SBE16 Hamburg

International Conference on Sustainable Built Environment Strategies – Stakeholders – Success factors

7th - 11th March 2016

Conference Proceedings

Organised by

ZEBAU

Karlsruhe Institute of Technology

Hochschule für angewandte Wissenschaften München

HCU HafenCity Universität Hamburg

Imprint

Conference organisers

ZEBAU – Centre for Energy, Construction, Architecture and the Environment GmbH

www.zebau.de

In cooperation with

Supported by

Edited by: ZEBAU – Centre for Energy, Construction, Architecture and the Environment GmbH, Große Elbstraße 146, 22767 Hamburg, Germany

This book was prepared from the input files supplied by the authors.

The publisher is not responsible for the use which might be made of the following information.

2016

Printed on 100% recycled paper.
Druckerei in St. Pauli, Große Freiheit 70, 22767 Hamburg, Germany

ISBN 978-3-00-052213-0
DOI: 10.5445/IR/1000051699

Façade design for night cooling by natural ventilation in different climate zones

Wellershoff
Frank
Univ.-Prof. Dr.-Ing.
HafenCity UniversityHamburg
Germany
frank.wellershoff@hcu-hamburg.de

Matthias Friedrich, M.Sc., HafenCity University, Germany, matthias.friedrich@hcu-hamburg.de
Prof. Lucila Chebel Labaki, State University of Campinas, Brazil, lucila@fec.unicamp.br
Luciana Fernandes, M.Sc., State University of Campinas, Brazil, luarq@fec.unicamp.br

Abstract

Depending on the climate region, the local comfort standard and the efficiency of existing building services, the share of energy for cooling, heating and artificial lightning of buildings is between 30% and 50% of the overall final energy consumption of the country. The required energy for cooling of buildings can be significantly reduced by night ventilation. In this case cool air is ventilated through the building to discharge heat energy stored in walls, floor slabs, and furniture. The efficiency of this method depends mainly on the air exchange rate between the outdoor environment and the indoor air volume. Driving forces for the air flow through façade openings are the outside air temperature drop during night, wind pressure distributions acting on the façade due to local wind and the availability of cross wind flow through the building. Resistances for the air flow are given by the size and the geometry of facade openings which can be quantified by discharge coefficients. In the facade design phase the relation between window size and effective opening area must be considered. With predicted discharge coefficients the overall energy efficiency and indoor temperature of buildings with natural ventilation can be analyzed in transient multi zone models. Exemplary buildings in Campinas, Brazil and Hamburg, Germany are analyzed concerning their potential of this method to save energy.

Keywords: energy efficiency, facade opening, discharge coefficient, night cooling, natural ventilation

1. Background

The city of Campinas is located in the Southeast of Brazil with summer average temperatures exceeding 30°C and high relative humidity levels throughout the year. Protection against overheating is one of the most important aspects to be considered in building physics. The city of Hamburg is located in the North of Germany. The moderate climate zone has strongly distinct seasons with cold winter and hot summer days. A thermal insulated building envelope is as important as an intelligent concept to avoid overheating. It is aimed to use the temperature amplitude between day and night in both countries for night ventilation to reduce the cooling loads. Massive concrete elements are heat storages during the day time. For night cooling the heat convection from inside to outside shall be maximized, but it is limited by the air exchange rate.

