façade with Manually Controlled Internal Shading)

	Glass 1	Glass 2	Glass 3	Glass 4	Glass 5	Glass 6	Glass 7
Glass SHGC	27%	30%	30%	33%	36%	40%	87%
Glass Tv	37%	41%	19%	22%	31%	38%	90%
Thermal Discomfort Reduction (Shading without aluminum)	43,0% IL1	42,3% IL1	47,0% IL1	45,7% IL1	43,9% IL1	42,4% IL1	40,7% IL1
Thermal Discomfort Reduction (Shading with aluminum)	67,2% IL1	68,5% IL1	58,0% IL1	57,7% IL1	57,9% IL1	57,5% IL1	71,1% IL1

Table 5 Thermal Discomfort Reduction (Baseline Façade without Shading)

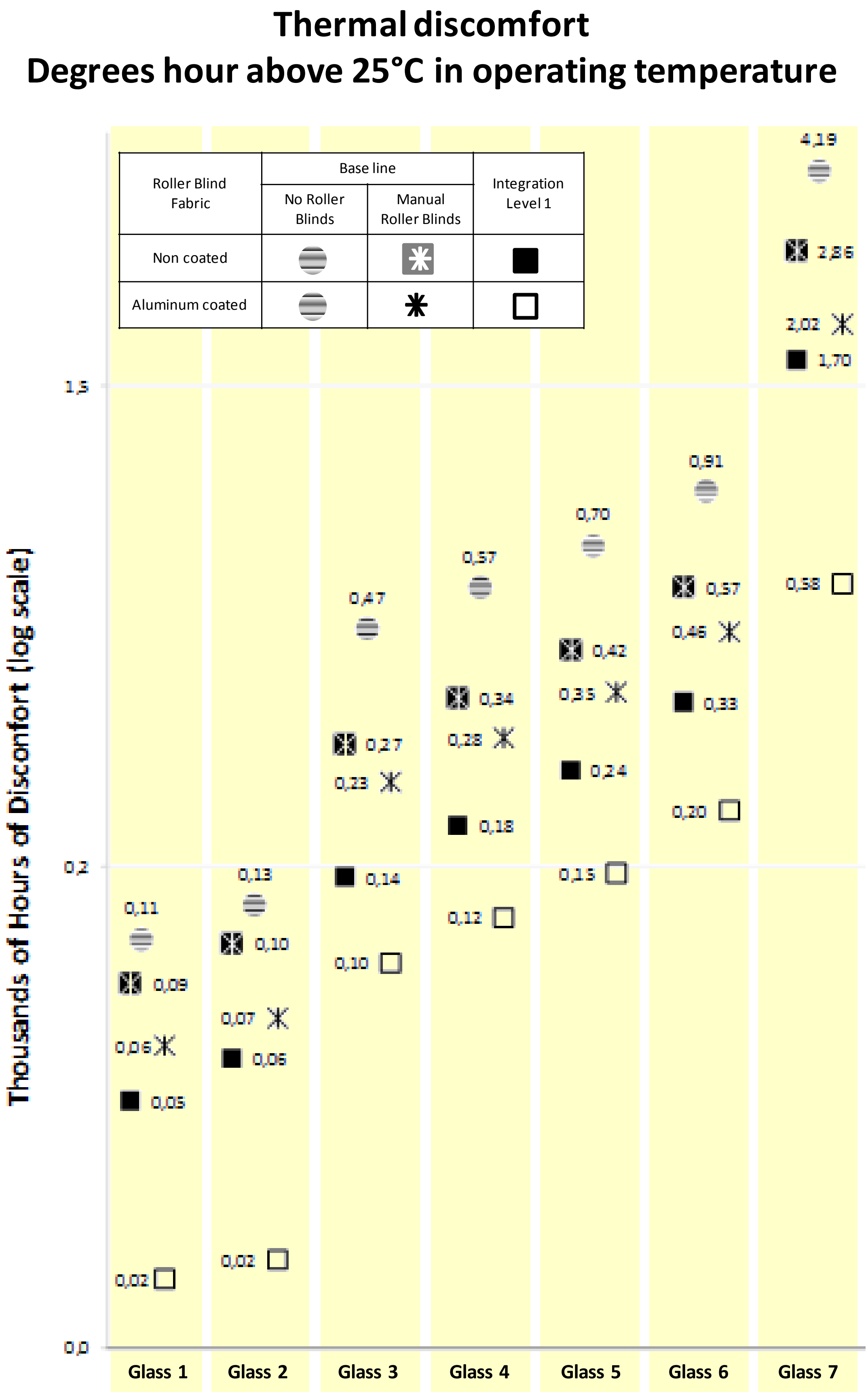

Figure 2 Thermal discomfort in degrees hour above 25°C in operating temperature.

Conclusions of thermal comfort study:

- The use of automated internal shading (IL1) reduces significantly the thermal discomfort, between 40,7% to 86,1% and therefore allows the specification of broader options of glasses with higher SHGC value without impairing the occupant comfort;
- The major reduction in discomfort is achieved in glasses with higher SHGC value;
- The internal shading with aluminum coated fabric achieved higher reduction in thermal discomfort;
- Besides the discomfort reduction the study also demonstrates reduction in radiant discomfort asymmetry usual in buildings with large glass area.

VISUAL COMFORT STUDY

The study evaluates the influence of the automated shading on occupant visual comfort along the façade perimeter.

The visual comfort is the maximum interior daylight iluminance measured at 0,5 meter from the façade considering the maximum outside luminance condition along the year. Several studies show 4.000 lux in interior daylight iluminance as the maximum acceptable for occupant's visual comfort.

The Table 6 and Table 7 show the reduction in the interior daylight iluminance and represent the various simulation scenarios based on the selected glass and shading fabric.

The Figure 3 shows, for the different types of glass, the interior daylight iluminance for baseline models and for each integration level considering two types of shading fabric.

Interior Daylight Iluminance Reduction (Baseline: Façade without Internal Shading)

	Glass 1	Glass 2	Glass 3	Glass 4	Glass 5	Glass 6	Glass 7
Glass SHGC	27%	30%	30%	33%	36%	40%	87%
Glass Tv	37%	41%	19%	22%	31%	38%	90%
Incoming Daylighting Reduction (Shading without aluminum)	88,6% IL1	89,1% IL1	87,4% IL1	88,5% IL1	88,8% IL1	88,7% IL1	94,3% IL1
Incoming Daylighting Reduction (Shading with aluminum)	90,8% IL1	89,8% IL1	89,1% IL1	90,4% IL1	91,5% IL1	90,9% IL1	94,7% IL1

Table 6 Interior Daylight Iluminance reduction (Baseline Façade without Shading)

Interior Daylight Iluminance Reduction (Baseline: Façade with Manually Controlled Internal Shading)

	Glass 1	Glass 2	Glass 3	Glass 4	Glass 5	Glass 6	Glass 7
Glass SHGC	27%	30%	30%	33%	36%	40%	87%
Glass Tv	37%	41%	19%	22%	31%	38%	90%
Thermal Discomfort Reduction (Shading without aluminum)	75,8% IL1	77,1% IL1	73,6% IL1	75,7% IL1	76,3% IL1	76,1% IL1	88,1% IL1
Thermal Discomfort Reduction (Shading with aluminum)	80,6% IL1	78,6% IL1	77,2% IL1	79,7% IL1	82,1% IL1	80,8% IL1	88,8% IL1

Table 7 Interior Daylight Iluminance reduction (Baseline: Façade with Manually Controlled Internal Shading)

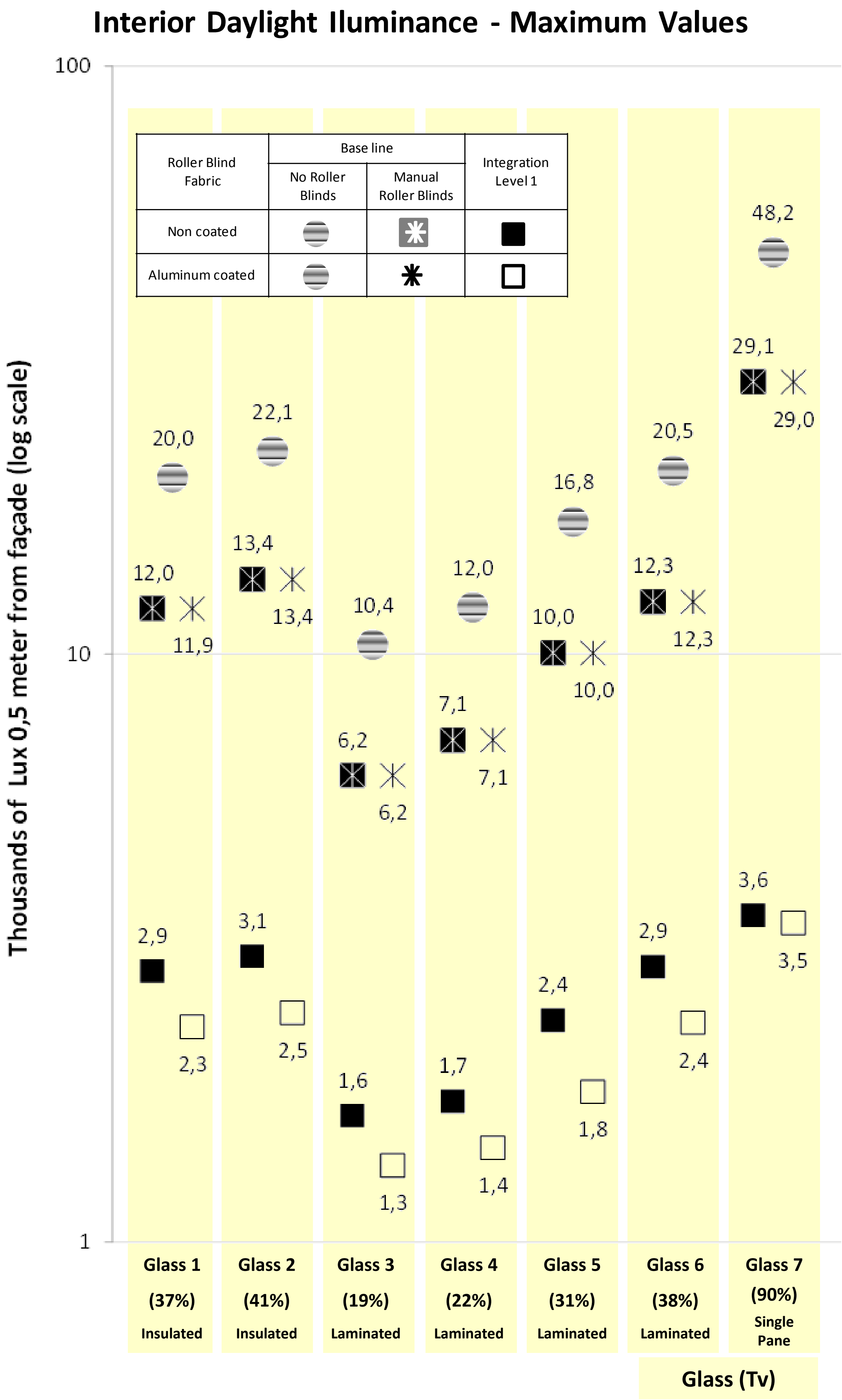

Figure 3 Interior Daylight Iluminance - Maximum Values

Conclusions of visual comfort study:

- It can be seen at the photometric curves that the use of automated internal shading significantly reduces the daylight iluminance levels near windows. This iluminance reduction brings uniformity of ambient light of the office area reducing discomfort due to difference in brightness;
- The reduction in daylight iluminance is between 73,3% and 94,7% at 0,5 meter from the façade;
- Automatically opening the internal shading at façades that are not having directly sun incidence, increases the clarity of these areas without creating discomfort and allows outside viewing to the occupants;
- The maximum interior daylight iluminance reduction was achieved with the glass with higher Tv.

