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CONCEPT 22/26, A HIGH PERFORMANCE OFFICE BUILDING WITHOUT ACTIVE HEATING, COOLING AND VENTILATION SYSTEMS

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Abstract

The introduced building concept goes beyond the conventional high performance building discussion by introducing an office building without any active systems for heating, cooling and ventilation. The building is accomplished in July 2013 and is located in the cold climate of Austria. The intelligent control of the building façade is the heart of the innovative building energy concept. It controls automated natural ventilation openings by using demand optimized automation strategies. Results of the first two years of building operation are demonstrating that the comfort level is acceptable in all seasons and that there are no complaints from beside the occupants. The exemplary realized building project demonstrates how innovative building automation technology can be used to reduce the total energy demand for building operation in a cold climate. Its technology can be used in other climate regions as an innovative hybrid ventilation concept.

Keywords: *Zero Net Energy Building, High Performance Building, Hybrid Ventilation, Solar Architecture*

1. Introduction

The introduced building concept goes beyond the conventional high performance building discussion by introducing an office building without any active systems for heating, cooling and ventilation. The building is accomplished in July 2013 and is located in the cold climate of Austria. The intelligent control of the building façade is the heart of the innovative building energy concept. It controls automated natural ventilation openings by using demand optimized automation strategies. Results of the first two years of building operation are demonstrating that the comfort level is acceptable in all seasons and that there are no complaints from beside the occupants. The exemplary realized building project demonstrates how innovative building automation technology can be used to reduce the total energy demand for building operation in a cold climate. Its technology can be used in other climate regions as an innovative hybrid ventilation concept.

Architects and engineers are in the agreement regarding the goal in net zero energy building design - to improve the building envelope so that the energy demand not met by passive systems could be covered by on-site energy harvesting systems (Torcellini,2006). Most researchers agree that this goals cannot be met in a building without active systems (Sartori,2012,Lu,2015).

Office buildings have relatively high internal heat gains from occupants, electrical appliances, artificial lighting and computer server stations. High internal heat gains result in generally higher room temperatures throughout the year. These higher room temperatures are helpful to reduce the heating energy demand in the winter but can increase the cooling energy demand in the summer. The right balance between heat gain and heat loss must be found to meet the thermal demands in all seasons.

The technical system of the "Concept 22/26" takes a different road then the conventional zero net energy building. An office building without any conventional active systems for heating, cooling and ventilation. The "Concept 2226" was realized in July 2013 and is located in the cold climate of Austria. The name Concept 2226 reflects the technical goal of operating a building in the highest thermal comfort levels at an internal temperature range between 22 and 26 C without any active systems. The thinking behind the Concept 22/26 system departs radically from conventional approaches.

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Two methods have been applied to achieve the goal of the Concept 22/26 building. First, the building envelope has been improved so that the internal heat release is able to cover the heating energy demand in the heating season. Then, an innovative building automation system has been developed to control the natural ventilation openings based on the internal carbon dioxide concentration, temperature levels, and occupant demands. The challenge is to ensure comfortable room conditions and indoor air quality without using conventional heating or cooling devices. The room temperature of a building is defined by the factors heat gains, heat loss and internal thermal heat storage effects. To reduce the energy demand for building operation, we must control these three factors in a way that the room temperatures are in or close to the thermal comfort field. In other words, the room temperatures must be relatively low in the summer time and relatively high in the wintertime.

The outline of this paper is as follows: First, the methodology of the technical concept are explained in section 2. Section 3 presents the results of the measurements and the occupant surveys. Section 4 presents the conclusions and implications.

Fig. 1: The realized office building Concept 2226 (Photo: E. Hueber)

2.1. Building Envelope

To meet the goal for the heating season, the "Concept 22/26" building is designred with a building envelope with an extremely low heat transfer and with a high thermal capacity. The huge time delay of the heat flow resulting from the 72 cm external wall construction helps to maintain comfortable conditions even in extreme cold time periods (Tay et al.,1974, Shaviv, 2001). The building has a triple glazing with a U-value of 0.6 W/m^2K and an SHGC value of 0.5. A blower door test was done after completion oft he building. The infiltration was measured to have an average air change rate of 0.08 1/h. The deep structured facade design with a huge dimension of the overhang and wingwall deals as a fixed shading device. No active shading devices is added to the building. The building has an uncovered concrete slab of 20 cm . It is used as an internal thermal mass.

