Passive Heating
Performance of different facade types

JESSICA VERDONSCHOT, WIM ZEILER, GERT BOXEM

Technische Universiteit Eindhoven, TU/e, the Netherlands, w.zeiler@bwk.tue.nl

ABSTRACT: The concept of a ventilated double façade was invented with the intention of improving the thermal qualities of a fully glazed façade. The application of a fully glazed single skin façade used to result in a high energy consumption due to the poor thermal properties of the glazing. These properties have improved over the years and are reaching similar values as can be achieved with a ventilated double façade. The aim of this study is to compare different ventilated double facades to a single skin façade and determine which façade has the best passive heating performance.
Keywords: double facades, passive heating, G-ratio

INTRODUCTION
Preservation of energy resources, occupant comfort and environmental impact limitation are the key issues of modern sustainable architecture. A major portion of the total primary energy consumption, about 40 %, is due to create thermal comfort in buildings by heating, cooling, ventilating and lighting. The façade is in combination with the HVAC installation responsible for most of the energy used. Nowadays In high performance office buildings iit is common practice to use active and interactive double façade technology. Up to now double-skin facades have been used mainly for large buildings such as the Debis headquarters on Potsdamer Platz in Berlin [1], Uniqua Tower Vienna [2] or Center of Justice Leobon [3]. Up to now though these modern facades concepts were improved the efficiency of these facades is still under discussion [4]. Some characteristics of double facades opposed in comparison to single layer glass facades are; costs, much unusable space, increased cleaning costs and high cavity temperatures.

In favour for the double facades concepts are; modern transparent architecture, reliable weather independent solar control, low heat gain due to irradiance, low thermal transmission, improved sound isolation and possibilities for weather independent natural supply ventilation. Still remains the question remains for active and interactive glass facades that, based on forward knowledge about the state of the art and recent research results, if it is top or flop?[5].

Reduction in energy consumption and reduction of the required capacity of the HVAC system is one of the main arguments supporting the application of multiple facades [6,7]. The energy saving with respect to heating and cooling is an important argument that is often used to justify the application of a ventilated double façade.

The concept of a ventilated double façade is invented with the intention of improving the thermal performances of a fully glazed façade. The application of a fully glazed single skin façade used to result in high energy consumption due to the poor thermal properties of the glazing. These properties have improved over the years and are reaching similar values as can be achieved with a ventilated double façade. The total thermal transmittance, or U-value, of a glazed façade is one of the most important concepts in building-envelope design {8]. The for passive heating most important factor is the solar heat gain usually measured as the solar heat gain coefficient (SHGC), or G-ratio. This G-ratio is the fraction of incident irradiance entering glazing and becoming heat gain in the room-space. The G-ratio takes into account both directly transmitted solar heat and absorbed and subsequently re-emitted portion [8]. Regarding the reputation of Double Skin Facades (DSF) there is skepticism in the scientific field concerning the energy efficiency, the indoor air quality and thermal comfort levels that this type of façade can provide. Among the majority of the architects the reputation is good mainly because of aesthetics reasons. However, there is rather low level of knowledge on the energy performance of DSF among all [9]. There are three methods of calculating energy performance of DSF [10];
-energy calculations based measurements after a building has been completed,
-construction of a mock-up façade element and use this as a testing/measurement platform or
- calculations based on software simulation.

Each method of calculation has its benefits and drawbacks [1]. Although various authors have investigated the thermal behaviour the thermal design of buildings with BSF remains a challenging task [11]. At present there is very little consistent data on the overall performance of the actual built building façade, and there is still considerable misunderstanding in the industry as to the critical parameters in practice that influence façade performance [8]. There for it is important to compare theoretical based calculations with real on site measurements in buildings to compare the true performances of facades. The aim of this study is to compare different actual built facade types and determine which façade has the best overall passive heating performance [12].

METHODOLOGY

In this research several theoretical models are used to predict the u- and G-ratio values of the facades. Then, measurements are performed and the real characteristic

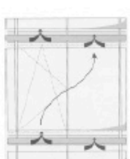
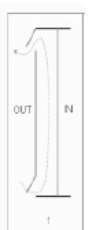
Building	Façade	Ventilation mode	
		Summer	Winter
Bouwhuis office Zoetermeer 	Ventilated double façade 'multi-storey' type 	Outdoor air curtain 	Air supply 
ABT office (Velp) 	Ventilated double window 	Indoor air curtain (reversed flow) 	
Kennedytoren Eindhoven 	Ventilated double façade partitioned by storey (corridor type) 	Outdoor air curtain 	
De Effenaar Eindhoven 	Double glazed single façade		

Figure 1: Façades and buildings that were compared

values of the facades are calculated, resulting in a review of the validity of the theoretical models for the types of facades that are investigated. The four Dutch facades were compared, see figure 1.