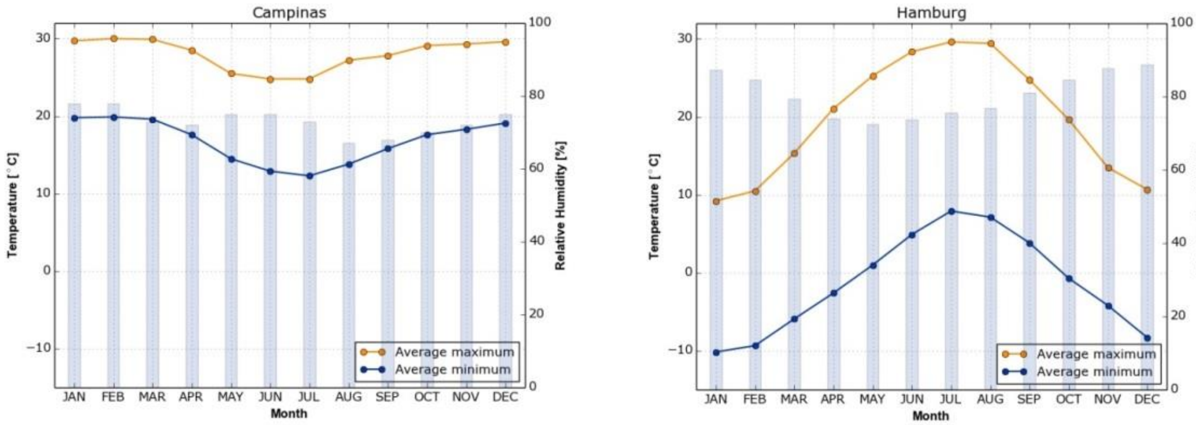


Fig. 1: Weather profile of Campinas, Brazil (left) and Hamburg, Germany (right)

2. Methods

The energy efficiency and indoor temperatures are analyzed with transient multi zone simulations. The thermo-energetic performance using night ventilation in exemplary office rooms of non-residential buildings is simulated with EnergyPlus. EnergyPlus is a building energy simulation program to model energy consumption and water use in buildings. It is a free and open-source software funded by the U.S. Department of Energy (DOE) Building Technologies Office (BTO) and managed by the National Renewable Energy Laboratory (NREL) [1]. The studied rooms are located in Brazil (Campinas) and Germany (Hamburg) in university facilities with typical office activity.

Fig. 2: Southwest view of the campus building IFCH Campinas

Fig. 3: South view of the campus building HafenCity University, Hamburg

The analyzed room in the hot Brazil climate demands the use of air conditioning systems during most hours of the day to provide comfort for the users. Natural night ventilation can be used to reduce the cooling loads. The office room in Germany is naturally ventilated and has no mechanical ventilation. The external shading by the balcony construction shown in figure 3 and 4 in the area of the test room is not considered in the simulations for research purposes. To ensure the user comfort, the hours of overheating shall be minimized. According to national German standards [2], the maximum comfort temperature is 26°C. Generally the amount of overheating can be quantified by different methods. Just counting the number of hours above 26°C would be insufficient for the reason that the user comfort decreases with raising temperature. Therefore it is common to consider the delta to the maximum comfort temperature. An appropriate and simple method to use is to determine the energy consumption of an imaginary air conditioning system that cools the room temperature to 26°C if required. Hourly local weather data are used for both entire year simulations. The thermal loads are given by internal gains from occupancy, equipment and lighting systems. Air flow resistances by openings for passive ventilation modes are taken from the literature and adjusted for use in each façade. Details about each room as well as modeling settings are presented in Table 1.

Table 1 - Details about the rooms

		Unicamp - IFCH Campinas/SP, Brazil	**HafenCity University Hamburg, Germany**
Use		Office Mo - Fr 9 a.m. – 5 p.m.	Office Mo - Fr 8 a.m. – 7 p.m.
Floor Area		29.4 m²	40.1 m²
Internal Gains			
People	number	3	4
	activity level [3]	130 W	130 W
	heat gain	13.3 W/m²	13.0 W/m²
	fraction radiant [3]	0.58	0.58
	sensible heat fraction [3]	0.58	0.58
Lights		13.0 W/m²	7.4 W/m²
Equipment		12.1 W/m²	15.0 W/m²

Temperature Limits		25°C HVAC (PTAC) COP 2.11W/W during working hours	26°C Natural ventilation only
Window Glass Area (see also table 2)		5.14 m² single glazing	15.44 m² triple glazing
Openable Area		2.68 m² Horizontally pivoted	2.30 m² Bottom pivoted
Discharge Coefficient c_d		0.61	0.61
Opening Factor		0.12	0.458
Orientation		North-East	South
Shading		Blinds and external fixed side elements	Blinds max. 180° close above 300 W/m²
Natural Ventilation modes	Base	“No Natural Ventilation”	“No Natural Ventilation”
	Vent 1	“Static Night Cooling” Night Ventilation from 9 p.m. until 9 a.m.	“Static Night Cooling” Night ventilation from 7 p.m. until 8 a.m.
	Vent 2	“Selective Ventilation” Natural Ventilation when $T_{in} > T_{out}$ and $T_{in} > 24°C$	“Selective Ventilation” Natural ventilation when $T_{in} > T_{out}$ and $T_{in} > T_{set}$ T_{set} = 21°C when occupancy, else 18°C