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2.2. Building Automation

The goal of the building automation design is to operate the natural ventilation openings in a way so that maximal comfort and indoor air quality can be achieved without the use of conventional HVAC units. A balance must be found to (1) ventilate the amount of fresh air that needs to be supplied to achieve indoor air quality requirements, and (2) conserved heat in the room in the heating season. A conflict arises in the transition period and the winter season when natural ventilation is used as the fresh air supply source and the external air temperature is below the minimal comfort indoor air temperature (Heisselberg and Tjelflaat, 2006). Fresh air supply is needed to insure an appropriate indoor air quality by removing internal pollutants like CO_2. However, natural ventilation in the heating season is a heat sink and the time period for natural ventilation should be as short as possible.

To avoid too cool temperatures even in extreme situations, a new building automation system controls natural ventilation openings individually for each room, depending on the user demand and the weather condition. It uses predictive control strategies to use renewable energy sources and sustainable grid energy in a more efficient way. To maximize the performance of the automated natural ventilation openings, a control logic was developed and tested in a simulation model. It uses an on-off controller with death band, DB, (also known as hysteresis controllers) to actuate natural ventilation openings, mechanical ventilation, and heating and cooling devices. A night ventilation strategy is used to cool the internal thermal mass in the summer time (Haase and Amato, 2009).

The novel hybrid building automation uses automated window openers as the main part of the innovative building energy concept. It controls the natural ventilation openings based on the internal carbon dioxide concentration, temperature levels and the occupant demands to ensure comfortable room conditions in all seasons (El Mankibi and Michel, 2009). The hybrid control logic is extended by the control parameters of external humidity level and artificial lighting for the use in Building 22/26. It ensures that the internal thermal comfort limit for relative humidity will not be exceeded and considers the internal humidity emission of occupants. The control of the artificial lighting ensures that the illuminance value will meet the required threshold value of 500 Lux at occupied working spaces. It will also provide additional internal heat gains in extremely cold situations in the heating season. Figure 2 shows the flow plan of the building automation in a simplified form.

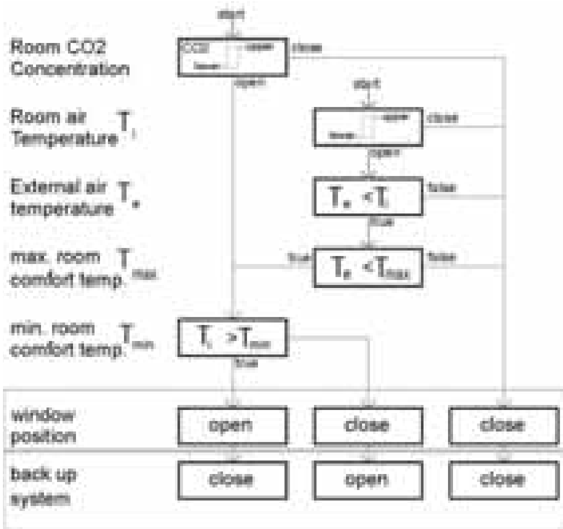

Fig. 2: Simplified illustration of the building automation

A simple predictive control strategy is integrated into the control strategy for the natural ventilation. The goal of the predictive control is to support the novel building automation system in operating the building in the winter or summer "mode". Predictive control is particularly important in the Concept 22/26 to avoid too cold temperatures caused by night ventilation. The operation mode is defined by the external temperature. The system predicts too cold temperatures when the external temperature undergoes a predefined treshold value for a given time period. It is the goal to use an advanced prdictive control logic in the future that involves single zone simulation tools.

The building control concept includes a back up operation to ensure comfortable room conditions in extreme cold weather situations. Additional internal gains are used for back up heating in time periods where extreme cold temperatures are expected in the morning hours. The artificial lighting is going to be used as additional heating to increase the surface temperature of the internal thermal mass. The back up system is controlled by the predictive control logic.

2.3. Measurement Device

Each room is equipped with an air temperature, humidity and a CO_2 concentration sensor. The sensors are located at the inside wall at a height of 1.1 m. The temperature, humidity and CO_2 concentration sensor is a GIRA SK01. The producer provides an accuracy of 0.3 K fort he temperature, 3 % fort he humidity and 50 ppm fort he CO_2 concentration. The room temperature, humidity and CO_2 concentration is measured for each room in the building since August 2013.