Bouwhuis Zoetermeer On the south-west, south-east and north-east side of the building, from the second floor to the eleventh floor, the façade is constructed as a ventilated double façade. multi-storey type. In the summer natural ventilation is applied and the ventilation mode can be defined as an outdoor air curtain. In the winter mechanical ventilation is applied and the ventilation mode is air supply. In the winter, the pre-heated air in the cavity is supplied to the air-conditioning unit and after that it is used to heat the building. This requires less pre-heating in the air-conditioning unit and therefore limits the energy cost. The use of mastic compound for the joints of the outer skin, prevents cold air to be sucked in through the joints which would neutralize the heat gain.

ABT Office Velp The façade can be classified as a mechanical ventilated double window. The air in the room is exhausted through the slots at the top of the ventilated double window through the cavity to the slots at the bottom of the cavity and via the exhaust ducts in the concrete apron wall and the platform floor to the air conditioning unit and to the outside. In the winter the warm exhausted air leads to a warm air curtain in the cavity, which increases the comfort in the area near the façade. In the summer, the shading device is heated by the sun and by exhausting the air through the cavity past the shading device; this heat is instantly removed, resulting in a lower heat load.

Kennedy Tower Eindhoven The façade is a ventilated double façade partitioned by story, corridor type. Natural ventilation is applied and the ventilation mode is an outdoor air curtain. Outdoor air enters the cavity and is warmed up by the sun or diffuse light causing the air to rise. After which, at the top of the storey high cavity, the air leaves the cavity. To prevent already warmed up air to enter the cavity for the second time, cross ventilation is applied. This means that the air enters the cavity at the bottom of the element and leaves the cavity at the top of the adjacent element. On the corners of the building, in the cavity, a vertical glazing is placed to prevent unwanted air movement caused by differences in solar radiation and wind pressure on the façades with different orientations.

Effenaar Eindhoven The outer walls of the east and west façade that are adjacent to the large hall are cast in concrete and the rest of the east and west façade are constructed of a special double glazing. This glazing has a very low U-value and G-ratio and is applied from floor to ceiling.

Calculations The computer program Window Information System (WIS) version 3.0.1 is used to calculate the U-value and the G-ratio of the different facades [13]. WIS is a software tool for the calculation of the thermal and solar properties of window systems on the basis of known component properties, thermal and solar/optical interactions between the components and assumptions concerning the environment. The general approach for the calculation of the properties of a window system is to first calculate the heat flow through each pane due to the absorption of short wave radiation due to the sun. Then, to calculate the heat transfer coefficients between all panes, shading layers and both environments. The third step is to calculate the panes, shadings and gas temperatures, followed by an iteration of the process from step 2 because of temperature dependent heat transfer rates. And finally, to calculate the aggregate properties [13,14].

The U-value of the facade is determined by calculating the U-values of the outer and inner skin as well as the external and internal heat transfer coefficients and the heat transfer coefficient of the cavity. The latter is calculated by assuming that the difference between the two measured heat fluxes is the heat flux that leaves the cavity caused by the vertical temperature difference. The U-value of the façade can then be calculated by adding these five values. The equations are:

Outer skin:

$$U_e = \frac{q_e}{T_{sce} - T_{se}}$$

Inner skin:

$$U_i = \frac{q_i}{T_{si} - T_{sci}}$$

External heat transfer coefficient:

$$\alpha_e = 5.4 \cdot e_L + 4 \cdot v \quad \text{if v <5 m/s}$$

$$\alpha_e = 5.4 \cdot e_L + 7.14 \cdot v^{0.8} - 5.8 \quad \text{if v > 5 m/s}$$

Internal heat transfer coefficient:

$$\alpha_i = \frac{q_i}{T_i - T_{si}}$$

Heat transfer coefficient cavity:

$$\alpha_c = \frac{|q_i - q_e|}{|T_{ch} - T_{cl}|}$$

U-value of the façade:

$$\frac{1}{U} = \frac{1}{U_e} + \frac{1}{U_i} + \frac{1}{\alpha_e} + \frac{1}{\alpha_i} + \frac{1}{\alpha_c}$$

The calculated properties that are important for this project are the U-value and G-ratio of the transparent systems. The results of the calculations with WIS can be found in table 2 and 3.