3. Natural Ventilation Simulation in EnergyPlus

This research addresses a method to quantify relevant characteristics of façade design relative to its suitability for natural nocturnal ventilation. Hence, two different ventilation strategies are analyzed for both rooms described in Table 1. The static night cooling allows natural ventilation during the night independently of the outdoor air temperature. This method is easy to implement in existing, motorized windows and there is no need for complex façade control software. Additionally, a selective ventilation mode is simulated. This mode allows natural ventilation during the day, especially during early daytime, as well as during the night, if the room air temperature is above the outdoor air temperature and the room temperature is above a temperature setpoint. This setpoint will be chosen by local climate conditions (Table 1).

Beside the ventilation strategy, the performance of natural ventilation depends on the design of the airflow path. Changes in geometry and friction among the airflow path are the most significant flow resistances. In energy simulation tools (e.g. EnergyPlus) these resistances are often summarized to discharge coefficients c_d which indicate the effectiveness of airflow though openings. For rectangular openings, e.g. 90 degrees open windows, the resistance coefficient $\zeta = 1/c_d$ is in a small range between 2.7 and 2.8 [4] and therefore the discharge coefficient is 0.61. For common used window constructions the obstruction of the pane in pivoted cases must also be considered. The tilted pane reduces the effective area Aeff which is available for the airflow. Consequently it is not sufficient to use the discharge coefficient $c_d = 0.61$ to describe all impacts. Bottom pivoted windows are used at the HafenCity University in Germany (Figure 4, right). Hult et al. [5] studied the algorithm used by EnergyPlus for pivoted windows and modified the expression in order to achieve better results for top pivoted windows. For this study the expression is transformed for the calculation of Aeff for bottom pivoted windows to take the different position of the rotating axis into account. W/H is the window width/height, α is the opening angle and z is the vertical coordinate starting from the pivoting axis. The effective window area for the window system in Hamburg is calculated according to the equations (1) and (2):

$$A_{eff} = \int_{0}^{H\cos(\alpha)} W_{pivot}(z)\,dz + \int_{H\cos(\alpha)}^{H} W dz \quad (1)$$

$$W_{pivot} = \left(\frac{1}{W^2} + \frac{1}{(2\,z\,\tan(\alpha) + \sin(\alpha)W)^2}\right)^{-0.5} \quad (2)$$

The IFCH building in Brazil has horizontally pivoted windows where the rotation axis is eccentrically placed (Figure 4, left). There is no reliable reference available for this window construction. Geometric analysis provides opening factors equivalent for the ratio of effective and geometric opening area. The effective area for ventilation is the rectangular area which remains open when the pane is tilted (Figure 5). The lateral areas for ventilation of the windows are not considered as they are obstructed by shading elements. The ratio between the effective area and the opening area resulted in an opening factor of 0.12 (Table 1).

Fig. 4: Illustration of the openings for ventilation of IFCH Campinas (left) and HafenCity University, Hamburg (right)

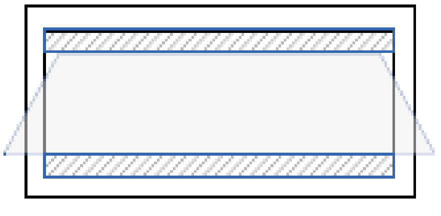


Fig. 5: Effective area for ventilation that is considered in IFCH building

The thermal properties of the envelope are also important for the effectiveness of the natural ventilation, as an additional thermal load is transmitted through the envelope and needs to be removed by natural or artificial ways. Table 2 shows the thermal properties of the envelope for both buildings.