2.4. Occupant Survey

An occupant survey is done in March 2015 to validate the occupant satisfaction for the termal comfort and the internal air quality. The survey contains questions about the satisfaction in the winter and summer season in general . It also includes questions about the most extreme time periods in each season.
The questions are similar to the method introduced by Fanger (Fanger), where the occupant has 7 options to

evaluate the condition for much too warm, too warm, slightly warm, OK, slightly cold, too cold and much too cold. For the indoor air quality, the occupants have had five options: good, OK, acceptable, poor, very poor. Additional questions are asking for the gender, the typical type of clothing and the discomfort caused by air drag effects.

2. Results

3.1. Room Temperatures

Results for the first 1.5 years of operation are illustrating that the room temperatures are in the comfort level the winter season in all rooms of the building. The room air temperatures in the north oriented office space are 0.5 K below these of the south oriented office space. The internal surface temperatures are at an average of 22 C.

In the summer, the temperatures are in the comfort level in most of the time. There are a few hours with temperatures above the comfort standard in the west oriented office space. However, the temperatures are in the comfort field for 95% of the summer time.

Fig. 3 and Fig. 4 show the measured temperature in the west oriented office room at the most extreme weather periods in the winter (fig.3) and in the summer (fig.4). The west oriented open space office room has the highest challenge to be operated without mechanical systems because it does not have solar gains in the winter and does have extreme solar gains in the summer time. The room is occupied by maximal 8 people and each working space is equipped with a computer (180-230 W).

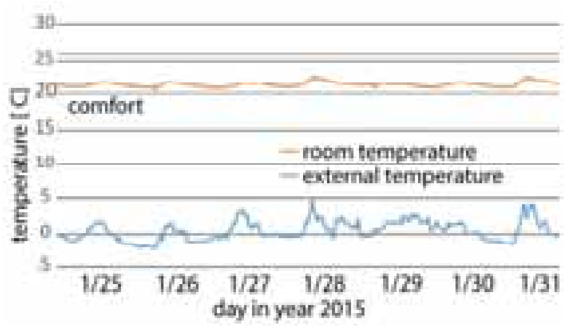

Fig. 3: External and room temperature for the west oriented office space in the coldest week in 2015

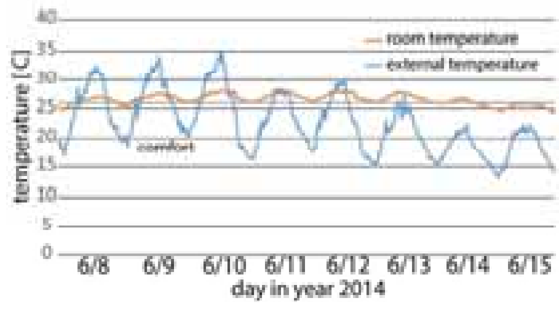

Fig. 4: External and room temperature for the west oriented office space in the warmest week in 2015

For the winter, the internal air temperature drops at time periods where the ventilation openings are open for fresh air supply. However, the temperature never goes below the comfort limit of 20 C.

The measured data for the hottest week in the summer time illustrates that the room temperature rise to as much as 3 K above the temperature goal of 26 C. It also illustrates that the night ventilation effect is not always sufficient to cool the internal thermal mass to an appropriate level (Haase et al.,2009). However, the time period with temperatures above the static comfort limit of 26 C is relatively short. The majority of occupants do accept higher temperatures when the external temperature is high (section 3.4).

3.2. CO_2 Concentration

Figure 5 shows the result of the CO_2 concentration for the west oriented office space. The measurement is done in the same time period in the winter like the temperature measurement in figure 3. It illustrates that the CO_2 concentration does not exceed the limit for the good indoor air quality of 1000 ppm. The automated natural ventilation opening is activated three to four times a day. A comparison between the room temperature (fig. 3) and the CO_2 concentration shows that the room temperature does not drop below the comfort limit at time periods where the ventilation opening are open.