The G-ratio of the façade is calculated by dividing the vertical solar radiation that is measured inside the office by the vertical solar radiation outside. The global horizontal solar radiation is measured outside and this value is converted to the vertical solar radiation outside with the same orientation as the façade by using the model from Duffie et al. [15].

Measurements Measurements were performed on every façade to estimate the U-value of the façade. To be able to calculate this value, the surface temperatures of both sides of the inner façade and both sides of the outer façade were measured. Furthermore, the air temperatures inside, in the cavity and outside had to be known. And last, the heat fluxes through both skins and the air velocity outside alongside the façade had to be known. The second aspect concerned the G-ratio. The parameters that were measured to calculate this value were the vertical solar radiation that enters the building through the façade and the vertical solar radiation just in front of the façade. Since this last position was not easy to reach, the horizontal solar radiation was measured on top of the building and this value was converted to the vertical solar radiation in question

The measurements were performed in the month February, in the Kennedy Tower from the 6th of February till the 14th of February and in the Effenaar from the 14th of February till the 22nd of February and in March, in the ABT office from the 9th of March till the 17th of March and in the Bouwhuis from the 20th of March till the 27th of March. The outside air temperatures in these periods were between 0 ºC and 10 ºC. Except for the last three days of measurement at the Bouwhuis, where the temperature was between 10 and 15 ºC, and the 3th, 4th and 5th night at the ABT office, where the temperature was below zero. Furthermore, the days of measurement at the Effenaar and the Kennedy Tower were less sunny days than the days of measurements at the ABT office and the Bouwhuis.

The different sensors that are used for measuring the different parameters are listed in table 1. Since the measurements continue for one week, the data is stored with data loggers.

Table 1. Sensors used

Type of Sensor	Parameter	Accuracy
NTC thermistor Escort TX2-H RV/T transmitter	Temperature	calibrated sensitivity 0.2 K

Hukseflux heat flux sensor HFP01	Heat flux	calibrated sensitivity
Pyranometer (CM5 and CM11)	Solar radiation	1 %

The measurements set-up at the four different facades is basically the same. The surface temperatures (T_s) of both sides of both panes are measured in one line and not too close to the window frame. Only the external surface temperatures of the second skin are measured at a different position, as the measurements take place at elevated floors and the external surface of the second skin at those floors can not be reached. The heat fluxes are measured similar to the surface temperatures. The air temperatures (T_a) in the cavity are measured at three heights, as low as possible, as high as possible and in the middle. The air velocities (v) in the cavity are also measured at three positions, but at the same height. The pyranometers to measure the outside conditions are placed on appropriate positions on the roof, where there are no obstructions. The air temperatures and the air velocities inside are measured at 0.5 m from the façade at a height of 0.10, 0.50, 1.10 and 1.75 m and in the middle of the room. The solar radiation inside is measured vertically at a minimum distance of the façade. And the lux meters inside are placed at a height of 0.7 m at 0.5, 1.0, 2.0 and 3.0 m from the façade in one straight line.

RESULTS

For the calculation of the U-value of the facades the measurement results are used from sensors that are not influenced by the sun. This means that the measurement results of sensors that are necessary to calculate the U-value are compared to the measurement results of the solar radiation sensor to determine when the influence of direct sunlight on the temperatures or heat fluxes is too big. The U-values are calculated from the remaining data and put into a histogram to determine the range of the U-values (figures 2 to 5) and the mean U-value. The average and the percentage of occurrence of the U-values are calculated, resulting in a range of U-values