Final conclusion:

The integration of Somfy automation systems, Philips and CCN, linked to the Uniflex internal shading brings benefits to all areas, reducing the building's consumption and also improving the thermal and visual comfort levels for office occupants.

2. DESCRIPTION OF THE INTEGRATED AUTOMATION SOLUTION

The solution integrates the Internal Shading, lighting and HVAC systems.
The use of high performance materials for solar protection and their automation enables greater use of natural light in the workplace ensuring thermal and visual comfort and providing better working conditions for its occupants. When integrated to lighting and HVAC automation significantly increases the energy efficiency of the building by reducing consumption of HVAC and artificial lighting.

2.1 INTERNAL SHADING (INTERIOR ROLLER BLINDS) - UNIFLEX

In the study two distinct shading fabrics were used:

- The "Thermoscreen", without aluminum layer (Figure 4)

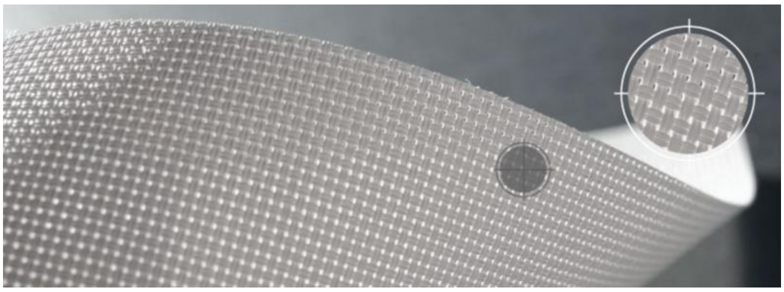

Figure 4 Thermoscreen fabric

- The "Platinumscreen", with aluminum layer (Figure 5)

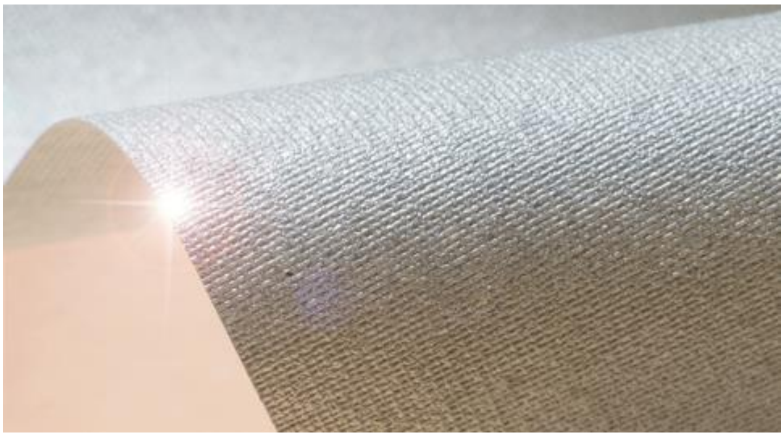

Figure 5 Platinumscreen fabric

The Figure 6 shows the interior shading (interior roller blinds) installation close to façade.

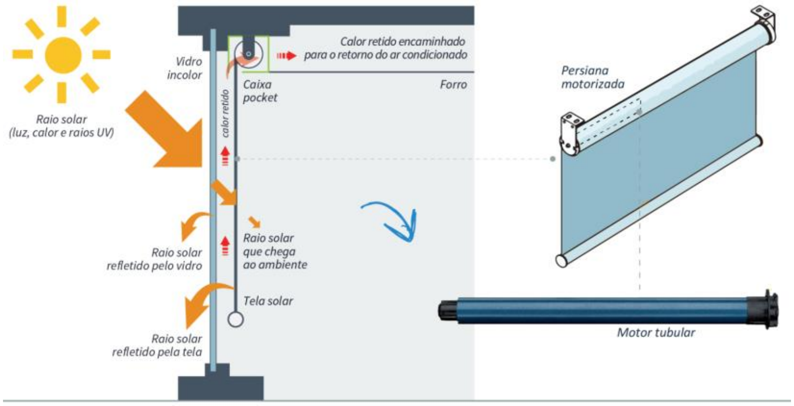

Figure 6 Interior shading installation

2.2. INTERNAL SHADING AUTOMATION – SOMFY

The SOMFY system is a dynamic solar shading control which reacts by taking into account the external climatic conditions and the sun position along the day in order to achieve energy saving and occupant's comfort.

The solar Internal Shading is dynamically positioned to maximize the daylighting but avoiding the direct glare and heating.

At any time the occupants are able to override the system and control the position of the solar Internal Shading manually via a remote control.

When the system is integrated with lighting automation, occupancy information could be used to lower the solar Internal Shading (Eco mode) when the space is vacant or turn to automatic control (Comfort mode) when the space is occupied.

2.3 LIGHTING AUTOMATION – PHILIPS

The PHILIPS system is a dynamic lighting control system, which reacts by taking into account the occupant presence and natural daylighting in order to achieve visual comfort and energy saving.

Visual comfort is the priority if the space is occupied (Comfort mode). A photo sensor installed at the ceiling control the luminaire to maintain 500kLux on the working pane. The luminaire is dimmed based on the daylighting allowed by the shading automation. If the space is vacant an occupancy sensor turned off the luminaires (Eco mode).

2.4 HVAC AUTOMATION – CCN AUTOMAÇÃO

The CCN AUTOMAÇÃO system controls the HVAC automation to maintain comfort setting point of 23oC.

When the system is integrated with shading and lighting automation, occupancy information could be used to increase the setting point to 28oC (Eco mode) when the space is vacant or turn to 23oC (Comfort mode) when the space is occupied.

2.5 INTEGRATION LEVELS

The integrated automation solution is composed by 3 progressive integration levels between Internal Shading, lighting and HVAC (Table 8).

The integration is made possible by the use of open communication protocols.

Integration Levels	**Systems**			Remarks
	Internal Shading	Lighting	HVAC	
Integration Level 1				Manual lighting Control HVAC not integrated
Integration Level 2				HVAC not integrated
Integration Level 3				All systems integrated

Table 8 Integration levels

3. CONTROL ALGORITHMS

3.1. INTERNAL SHADING

3.1.1. MANUAL CONTROL

In this control mode, the shading is manually operated by the occupants. The control model of the shading was based on models identified in technical literature. According to Silva, in 2012 the shades are operated based on three reasons:

- The Illuminance on the work plane
- The visual discomfort caused by light
- Direct sunlight, which influences both the thermal and visual comfort.

According to the literature the shades are open when the first person arrives at the office and is closed using the parameters described in the paragraph above, and according to Mahdavi these shades remains closed until the end of the day.

Silva, 2012 presents a compilation of literature and methodologies of the manual control of shades, amongst them the EN ISO 13790 which assumes that the shadings are closed when the radiation reaches 300 W/m2. Others assume the value of 50 W/m2. Mahdavi assumes the value of 250W/m2 and distinct occurrence frequency for each facade.

Mahdavi, 2009 shows that the probability of the shades be closed will vary with the level of incidence on the facades. The exception would be the northern and southern facades that practically do not vary with solar radiation according to a survey done by him in 5 offices and presented Figure 7.

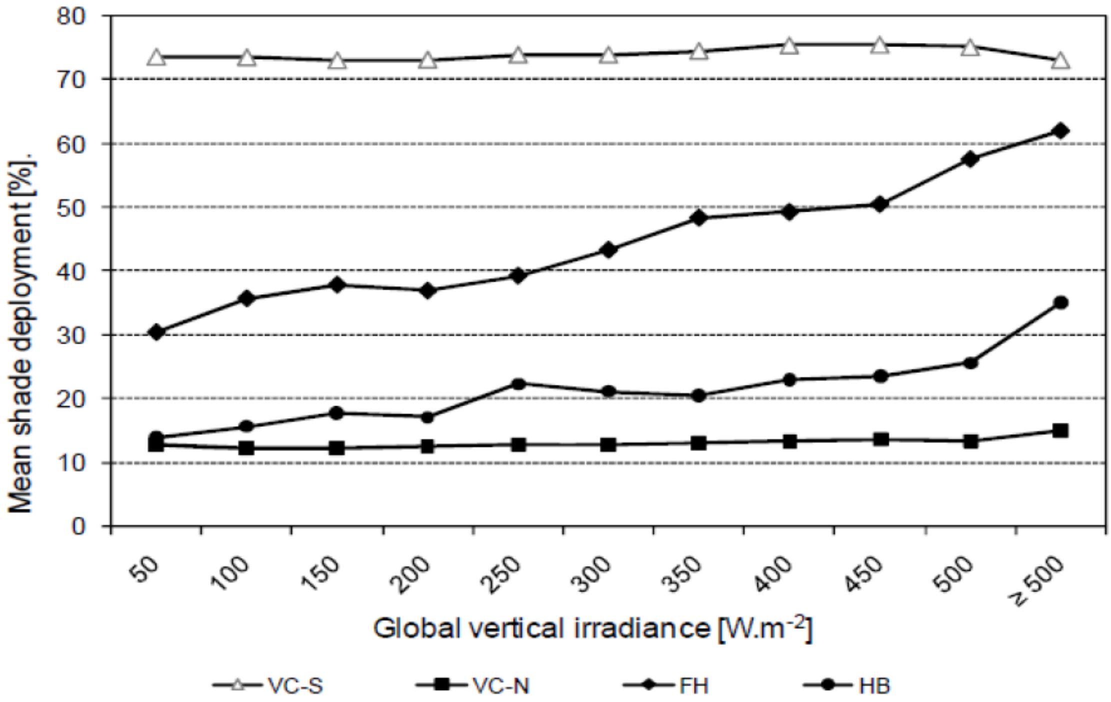

Figure 7 Percentage of shade deployment according to solar radiation

According to **Figure 7** the lowest percentage of usage is 15% closed in south facades for a maximum of 75% closed in the north facade and between 15% and 75 % for the other facades. Based on this information the methodology was developed, as shown in Table 9**.**

NORTH Facade (22.5° azimuth)	**Early in the morning**: blinds are opened (15% remain closed) **During the day:** 75% of the blinds are closed after 250 W/m2 **At the end of the workday:** Blinds are opened (15% remain closed)
SOUTH facade (Azimuth 202.5°)	**Early in the morning:** blinds are opened (15% remain closed) **During the day:** 15% of the blinds are closed after 250 W/m2 **At the end of the workday**: Blinds are opened (15% remain closed)
EAST -WEST Facade (Azimuth 112.5° and 292.5°)	**Early in the morning:** blinds are opened (15% remain closed) **During the day:** 50% of the blinds are closed after 250 W/m2 and 75% are closed after 500 W/m2 **At the end of the workday:** Blinds are opened (15% remain closed)
Remark: After closing the blinds, they remained closed until the end of the day	

Table 9 Manual control of blinds

3.1.2. AUTOMATED CONTROL

3.1.2.1 TIMER AND EXTERNAL ILLUMINANCE BASED CONTROL (INTEGRATION LEVEL 1)

The blind is automatically controlled according to external illuminance level and sun position along the day according to sun tracking system developed by Somfy. When the façade does not receive direct radiation from the sun the blinds are 40% lowered to offer a better visual comfort to the occupants.