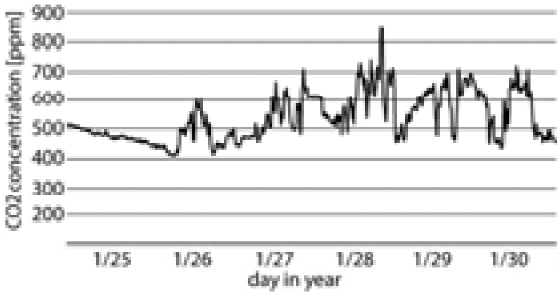

Fig. 5: CO_2 concentration in the west oriented office space in the coldest week in 2015

3.3. Relative Humidity

Figure 6 shows the internal relative humidity in the west oriented office space. The measurements show that the relative humidity is below 40%. It is above the recommended comfort limit of 30% and is therefore sufficient to meet the thermal comfort expectations (ISO norm). The constant relative humidity in the room is partly produced by the occupants. In the summer, the relative humidity is between 40 and 50%. It meets the comfort limit of 60%.

Fig. 6: Relative Humidity in the west oriented office space in the coldest week in 2015

3.4. Occupant Survey

Fig. 7 and fig. 8 shows the results of the occupant survey for the heating and the cooling season. It shows that the majority of the occupants are generally satisfied by the human comfort in both seasons.

Fig. 9 and Fig. 10 show the evaluation of the indoor air quality. The results are demonstrating that the occupants are satisfied with the indoor air quality in all seasons. None of the occupants evaluated the indoor air quality as to be only “acceptable”.

Fig. 11 shows the evaluation of the human comfort at the coldest period. It shows that the majority of the occupants are satisfied with the comfort in the extreme period. One female occupant describes the room temperature as to be too cold. However, there is a larger group of occupants evaluating it as to be slightly too warm.

Fig. 12 shows the comfort evaluation for the warmest time period. Like in the figures before, it illustrates that the majority of the occupants are satisfied with the thermal comfort in the warmest season. The diagram shows that there is a group of four occupants which are evaluating the thermal comfort as to be too warm. These four occupants are located in the west oriented office space.

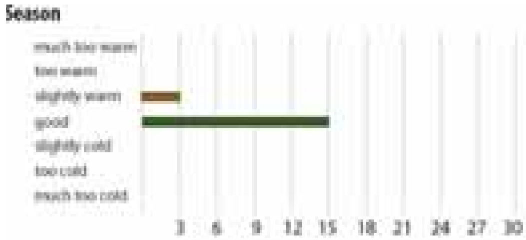

Fig. 7: Results of the occupant survey for the winter

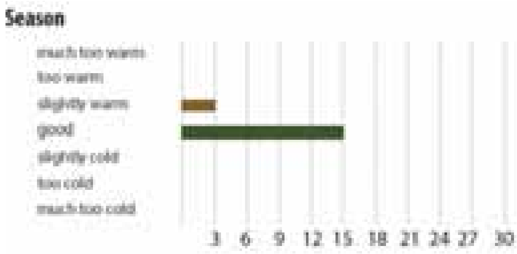

Fig. 8: Results of the occupant survey for the summer

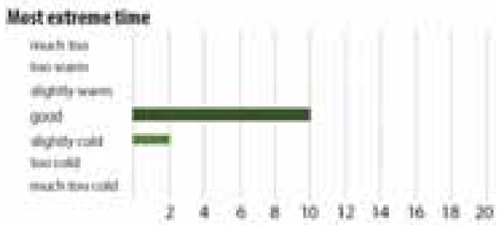

Fig. 9: Results of the occupant survey for the coldest time period in winter 2015

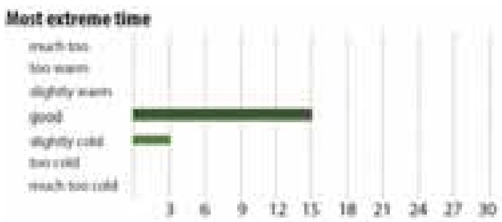

Fig. 10: Results of the occupant survey for the warmest time period in summer 2015

Fig. 11: Results of the occupant survey for the indoor air quality for the coldest time period in winter 2015

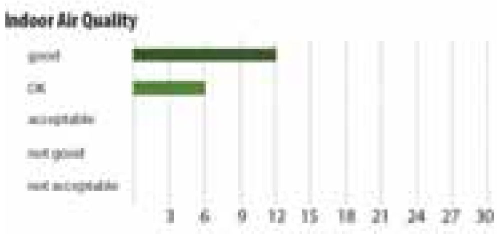

Fig. 12: Results of the occupant survey for the indoor air quality for the coldest time period in winter 2015

Notice: the occupants in the west oriented office space are mainly complaining about the temperatures with overheating in the time period from June 11 to June 13. The room temperatures in this time periods are above the comfort field even when the external temperature is relatively low. This illustrates that the adaptive comfort model introduced by Brager and DeDear (2008) is applicable in the controlled natural ventilation environment in this study.