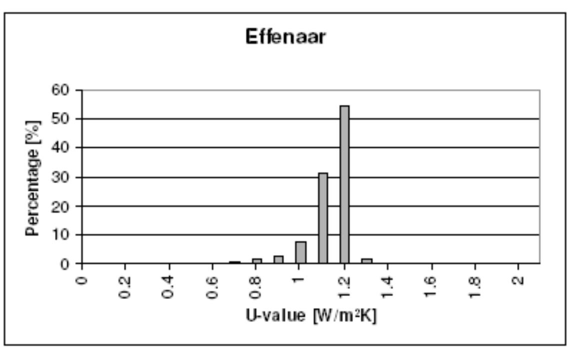


Figure 2, Distribution U-values Effenaar

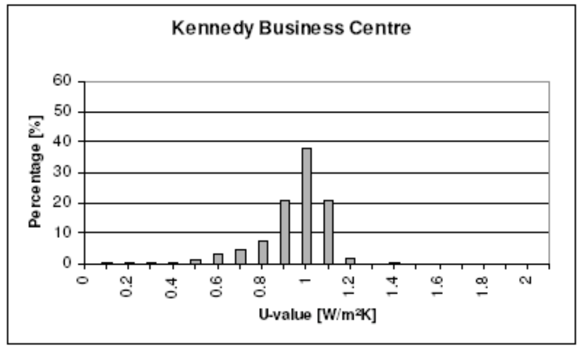


Figure 3, Distribution U-values KennedyTower

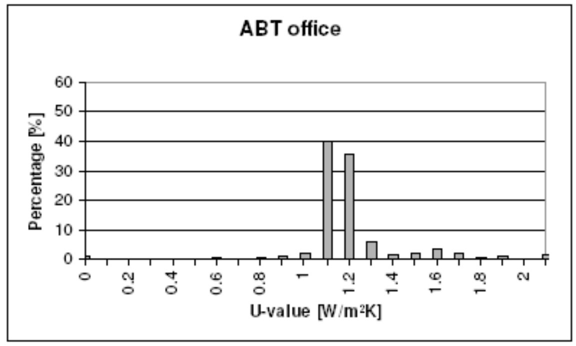


Figure 4, Distribution U-values ABT office

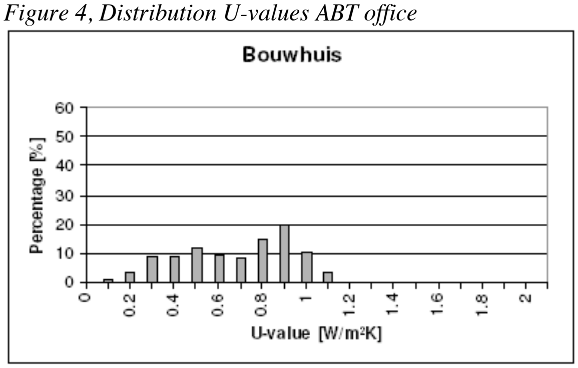


Figure 5, Distribution U-values Bouwhuis

(+80% of the values are within this range) and a mean U-value (table 2). The accuracy of the measurement equipment is used to calculate the relative error of the calculated mean U-value. The maximum deviation is 6.6% higher and the minimum deviation is 14.5% lower (table 2).

Table 2, Results U-value

	Theory	Measurements		
Building	U-value [W/m^{2}K]	Range U-value [W/m^{2}K]	Mean U-value [W/m^{2}K]	Min-max deviation [W/m^{2}K]
Effenaar	1.07	1.1 – 1.2	1.14	0.97 –1.22
Kennedy Tower	0.87	0.9 – 1.1	0.95	0.81 –1.01
ABT office	1.24	1.1 – 1.2	1.24	1.06 –1.32
Bouwhuis	1.14	0.4 – 1.0	0.69	0.59 –0.74

The G-ratio of the façade is calculated over the periods from sunrise until sunset. These times are obtained from the KNMI (the Dutch National Meteorological Institute). The G-ratios are calculated from those data and put into a histogram to determine the range of the G-ratios (figures 6 to 10) and a mean G-ratio of each façade is determined.