There are distinct control modes dependent on the weekday and weekend. During weekdays the blind control is actively and during the weekend the blinds are lowered and static to prevent heating.

3.1.2.1 OCCUPANCY, TIMER AND EXTERNAL ILLUMINANCE BASED CONTROL (INTEGRATION LEVEL 2 AND 3)

The blind is automatically controlled according first to occupancy schedule and then to external illuminance level and sun position along the day.

3.2. LIGHTING

3.2.1. TIME BASED CONTROL (INTEGRATION LEVEL 1)

The model operates continuously from the early hours until the end of the day, 7.00 until 22.00 during the weekdays.

During the weekends the lights are off.

3.2.2. OCCUPANCY BASED SWITCHING AND DAYLIGHT DIMMING CONTROL (INTEGRATION LEVEL 2 AND 3)

This is an automated switching control based on the sensed occupancy status and also adds dimming due to available daylight.

The illumination is controlled by the presence sensor and the light sensor, which is influenced by the operation of the shadings.

3.3. HVAC

3.3.1. TIME BASED CONTROL (INTEGRATION LEVEL 1 AND 2)

The model operates continuously, maintaining the comfort set point (23oC) from the early hours until the end of the day, 7.00 until 22.00 during the weekdays.

3.3.2. OCCUPANCY BASED CONTROL (INTEGRATION LEVEL 2 AND 3)

This is an automated control based on the sensed occupancy status increasing the set point from 23oC to 27oC when there isn't occupancy at the controlled zone. With occupancy the set point is maintained at 23oC (comfort temperature).

4. ENERGY EFFICIENCY STUDY

4.1 METHODOLOGY

Dynamic computer simulation based on an office building model was used to quantify the impact in energy consumption (kWh/year) of the progressive integration levels between Internal Shading, lighting and HVAC automation. The energy consumption with no shading and with manual shading was also calculated in order to indicate the energy savings provided by each integration level.

The simulation focused on the open plan and meeting room areas, excluding the circulating area.

4.1.1 CLIMATIC CONDITION

To conduct the heat load simulation and then the analysis of annual energy performance of the building , files with temperature data, dry bulb and wet bulb , air pressure, wind speed and direction, solar radiation and cloud cover will be used to represent the climate conditions of the city of Rio de Janeiro - RJ. The location of Rio de Janeiro is 22.9° South and 43.17° West and altitude of 3 m. Climate data, which was used in energy simulation, have the TMY format (Test Meteorological Year) and were developed by the National Institute for Space Research (INPE). From this climate file gives the parameters; Radiation, Illuminance and Temperatures, dry and wet bulb.

Solar radiation is shown in Figure 8 and is responsible for heat passing through the window area of the building.

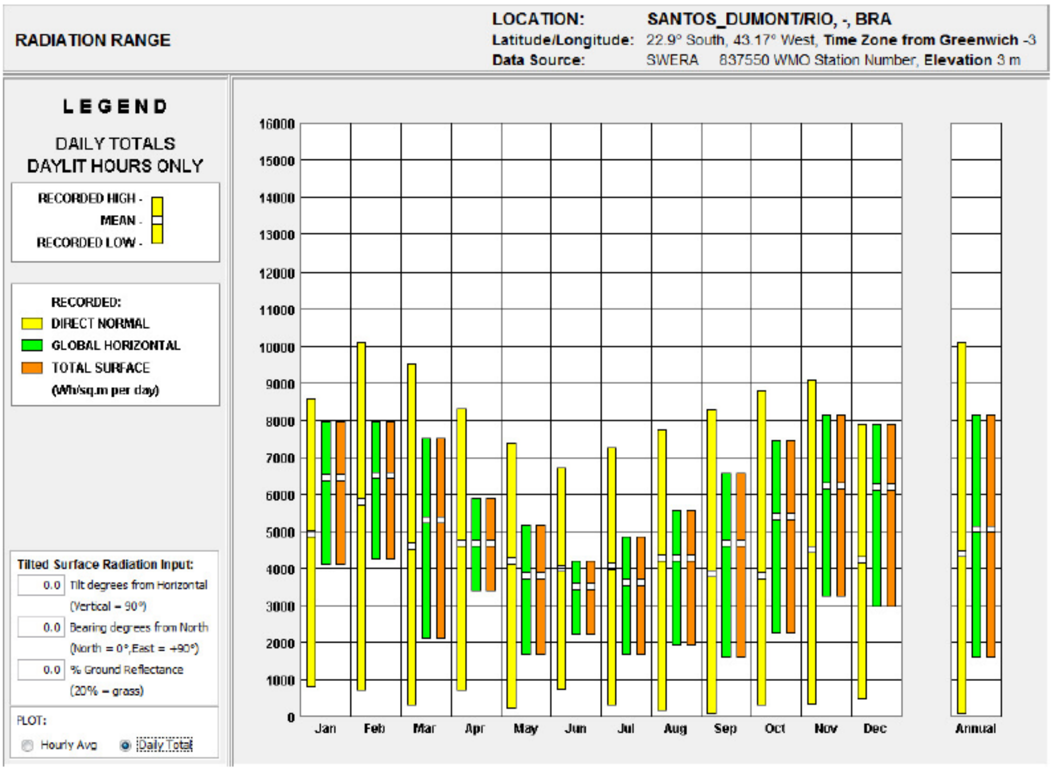

Figure 8 Direct and global solar radiation on a horizontal plane, total media a day [Wh / sf2]

The external Illuminance is shown in Figure 9 and will be responsible for the lighting of the work environment, which influenced the rate of natural lighting.

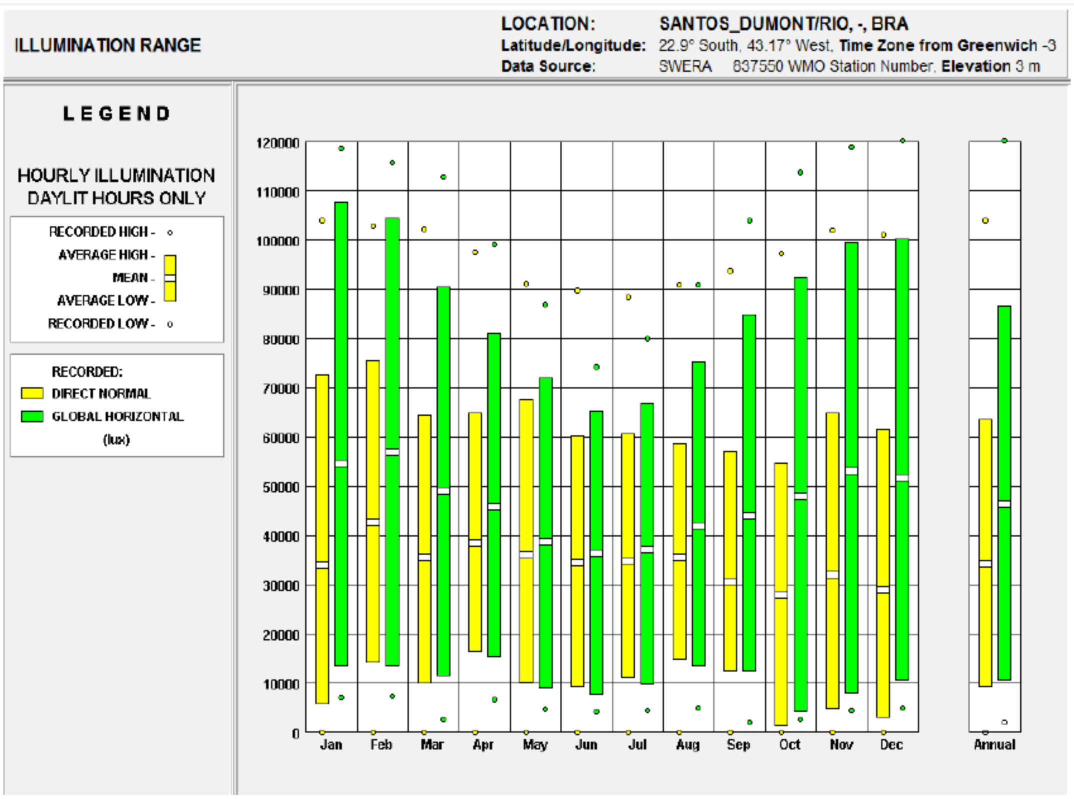

Figure 9 Direct and global illumination on a horizontal plane, hourly average [lux]

The dry bulb temperature and wet bulb data are shown in Figure 10, and are responsible for heat exchange in the envelope and the heat load of the renovation air.

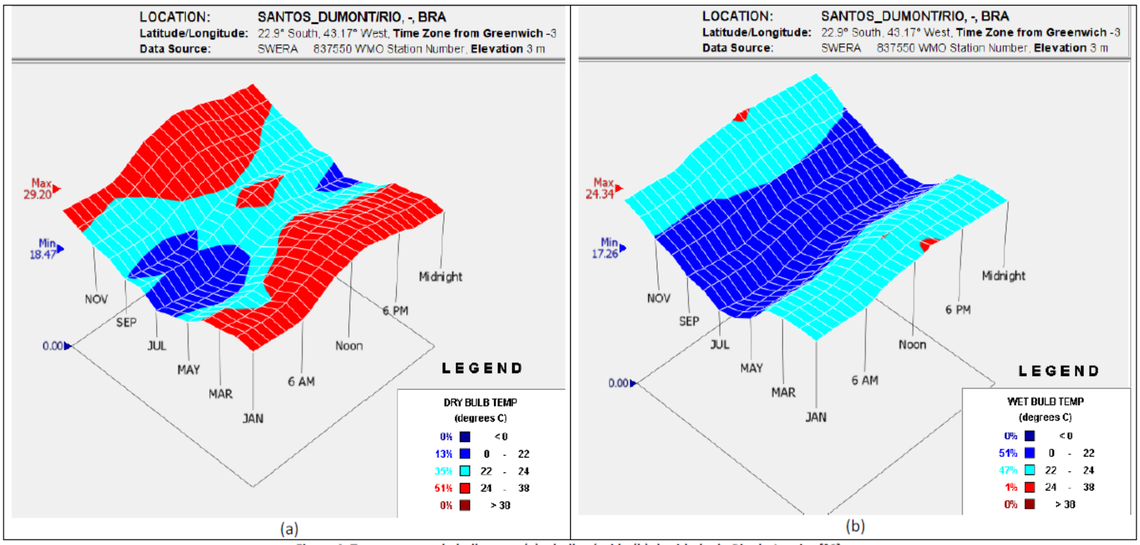

Figure 10 Temperature [° C] of dry bulb (a) and wet bulb (b) of the city of Rio de Janeiro

The design data for calculating the cooling load condition are shown in Table 10. The peak conditions used to scale the capacity of the equipment are obtained from three days defined in ASHRAE 90.1-2007 standard design with the following probability of occurrence: 99.6 % for heating design temperature and 1 % for cooling design temperature of dry bulb and wet bulb.