None of the occupants have had any discomfort caused by the cold air drag effect at the ventilation openings or at the large windows. The occupants do not use additional local heating or cooling devices like resistance heaters to control the temperatures at the working space.

3.5. Indoor Air Quality

The Indoor air quality have been evaluated for the building at operation by a professional company. The concentration of the most critical components and pollutants have been measured. Also the VOC and germ concentration is measured. Their results are showing that the natural ventilation provides excellent indoor air quality conditions even in time periods where the ventilation openings are closed. Further tests will follow in the future. The results are showing that the pollution concentration is comparable like for a building with mechanical ventilation (Chou et al.2006).

3.6. Energy Demand

The total use energy demand for building operation including artificial lighting and electrical devices is measured for the Concept 22/26 for all time periods after completion of the project. The average specific use energy demand of the building is 38 kWh/m^2 year (measurement time period 9/1/2013 to 8/30/2014). The office space has a specific use energy demand of 42 kWh/m^2. The owner of the building operates the building with electricity that is produced with renewable energy sources (photovoltaic, hydropower). This type of primary energy source ensures that the building can be operated almost without greenhouse gas emission. The data shows that the use energy demand of the Concept 22/26 is 30% below comparable high performance buildings.

3.7. Improvements in Building Operation

Like every prototype, minor improvements needed to be done on the building control logic. (1) It was planned to operate only two ventilation openings per room to provide night ventilation. The operation logic have been changed to have 5 ventilation openings available for the night ventilation. (2) Some of the windows are now equipped with curtains to avoid radiation asymmetry in the summer time.

4. Conclusion

The measurement results for the Concept 22/26 building demonstrates that a building can be operated without conventional heating, cooling and ventilation systems in a cold climate when innovative building automation technology is paired with a well designed building envelope. It also illustrates that the demand controlled natural ventilation technology can significantly reduce the overall energy demand of an office building.

As indicated in the results section, measured room temperatures have been shown to be at least 21 C for all occupied hours in the year and in all rooms of the building. A small number of hours with overheating problems have been counted in the west oriented office space. However, the results demonstrate that the number of hours with overheating problems never exceed 3% of the total operation time of the building. Furthermore, the results of the occupant survey are illustrate that the higher temperatures are accepted when the external temperature is high.

In general, the automation concept of the Concept 22/26 is very effective in a building with hybrid ventilation to increase the number of hours where no mechanical heating or cooling is needed. The results are promising to be effective as a natural ventilation control in a hybrid ventilation system in even more challenging climate regions.

The results of the occupant survey illustrate that the controlled natural ventilation concept provides comfortable conditions for the majority of occupants in most of the operation time. It shows also that there is a minority of occupants, which are not satisfied in most extreme time periods with very cold or hot weather. Localized active solutions might be a good solution for these very short time periods.

On the basis of these results, we believe that the Concept 22/26 can be effectively applied into hybrid-ventilated office buildings suiltable for a wide range of climate regions.

5. References

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Appendix: **UNITS AND SYMBOLS IN SOLAR ENERGY**

In 1977, a committee of ISES developed a set of recommended nomenclature for papers appearing in *Solar Energy.* This is a condensed and revised version

Volume
Volumes are measured in m^3 or litres (1 litre = 10^{-3} m^3). Abbreviations should not be used for the litre.

Flow

Temperature
The S.I. unit is the degree Kelvin (K). However, it is also permissible to express temperatures in the degree Celsius (°C). Temperature differences are best expressed in Kelvin (K).
When compound units involving temperature are used, they should be expressed in terms of Kelvin, e.g. specific heat J kg^{-1} K^{-1}.