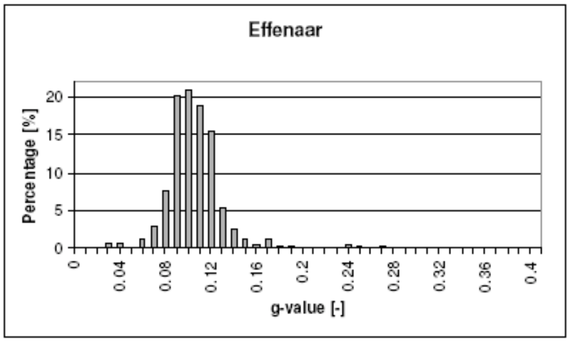


Figure 6, Distribution G-ratios Effenaar

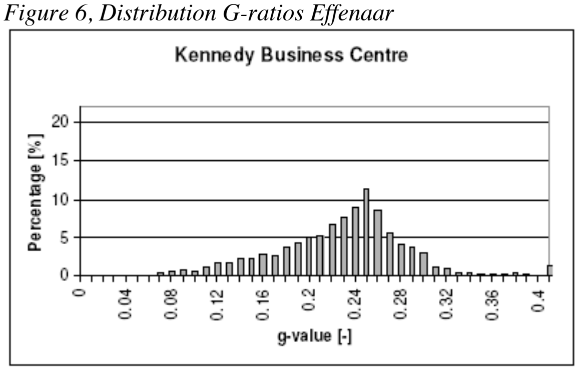


Figure 7, Distribution G-ratios Kennedy Tower

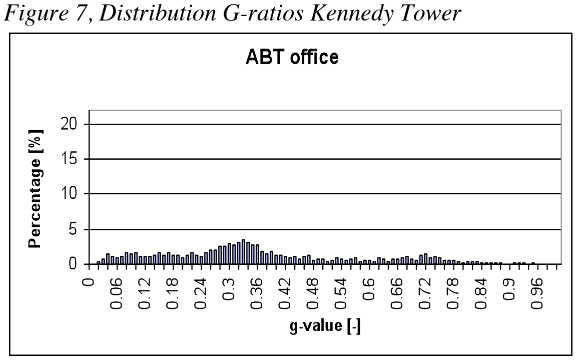


Figure 8, Percentage G-ratios ABT office

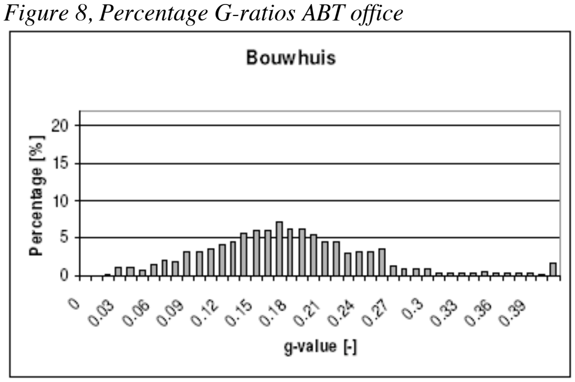


Figure 9, Percentage G-ratios Bouwhuis

The average and the percentage of occurrence of the G-ratios are calculated, resulting in a range of G-ratios (+50% of the values are within this range) and a mean G-ratio (table 3). The accuracy of the measurement equipment is used to calculate the relative error of the calculated G-ratio, which is also shown in table 3.

Table 3, Results G-ratio

	Theory	Measurements		
Building	G-ratio	Range G-ratio	Mean G-ratio	Error (37%)
Effenaar	0.22	0.09 – 0.11	0.11	0.07 – 0.15
Kennedy Tower	0.31	0.21 – 0.27	0.23	0.15 – 0.31
ABT office	0.65	0.19 – 0.45	0.37	0.24 – 0.50
Bouwhuis	0.25	0.13 – 0.21	0.19	0.12 – 0.26

DISCUSSION

Comparing the results of the theoretical model to the measurements leads to the conclusion that the values are almost the same for the Effenaar (1,07 versus 1,14), Kennedy Tower (0,87 versus 0,95) and the ABT office (1,24 versus 1,24,). However the theoretical U-value of the Bouwhuis much higher than the measured U-value is (1,14 versus 0,69) . The U-value of the inner skin of the Bouwhuis (insulated glazing) has a higher U-value in the theoretical model than in the measurement results. A possible explanation is that the exact spectral data of the glazing that WIS uses to calculate the properties can differ from the data that is used, which can cause the difference in the U-value.