Parameter	**DBT 99,6% Heating**	**DBT 1,0% Cooling**	**DBT 1,0% Cooling**
Maximum dry bulb temperature (° C)	16,1	32,7	30,3
Temperature Range (° C)	0	6,1	6,1
Wet bulb temperature (° C)	13,5	25,0	26,2
Atmospheric pressure (Pa)	101290	101290	101290
Wind speed (m /s)	2,5	3,9	3,9
Wind direction (degrees from the northern)	310°	30°	30°
Sky cloud Index	0 (cloudy sky)	1,00 (clear sky)	1,00 (clear sky)
Day of the month	21	21	21
Month	July	February	February

Table 10 Cooling and heating load calculation (São Paulo - SP)

4.1.2. OFFICE BUILDING MODEL

The extensive use of glass façade on the modeled building is representative of the current commercial building architecture. The building was modeled in EnergyPlus software. Its volume and internal layout were shown in Figure 11.

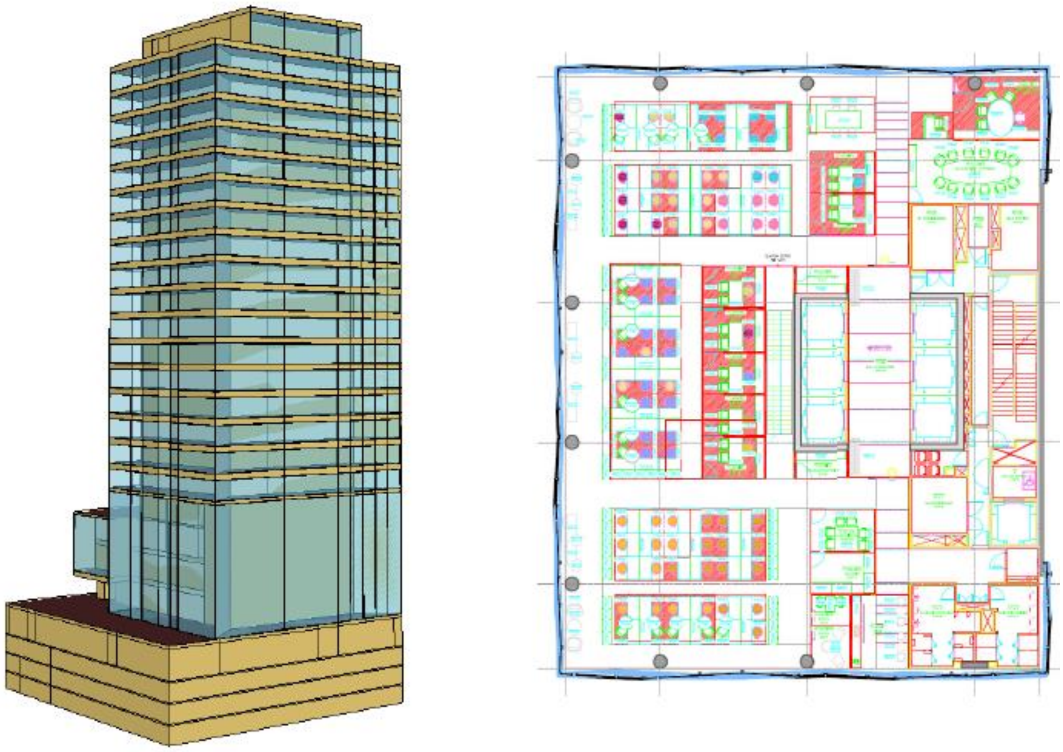

Figure 11 Volume and internal layout of studied building

The characteristics of the building envelope, its materials and dimensions have been established following the architectural project, which are shown in Table 11.

Characteristics		**Proposed**
Thermal transmittance (U) [W / m^2.K]	Façade Glass	**See Table 2**
	Wall	1,6
	Floor	3,6
	Roof	3,6
Façade Glass SHGC		See Table 2
Visible Light transmittance		See Table 2
Glass area of the facade		63% (of the whole façade)
		65% (of the typical floor plan)

Table 11 Characteristics of the building envelope

The properties of the seven types of façade glass used in the study are shown in Table 12.

Glass #	1	2	3	4	5	6	7
Glass Type	Coated Insulated	Coated Insulated	Coated Laminated	Coated Laminated	Coated Laminated	Coated Laminated	Non Coated Single Pane
Thermal transmittance (U value)	2,8	2,8	5,16	5,16	5,16	5,16	**XX**
SHGC (g value)	0,27	0,30	0,30	0,33	0,36	0,40	0,87
Visible Light transmittance (Tv)	0,37	0,41	0,19	0,22	0,31	0,38	0,90

Table 12 Characteristics of simulated glass

The thermal loads used in this model are detailed in Table 13.

	Thermal Loads
Lighting	6,3 W/m2 (Based on Philips lighting design)
Equipments	16.2 W/m2 (Market average)
Personnel	Office area : 96 people General Director: 1 person Meeting room 1: 12 people Meeting room 2 : 6 people 2 Booth Room : 4 people 1 room service : 2 people Coffee room : 4 people
External air	27 m3/h People (117 people)

Table 13 Data of thermal loads

The occupancy pattern was based on the average for a commercial building between 7.00 and 22.00 and followed a pattern of random distribution as adopted by Shen (2014) and Andersen (2013), and standard Open Office occupation area following the occupation of Figure 12**,** as the rest of the rooms operates according to Table 14.

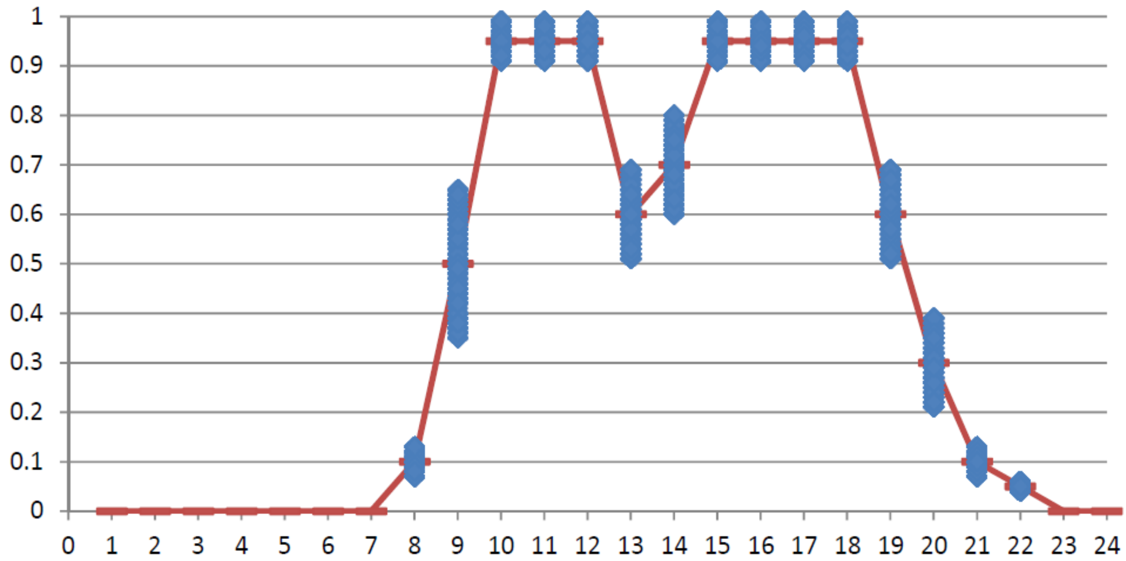

Figure 12 Open Office occupation pattern showing the daily changes every hour

Location	Operation schedule
Office area	**See Figure 5**
Director's office	8h-22h (Occupation of 70%)
Booth Room	8h-22h (Occupation of 50%)
Maintenance Room	8h-22h (Occupation of 50%)
Meeting Room	10h-12h and 14h-15h

Table 14 Standard occupancy for all environments

The Lighting system is composed by 81 Philips luminaries TBS165 with power density of 6.3 W / m2, representing an installed power of 4.455 W for the office area. The lighting project can be seen in Figure 13, where one can also observe the photometric curves.

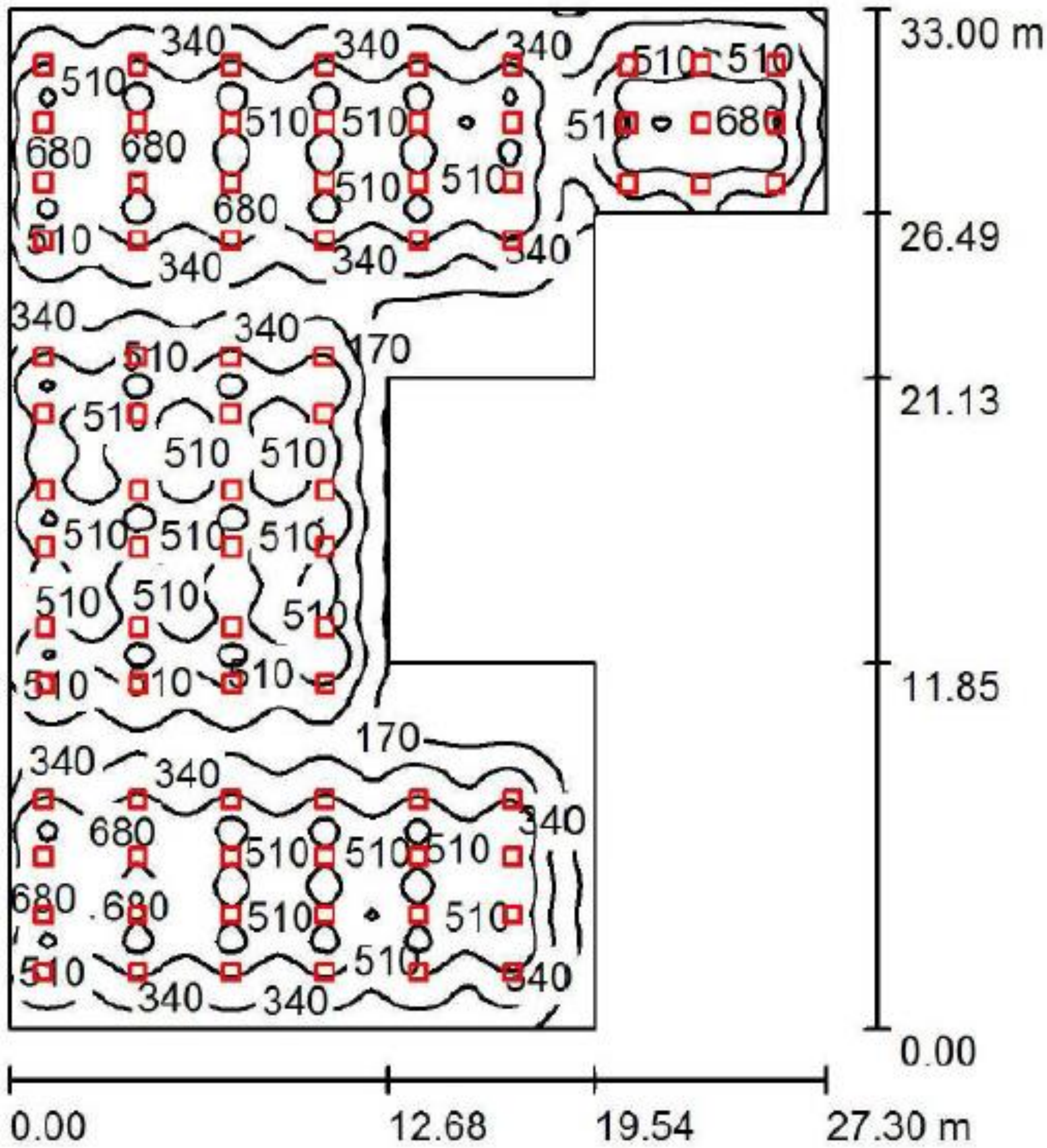

Figure 13 Lighting design model with 81 luminaries

Figure 14 shows the seven HVAC VAV's and their distribution on the floor pan.