2. NOMENCLATURE AND SYMBOLS

Tables 1-5 list recommended symbols for physical quantities. Obviously, historical usage is of considerable importance in the choice of names and symbols and attempts have been made to reflect this fact in the tables. But conflicts do arise between lists that are derived from different disciplines. Generally, a firm recommendation has been made for each quantity, except for radiation where two options are given in Table 5.
In the recommendations for *material properties* (see Table 1), the emission, absorption, reflection, and transmission of radiation by materials have been described in terms of quantities with suffixes 'ance' rather than 'ivity', which is also sometimes used, depending on the discipline. It is recommended that the suffix 'ance' be used for the following four quantities:

$$\text{emittance}\,\varepsilon = \frac{E}{E_b}\left(or\,\frac{M_s}{M_{sb}}\right)$$

$$\text{absorptance}\,\alpha = \frac{\Phi}{\Phi_i}$$

$$\text{reflectance}\,\rho = \frac{\Phi}{\Phi_i}$$

$$\text{transmittance}\,\tau = \frac{\Phi}{\Phi_i}$$

where E and ϕ is the radiant flux density that is involved in the particular process. The double use of α for both absorptance and thermal diffusivity is usual, as is the double use of ρ for both reflectance and density. Neither double use should give much concern in practice.

Table 1: Recommended symbols for materials properties

Quantity	Symbol	Unit
Specific heat	c	J kg^{-1} K^{-1}
Thermal conductivity	k	W m^{-1} K^{-1}
Extinction coefficient^{+}	K	m^{-1}
Index of refraction	n	
Absorptance	α	
Thermal diffusivity	α	m^2 s^{-1}
Specific heat ratio	γ	
Emittance	ε	
Reflectance	ρ	
Density	ρ	kg m^{-3}
Transmittance	τ	

$^{+}$ In meteorology, the *extinction coefficient* is the product of *K* and the path length and is thus dimensionless.

Quantity	Symbol	Range and sign convention
Altitude	α	0 to ± 90°
Surface tilt	β	0 to ± 90°; toward the equator is +ive
Azimuth (of surface)	γ	0 to 360°; clockwise from North is +ive
Declination	δ	0 to ± 23.45°
Incidence (on surface)	Θ, i	0 to + 90°
	Θ_z	0 to + 90°
	Φ	0 to ± 90°; North is +ive
	ω	-180° to +180°; solar noon is 0°, afternoon is +ive
eflection (from surface)	r	0 to + 90°

Table 3: Recommended symbols for miscellaneous quantities

Quantity	Symbol	Unit
Area	A	m^2
Heat transfer coefficient	h	W m^{-2} K^{-1}
System mass	m	kg
Air mass (or air mass factor)	M	
Mass flow rate	$\dot{m}$	kg s^{-1}
Heat	Q	J
Heat flow rate	$\dot{Q}$	W
Heat flux	q	W m^{-2}
Temperature	T	K
Overall heat transfer coefficient	U	W m^{-2} K^{-1}
Efficiency	η	
Wavelength	λ	m
Frequency	ν	s^{-1}
Stefan-Boltzmann constant	σ	W m^{-2} K^{-4}
Time	t, τ, Θ	s

Table 4: Recommended subscripts

Quantity	Symbol
Ambient	a
Black-body	b
Beam (direct)	b
Diffuse (scattered)	d
Horizontal	h
Incident	i
Normal	n
Outside atmosphere	o
Reflected	r
Solar	s
Solar constant	sc
Sunrise (sunset)	sr, (ss)
Total of global	t
Thermal	t, th
Useful	u
Spectral	λ

Table 5: Recommended symbols for radiation quantities

	Preferred name	Symbol	Unit
a)	Nonsolar radiation		
	Radiant energy	Q	J
	Radiant flux	Φ	W
	Radiant flux density	Φ	W m^{-2}
	Irradiance	E, H	W m^{-2}
	Radiosity or Radiant exitance	M, J	W m^{-2}
	Radiant emissive power (radiant self-exitance)	M_s, E	W m^{-2}
	Radiant intensity (radiance)	L	W m^{-2} sr^{-1}
	Irradiation or radiant exposure	H	J m^{-2}
b)	Solar radiation		
	Global irradiance or solar flux density	G	W m^{-2}
	Beam irradiance	G_b	W m^{-2}
	Diffuse irradiance	G_d	W m^{-2}
	Global irradiation	H	J m^{-2}
	Beam irradiation	H_b	J m^{-2}
	Diffuse irradiation	H_d	J m^{-2}
c)	Atmospheric radiation		
	Irradiation	$\Phi\downarrow$	W m^{-2}
	Radiosity	$\Phi\uparrow$	W m^{-2}
	Exchange	Φ_N	W m^{-2}