The measurement results determine the evaluation of the U-value (energy saving with respect to heating and cooling). The range of U-values and the minimum and maximum deviation both show that the U-values of the Effenaar and the ABT office are comparable. The range of U-value of the Kennedy Tower is a little lower and that the U-value of the Bouwhuis is much lower. The mean U-values also show the same ranking order of the different building facades. The difference of the U-values of the Effenaar compared to the ABT office is only 0.10, compared to the Kennedy Tower 0.19 and compared to the Bouwhuis 0.45. So the energy loss in winter is smallest in the Bouwhuis

There are rather large difference in the calculated G-ratio and the measured G-ratio. Also quite large are the differences between the calculated G-ratios of the Kennedy Tower and the Bouwhuis both typical modern double facades. The theoretical G-ratios are for all facades higher than the measured mean G-ratios, but the difference ranges from 0.06 to 0.28. However, the ranking of the theoretical G-ratios is the same as the ranking of the measured G-ratios. Therefore this ranking can be used for the evaluation. Since the error of the measurements is not very small, the conclusions that can be made based on the measured G-ratios is that the Effenaar has the lowest value (0,11), the Kennedy Tower (g=0,23) and the Bouwhuis (g=0,19) have a similar G-ratio and the ABT office has the highest G-ratio (g=0,37). The measured mean G-ratio best represents this ranking.

CONCLUSION AND RECOMMENDATIONS

Comparing the results of calculated U-values and G-ratios with the actual measured values in projects show sometimes big differences. Partly these differences can be the results of measurements faults or inaccuracies, but also there are simplifications in the calculations and estimations of average values which are not correct. There is definitely a need to more detailed comparison between calculated u- and G-ratio and real measured values for these parameters.

For passive heating performance the most important aspect is the G-ratio: being the fraction of incident irradiance entering glazing and becoming heat gain in the space. As such the façade of ABT has the best passive heating performance whether the calculated values are considered for comparison or the actual measured data.

The measurements that are performed in this study only address the performances of the façades in the winter period. There measurements in summer could lead to different G-ratios and u-values due to effects of high sun radiation levels.

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REFERENCES

1. Oesterle, E., Lieb, R.D., Lutz, M., Heusler, W., (2001). Double-skin Facades, Integrated Planning, Prestel Verlag, Munich, 2001, ISBN 3-7913-2504-3
2. http://tower.uniqa.at/index_tow.php
3. Hofer, G., Streicher, W. , (2007). ProEcoPolyNet Technology Profile Glazed Double Skin Façade, June 2007; update: October 2007 http://www.proecopolynet.info/pdf_files/PEP_Net_GDF_LV_(en)_071001.pdf
4. Eicke-Henning, W., (2004). Vieles nur Fassade, Glasarchitektur – lehren aus einem Grossversuch, CCI Print InfoSystem Gebaude Technik, ausgabe 2 October 2004
5. Renckens, J., (2004). Introduction, Actieve en interactieve dubbelschalige glasgevels: top of flop?, proceedings symposium Leerstoel Productontwikkling, Faculteit bouwkunde, TU-Delft, 10 mei 2004, ISBN 90-5269-312-9.
6. Saelens, D., (2002). Energy performance assessment of single storey multiple-skin facades, Proefschrift Katholieke Universiteit Leuven, Faculteit Toegepaste Wetenschappen, September 2002, ISBN 90-5682-370-1
7. Saelens, D., Carmelit, J., Hens, H., (2003). Energy Performance Assesment of Multiple Skin Facades, International Journal of HVAC&R Research, vol.9, nr.2,pp 167-186
8. Lim, K., (2005). Responding to the challenges of glazed facades, Modern Building services, January 2005
9. Santamouris, M., Farrou, I., Zerefos, S., (2005). BESTFAÇADE Best Practice for Double Skin Façades, EIE/04/135/S07.38652 WP2 Report ‘Cut back of non-technological barriers’ Date: 30.12.2005 http://www.bestfacade.com/pdf/downloads/WP2_report_NKUA_final.pdf
10. Zerefos, S., (2007). On the performance of double skin facades in different environmental conditions, international journal of Sustainable Energy, Vol.26, No.4, December 2007, 221-229
11. Manz, H., Frank, Th., (2005). Thermal simulation of buildings with double-skin facades, Energy and Building 37 (2005) 1114-1121
12. Verdonschot, J.H.A., (2006). Performance of ventilated double facades compared to a single skin façade, MSc thesis Technische Universiteit Eindhoven, june 2006
13. Dijk D. van, (2003).IS version 2.0.1 User Guide, Examples of windows as input for WIS. TNO Building and Construction Research, Delft.
14. http://windat.ucd.ie/wis/html/index.html
15. Duffie J.A., Beckman W.A., (1980). Solar engineering of thermal processes. John Wiley & Sons, United States of America.