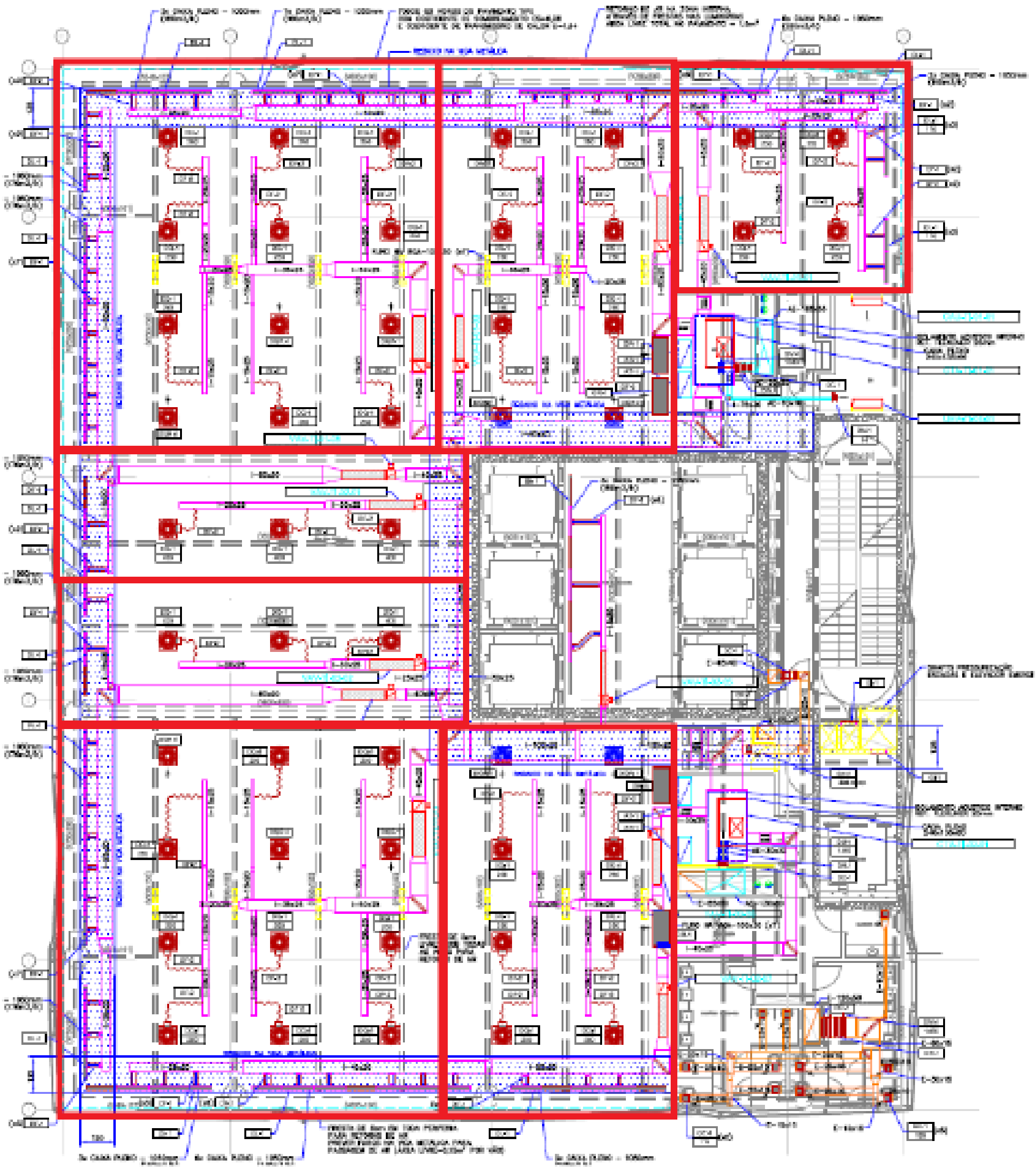

Figure 14 HVAC VAV's and their distribution on the floor pan

The properties of the two types of Internal Shading fabrics used in the study were shown in Table 15.

Shading Fabric (Internal Roller Blinds)						
Shading Properties	UNIFLEX Thermoscreen				UNIFLEX Platinumscreen (Aluminum coated)	
	Façade				Façade	
	West	North	East	South	North-West	South-Eats
Solar transmittance	1,0%	5,0%	6,0%	10,0%	5,0%	7,0%
Solar reflection	43,0%	41,0%	47,0%	55,0%	73,0%	71,5%
Visible transmittance	1,0%	7,0%	8,0%	11,0%	4,0%	7,0%
Openness Factor	1,0%	3,0%	5,0%	10,0%	3,0%	5,0%

Table 15 Shading Fabric Properties

4.1.3. SIMULATION MODELLING

The programs (software) used for the simulations were:

- SketchUp7 for modeling
- EnergyPlus v8.1 for energy performance simulation
- EES - Engineering Equation Solver for integration

Two baseline models with distinct façade arrangement were defined: one without shading and other with manual operated shading. Both of them have the same occupancy pattern, lighting and HVAC systems.

4.2 RESULTS

The energy reduction results are shown in Table 16, Table 17, Table 18, Table 19 and Table 20.

The energy consumption are shown in Figure 15, Figure 16 and Figure 17

4.2.1 INTEGRATION LEVEL 1 (IL1)

The savings in HVAC + lighting system was between 2,5 % and 16,4 % compared to the baseline model without shadings and 2,0 % and 8,8 % compared to the baseline model with manually controlled shadings.

The savings in HVAC was between 3,5 % and 21,3 % compared to the baseline model without shadings and 1,9 % and 11,8 % compared to the baseline model with manually controlled shadings.

4.2.2. INTEGRATION LEVEL 2 (IL2)

The savings in HVAC + lighting system was between 15,5 % and 30,8 % compared to the baseline model without shadings and 15,6 % and 24,6 % compared to the baseline model with manually controlled shadings.

The savings in HVAC system was between 7,2 % and 25,1 % compared to the baseline model without shadings and 5,7 % and 16,1 % compared to the baseline model with manually controlled shadings.

The savings in lighting system was between 35,9 % and 49,9 % compared to the baseline model with manually controlled lighting.

4.2.3 INTEGRATION LEVEL 3 (IL3)

The savings in HVAC + lighting system was between 16,7 % and 31,9 % compared to the baseline model without shadings and 16,9 % and 25,8 % compared to the baseline model with manually controlled shadings.

The savings in HVAC system was between 9,0 % and 26,5 % compared to the baseline model without shadings and 8,7 % and 18,2 % compared to the baseline model with manually controlled shadings.

The savings in lighting system was between 35,9 % and 49,9 % compared to the baseline model with manually controlled lighting.

HVAC + Lighting Energy Savings (Baseline: Façade without Internal Shading)

	Glass 1 SHGC 27% Tv 37%	Glass 2 SHGC 30% Tv 41%	Glass 3 SHGC 30% Tv 19%	Glass 4 SHGC 33% Tv 22%	Glass 5 SHGC 36% Tv 31%	Glass 6 SHGC 40% Tv 38%	Glass 7 SHGC 87% Tv 90%
Energy Savings (Shading without aluminum)	IL1 2,5% IL2 15,5% IL3 16,7%	IL1 2,6% IL2 16,2% IL3 17,4%	IL1 4,1% IL2 13,6% IL3 14,7%	IL1 4,3% IL2 14,4% IL3 15,6%	IL1 4,5% IL2 16,3% IL3 17,5%	IL1 4,9% IL2 17,6% IL3 18,8%	IL1 10,5% IL2 24,6% IL3 25,7%
Energy Savings (Shading with aluminum)	IL1 3,8% IL2 17,2% IL3 18,4%	IL1 4,2% IL2 18,2% IL3 19,4%	IL1 5,0% IL2 14,5% IL3 15,7%	IL1 5,4% IL2 15,6% IL3 16,7%	IL1 5,8% IL2 17,7% IL3 18,9%	IL1 6,4% IL2 19,2% IL3 20,4%	IL1 16,4% IL2 30,8% IL3 31,9%

Table 16 HVAC + Lighting Energy Savings (Baseline Façade without Shading)

HVAC + Lighting Energy Savings (Baseline: Façade with Manually Controlled Internal Shading)

	Glass 1 SHGC 27% Tv 37%	Glass 2 SHGC 30% Tv 41%	Glass 3 SHGC 30% Tv 19%	Glass 4 SHGC 33% Tv 22%	Glass 5 SHGC 36% Tv 31%	Glass 6 SHGC 40% Tv 38%	Glass 7 SHGC 87% Tv 90%
Energy Savings (Shading without aluminum)	IL1 2,0% IL2 15,6% IL3 16,9%	IL1 2,2% IL2 16,4% IL3 17,7%	IL1 2,5% IL2 12,3% IL3 13,5%	IL1 2,7% IL2 13,2% IL3 14,3%	IL1 2,9% IL2 15,2% IL3 16,4%	IL1 3,2% IL2 16,5% IL3 17,7%	IL1 8,8% IL2 24,6% IL3 25,8%
Energy Savings (Shading with aluminum)	IL1 2,0% IL2 15,6% IL3 16,9%	IL1 2,2% IL2 16,4% IL3 17,7%	IL1 2,5% IL2 12,3% IL3 13,5%	IL1 2,7% IL2 13,2% IL3 14,3%	IL1 2,9% IL2 15,2% IL3 16,4%	IL1 3,2% IL2 16,5% IL3 17,7%	IL1 8,8% IL2 24,6% IL3 25,8%

Table 17 HVAC + Lighting Energy Savings (Baseline Façade with Manual Shading)

HVAC Energy Savings (Baseline: Façade without Shading)

	Glass 1 SHGC 27% Tv 37%	Glass 2 SHGC 30% Tv 41%	Glass 3 SHGC 30% Tv 19%	Glass 4 SHGC 33% Tv 22%	Glass 5 SHGC 36% Tv 31%	Glass 6 SHGC 40% Tv 38%	Glass 7 SHGC 87% Tv 90%
Energy Savings (Shading without aluminum)	IL1 3,5% IL2 7,2% IL3 9,0%	IL1 3,7% IL2 7,6% IL3 9,3%	IL1 5,6% IL2 8,3% IL3 9,9%	IL1 6,0% IL2 8,7% IL3 10,4%	IL1 6,2% IL2 9,4% IL3 11,0%	IL1 6,7% IL2 10,1% IL3 11,7%	IL1 13,6% IL2 17,2% IL3 18,7%
Energy Savings (Shading with aluminum)	IL1 5,4% IL2 9,4% IL3 11,1%	IL1 6,0% IL2 10,1% IL3 11,8%	IL1 6,9% IL2 9,6% IL3 11,2%	IL1 7,5% IL2 10,3% IL3 11,9%	IL1 8,0% IL2 11,2% IL3 12,9%	IL1 8,8% IL2 12,3% IL3 13,9%	IL1 21,3% IL2 25,1% IL3 26,5%

Table 18 HVAC Energy Savings (Baseline Façade without Shading)

HVAC Energy Savings (Baseline: Façade with Manually Controlled Internal Shading)

	Glass 1 SHGC 27% Tv 37%	Glass 2 SHGC 30% Tv 41%	Glass 3 SHGC 30% Tv 19%	Glass 4 SHGC 33% Tv 22%	Glass 5 SHGC 36% Tv 31%	Glass 6 SHGC 40% Tv 38%	Glass 7 SHGC 87% Tv 90%
Energy Savings (Shading without aluminum)	IL1: 1,9% IL2: 5,7% IL3: 8,7%	IL1: 2,0% IL2: 6,0% IL3: 8,9%	IL1: 2,9% IL2: 5,6% IL3: 8,5%	IL1: 3,1% IL2: 5,9% IL3: 8,8%	IL1: 3,2% IL2: 6,5% IL3: 9,2%	IL1: 3,5% IL2: 7,0% IL3: 9,6%	IL1: 7,6% IL2: 11,4% IL3: 13,5%
Energy Savings (Shading with aluminum)	IL1: 2,8% IL2: 6,9% IL3: 9,9%	IL1: 3,1% IL2: 7,4% IL3: 10,3%	IL1: 3,6% IL2: 6,3% IL3: 9,3%	IL1: 3,8% IL2: 6,7% IL3: 9,6%	IL1: 4,1% IL2: 7,5% IL3: 10,2%	IL1: 4,5% IL2: 8,2% IL3: 10,8%	IL1: 11,8% IL2: 16,1% IL3: 18,2%

Table 19 HVAC Energy Savings (Baseline Façade with Manual Shading)

Lighting Energy Savings (Baseline: Manually Controlled Lighting)

	Glass 1 SHGC 27% Tv 37%	Glass 2 SHGC 30% Tv 41%	Glass 3 SHGC 30% Tv 19%	Glass 4 SHGC 33% Tv 22%	Glass 5 SHGC 36% Tv 31%	Glass 6 SHGC 40% Tv 38%	Glass 7 SHGC 87% Tv 90%
Energy Savings (Shading without aluminum)	IL1 0,0% IL2 35,9% IL3 35,9%	IL1 0,0% IL2 37,6% IL3 37,6%	IL1 0,0% IL2 27,2% IL3 27,2%	IL1 0,0% IL2 29,4% IL3 29,4%	IL1 0,0% IL2 34,7% IL3 34,7%	IL1 0,0% IL2 37,9% IL3 37,9%	IL1 0,0% IL2 49,1% IL3 49,1%
Energy Savings (Shading with aluminum)	IL1 0,0% IL2 36,5% IL3 36,5%	IL1 0,0% IL2 38,3% IL3 38,3%	IL1 0,0% IL2 27,2% IL3 27,2%	IL1 0,0% IL2 29,4% IL3 29,4%	IL1 0,0% IL2 34,8% IL3 34,8%	IL1 0,0% IL2 38,2% IL3 38,2%	IL1 0,0% IL2 49,9% IL3 49,9%

Table 20 Lighting Energy Savings (Baseline Manual Control)

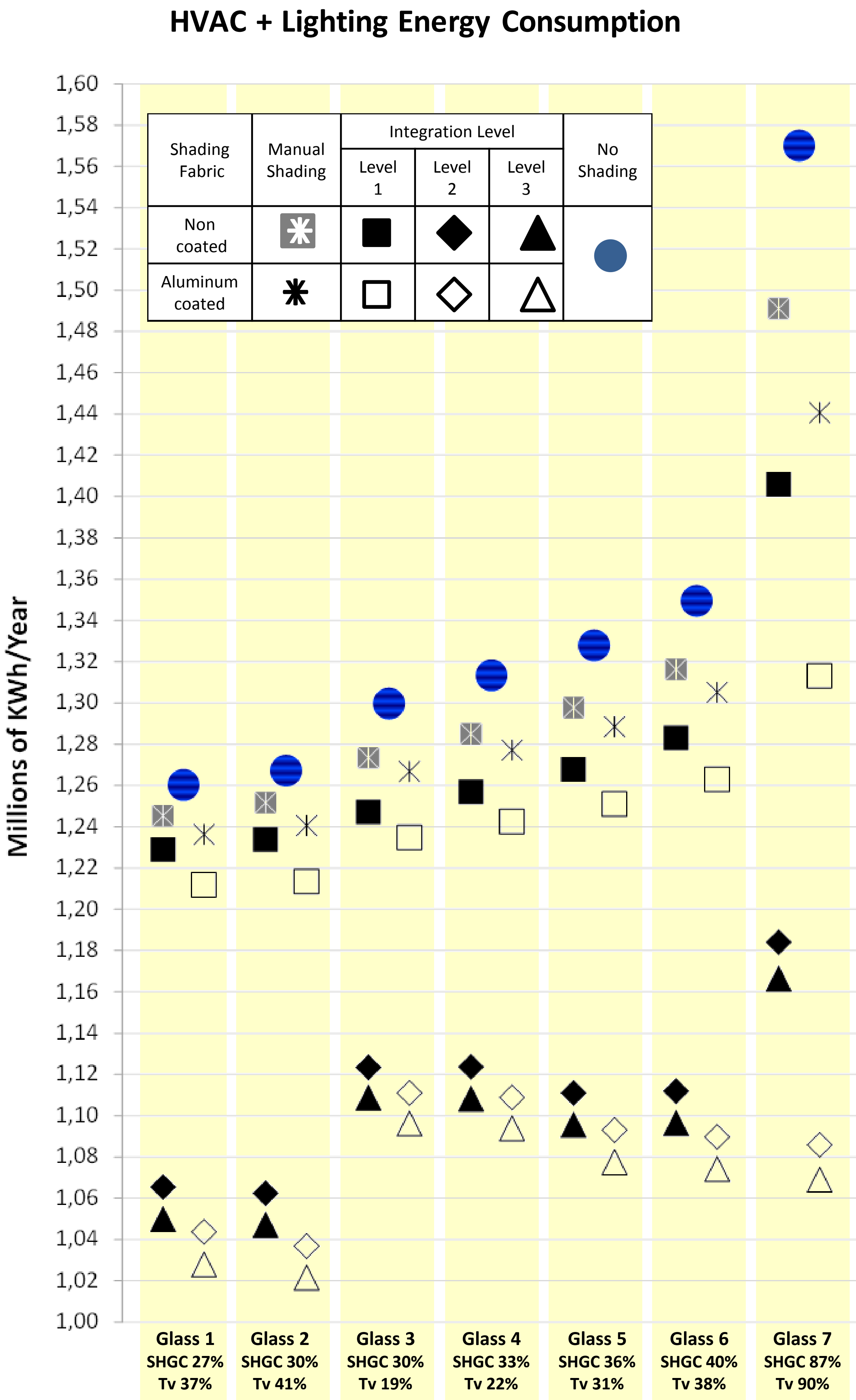

Figure 15 HVAC + Lighting Energy Consumption

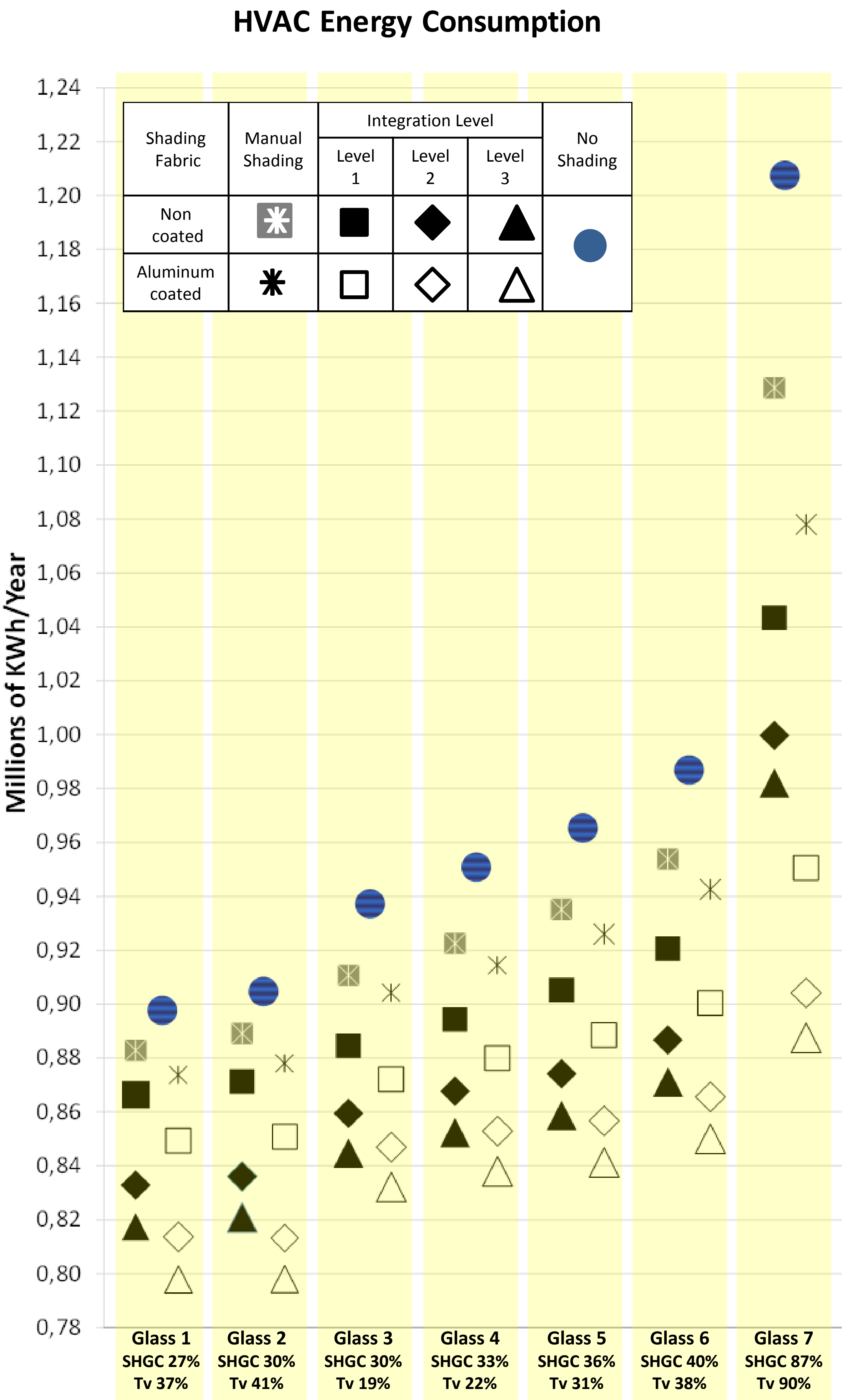

Figure 16 HVAC Energy Consumption

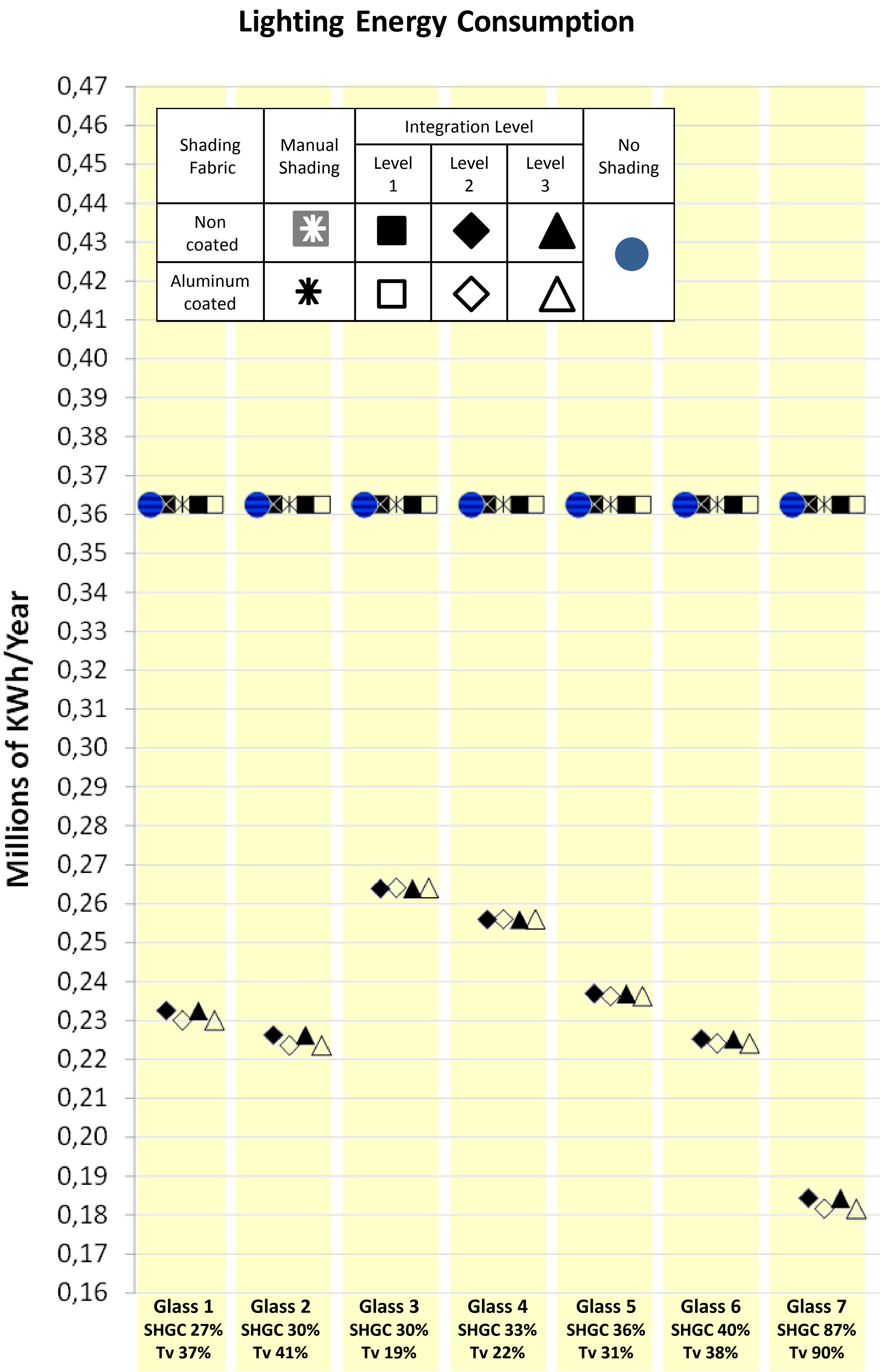

Figure 17 Lighting Energy Consumption

4.3. ENERGY EFFICIENCY STUDY CONCLUSIONS

- The results demonstrate energy efficiency improvement for all analyzed integration levels;
- The use of automated internal shading (IL1) reduces the HVAC energy consumption between 2,0% to 16,4% and therefore allows the specification of a broader options of glasses with higher SHGC value without impairing the energy consumption;
- The performance of internal shading with aluminum coated fabric increases when combined with glasses with higher SHGC value and should certainly be considered if higher OPEX are desired;
- The adoption of automated internal shading in retrofit of commercial buildings could allow the maintenance of the original glass with high SHGC values;
- The lighting automation integrated with internal shading automation (IL2) has a significant impact on energy consumption reduction, between 12,3% to 30,8% . This reduction is higher with glasses with higher transmittance of visible light (Tv) which enhances the harvesting of natural light into the workplace;
- The major savings in energy consumption is achieved when all systems are integrated (IL3), between 13,5% to 31,9%.

5. THERMAL COMFORT STUDY

5.1 METHODOLOGY

The analysis was based on standard thermal comfort ASHRAE 55-2004. To define the thermal comfort of occupied areas the parameters used, by HVAC designers, as shown in Table 21.

Parameter	Values	Reference
Air temperature	Minimum = 21° C Maximum = 25°C	Set point for office area (23°C ± 2 ° C).
Radiant temperature	-	Radiant temperature depends on the solar radiation on the facade of the building
Operating temperature	Minimum = 21° C Maximum = 25°C	Parameter used to assess the comfort level of the occupants. It should be close to air temperature, ie 23°C ± 2°C. Representing a percentage of dissatisfied occupants inside recommended by ASHRAE 55-2004 : 21°C = 7% of dissatisfied (winter situation) 25°C = 6% of dissatisfied (summer situation)
Relative humidity	Between 45 and 55 %	HVAC systems do not have humidity control, but are designed to keep the relative humidity near 50%
Air velocity	Summer < = 0.20m/s Winter < = 0.15 m/s	Air velocity predicted by NBR 16401 - Part 2
Cloth Factor	Summer = 0.5 clo Winter = 0.9 clo	Typical clothing for summer and winter situations, according to NBR 16401
Activity Level	1,2 met	Typical office activity

Table 21 Parameters for comfort analysis

The operating temperature is the parameter used for comfort, because it represents an equivalent temperature between the air temperature and radiant temperature, so representing the temperature perceived by the human body.

This temperature should be close to the air temperature, but does not necessarily occur due to high solar radiation rates in Brazil or the large glass area in commercial buildings.

In this analysis the operating temperatures exceeding 25 ° C will be verified.

This methodology analyzes the parameter of time equivalent degrees (° C-h), which represents how many times the temperature limit (25°C) was exceeded and for how long. For instance, if during the day a working temperature environment reach 27°C for 2 hours, then we will have an equivalent of (27°C-25°C)*2h = 4°C-h.

5.1.1 CLIMATE CONDITION

Same as used for Energy Efficiency Study.

5.1.2 OFFICE BUILDING MODEL

Same as used for Energy Efficiency Study.

5.1.3. SIMULATION MODELLING

The computer programs (software used for the simulations) were:

- SketchUp7 for modeling ;
- EnergyPlus v8.1 , for temperatures simulation
- EES - Engineering Equation Solver for processing the data.

5.2. RESULTS

The Thermal Discomfort Reduction are shown in Table 22 and Table 23. The reduction was between 52,0 % and 86,1 % compared to the baseline model without shadings and 40,7 % and 71,1 % compared to the baseline model with manually controlled shadings.

The results degrees-hour for each studied glasses is shown in Figure 18.

Thermal Discomfort Reduction (Baseline: Façade without Shading)

	Glass 1	Glass 2	Glass 3	Glass 4	Glass 5	Glass 6	Glass 7
Glass SHGC	27%	30%	30%	33%	36%	40%	87%
Glass Tv	37%	41%	19%	22%	31%	38%	90%
Thermal Discomfort Reduction (Shading without aluminum)	53,8% IL1	52,0% IL1	69,5% IL1	68,0% IL1	65,9% IL1	63,6% IL1	59,5% IL1
Thermal Discomfort Reduction (Shading with aluminum)	80,2% IL1	81,6% IL1	79,7% IL1	79,3% IL1	79,1% IL1	78,3% IL1	86,1% IL1

Table 22 Thermal Discomfort Reduction (Baseline Façade without Shading)

Thermal Discomfort Reduction (Baseline: Façade with Manually Controlled Internal Shading)

	Glass 1	Glass 2	Glass 3	Glass 4	Glass 5	Glass 6	Glass 7
Glass SHGC	27%	30%	30%	33%	36%	40%	87%
Glass Tv	37%	41%	19%	22%	31%	38%	90%
Thermal Discomfort Reduction (Shading without aluminum)	43,0% IL1	42,3% IL1	47,0% IL1	45,7% IL1	43,9% IL1	42,4% IL1	40,7% IL1
Thermal Discomfort Reduction (Shading with aluminum)	67,2% IL1	68,5% IL1	58,0% IL1	57,7% IL1	57,9% IL1	57,5% IL1	71,1% IL1

Table 23 Thermal Discomfort Reduction (Baseline Façade without Shading)

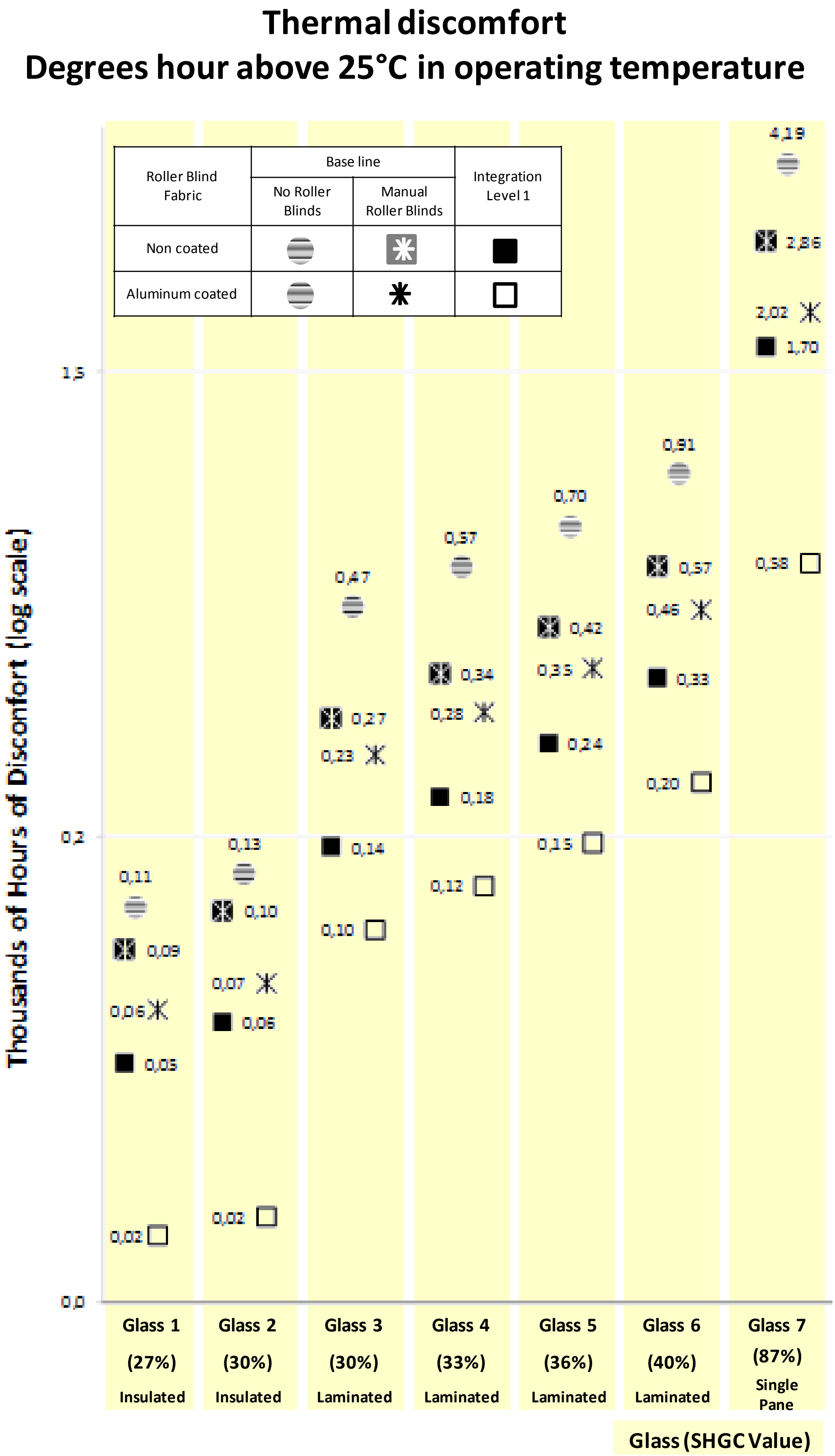

Figure 18 Thermal discomfort in degrees hour above 25°C in operating temperature

5.3. THERMAL COMFORT STUDY CONCLUSIONS

- The use of automated internal shading (IL1) reduces significantly the thermal discomfort, between 40,7% to 86,1% and therefore allows the specification of broader options of glasses with higher SHGC value without impairing the occupant comfort;
- The reduction in degree -hours value depends on the type of glass and the major reduction is achieved in glasses with higher SHGC value;
- The internal shading with aluminum coated fabric achieved higher reduction in thermal discomfort;
- Besides the discomfort reduction the study also demonstrates reduction in radiant discomfort asymmetry usual in buildings with large glass area.

6. VISUAL COMFORT STUDY

6.1 METHODOLOGY

The methodology for visual comfort analyzes how daylight is distributed within the studied areas. This distribution is mainly affected by three factors:

- Reflectance of internal surfaces: affected by the color of surfaces.
- Glass Properties: transmittance and light reflection glasses
- External Luminance: type of sky

The surfaces reflectance's are shown in Table 24.

	Reflectance	Equivalent color
Wall	0,7	Light-colored wall
Ceiling	0,7	White ceiling
Floor	0,2	Dark Carpet

Table 24 Surfaces reflectance's

The glasses used in this study are the same seven glasses used in the Energy Efficiency Study, detailed in Table 2.

These glasses can be divided into 3 groups:

- Glasses with high luminous flux (1 , 2, 6 and 7)
- Glasses with average luminous flux (5)
- Glasses with low luminous flux (3 and 4)

The types of sky studied were three: Clear, mixed and cloudy sky.

All types of skies were simulated for three days from 9.00 (worst case of the east facade), 12.00 (worst case of Northern facade) and 15.00 (worst case the west façade).

6.1.1 CLIMATE CONDITION

Same as used for Energy Efficiency Study.

6.1.2 OFFICE BUILDING MODEL

Same as used for Energy Efficiency Study.

6.1.3. SIMULATION MODELLING

The computer programs (software) used for the simulations were:

- Dialux 4.12 for simulating natural lighting.

- EES - Engineering Equation Solver to calculate the equivalent factors of transmittance and reflectance

The study considers 3 models

- Open base Model: considers the office with all shades open.
- Manual control Base model: considers the office shades operating on manual control model.
- Automated shading Model: considers the shades automation model presented by Somfy.

6.2. RESULTS

The interior daylight Reduction are shown in Table 25 and Table 26. The reduction was between 87,4% and 94,7% compared to the baseline model without shadings and 73,6 % and 88,8 % compared to the baseline model with manually controlled shadings.

The maximum interior daylight iluminances is shown in Figure 18.

Interior Daylight Iluminance Reduction (Baseline: Façade without Shading)

	Glass 1	Glass 2	Glass 3	Glass 4	Glass 5	Glass 6	Glass 7
Glass SHGC	27%	30%	30%	33%	36%	40%	87%
Glass Tv	37%	41%	19%	22%	31%	38%	90%
Incoming Daylighting Reduction (Shading without aluminum)	88,6% IL1	89,1% IL1	87,4% IL1	88,5% IL1	88,8% IL1	88,7% IL1	94,3% IL1
Incoming Daylighting Reduction (Shading with aluminum)	90,8% IL1	89,8% IL1	89,1% IL1	90,4% IL1	91,5% IL1	90,9% IL1	94,7% IL1

Table 25 Interior Daylight Iluminance Reduction (Baseline Façade without Shading)

Interior Daylight Iluminance Reduction (Baseline: Façade with Manually Controlled Internal Shading)

	Glass 1	Glass 2	Glass 3	Glass 4	Glass 5	Glass 6	Glass 7
Glass SHGC	27%	30%	30%	33%	36%	40%	87%
Glass Tv	37%	41%	19%	22%	31%	38%	90%
Thermal Discomfort Reduction (Shading without aluminum)	75,8% IL1	77,1% IL1	73,6% IL1	75,7% IL1	76,3% IL1	76,1% IL1	88,1% IL1
Thermal Discomfort Reduction (Shading with aluminum)	80,6% IL1	78,6% IL1	77,2% IL1	79,7% IL1	82,1% IL1	80,8% IL1	88,8% IL1

Table 26 Interior Daylight Iluminance Reduction (Baseline: Façade with Manually Controlled Internal Shading)

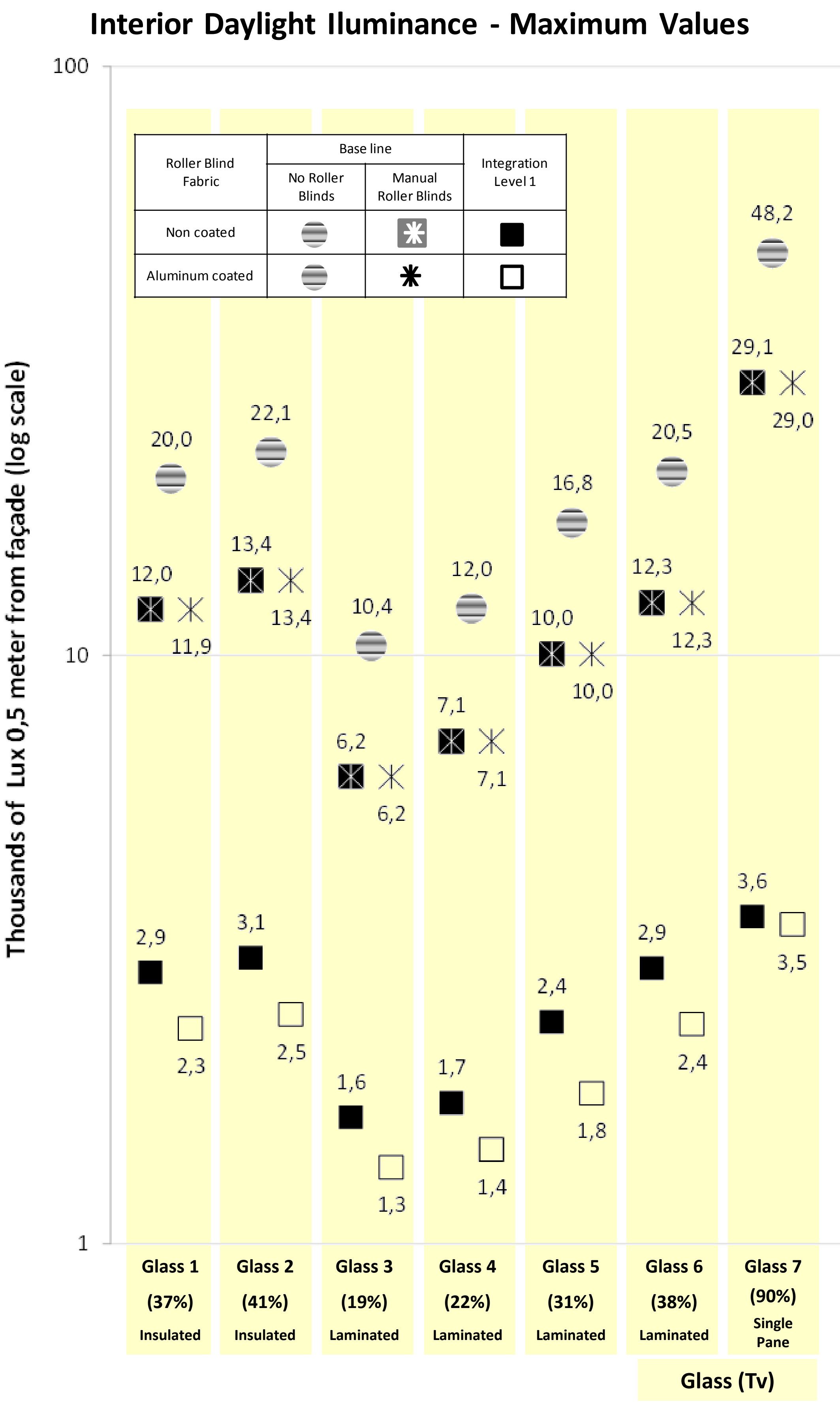

Figure 19 Maximum Incoming Daylighting

6.3. VISUAL COMFORT STUDY CONCLUSIONS

The automation of blinds generates the following benefits:

- It can be seen at the photometric curves that the use of automated internal shading significantly reduces the daylight iluminance levels near windows. This iluminance reduction brings uniformity of ambient light of the office area reducing discomfort due to difference in brightness;
- The reduction in daylight iluminance is between 73,3% and 94,7% at 0,5 meter from the façade;
- Automatically opening the internal shading at façades that are not having directly sun incidence, increases the clarity of these areas without creating discomfort and allows outside viewing to the occupants;
- The maximum interior daylight iluminance reduction was achieved with the glass with higher Tv.

7. APPENDIX

7.1 REFERENCE STANDARDS

The analyses in this report were developed based on the standards and / or procedures listed below:

- NRB 16.401 Parts 1, 2, 3-2008 (HVAC plants).
- ASHRAE Standard 90.1 Energy Standard for Building except Low- Rise Residential Buildings
- ASHRAE Standard 62.1 Ventilation for Acceptable Indoor Air Quality
- ASHRAE Standard 55 Thermal Comfort Conditions for Human Occupancy
- PROCEL EDIFICA Regulation for Labeling the Energy Efficiency Level of Commercial and Public Services Buildings.
- SMACNA Sheet Metal and Air Conditioning Contractors National Association.

7. 2 REFERENCES

- ASHRAE - AMERICAN SOCIETY OF HEATING, REFRIGERATING AND AIR-CONDITIONING ENGINEERS. Standard 90.1: Energy Standard for building Except low-Rise residential Buildings, Atlanta, 2007.
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