Table 2 - Thermal properties of the components of the model

	Component	U-factor (W/(m².K))	SHGC [-]
IFCH Campinas	External wall 1	2.65	
	External wall 2	3.09	
	Slab	2.04	
	Roof	1.74	
	Single glazing	3.84	0.818
HafenCity University	Triple glazing	0.60	0.450
	Internal walls and slabs	adiabatic	

4. Results and Discussion

4.1 Energy consumption

An overview of the monthly energy consumption for cooling of both rooms is presented and discussed for further analysis. From figure 6 it is possible to note that night ventilation for the Brazilian building (IFCH) is not that efficient from energy aspects considering the whole year. Evaluating the peak of cooling in October, natural ventilation allows reductions of the cooling load up to 14% (Table 3). Furthermore in winter, the strategy was more efficient reducing up to 29% of the cooling energy in July. The consumption during this season is not expressive; therefore it gives no big contribution to the annual energy demand (reductions around 6%). On the opposite, significant reductions are possible for the room in Hamburg (HCU), mainly with selective ventilation. The potential reduction reaches up to 87% percent in July through selective ventilation and 23% in times with peak cooling loads. Yearly it is possible to reduce 76% of the cooling demand with night ventilation and 93% with selective ventilation (Figure 7).

In general it is found that natural ventilation is an effective method to reduce the energy consumption for cooling as well as the peak loads. In moderate climate with cooler nighttime air temperatures the efficiency is also driven by the ventilation strategy. An adaptive opening control allows the usage of temperature difference between indoor and outdoor for passive cooling but it can also prevent the room against overheating, while the static ventilation does not consider the outdoor temperature. In hot climates the positive effect of natural ventilation is less noticeable. For the case of static night cooling an energy conservation of 6% is calculated. For the flexible ventilation strategy based on the temperature difference the same energy conservation percentage of 6% is calculated. A higher benefit for a flexible ventilation strategy cannot be determined because the windows are open less frequently.

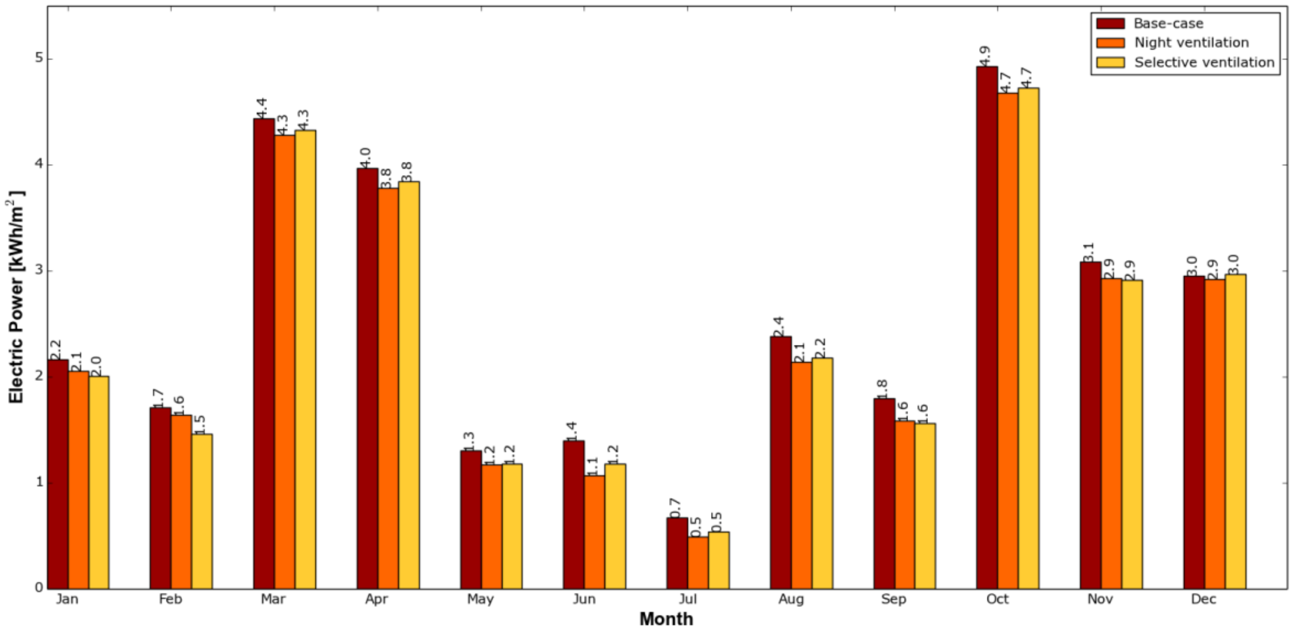


Fig. 6: Monthly air conditioning use for the room in Campinas

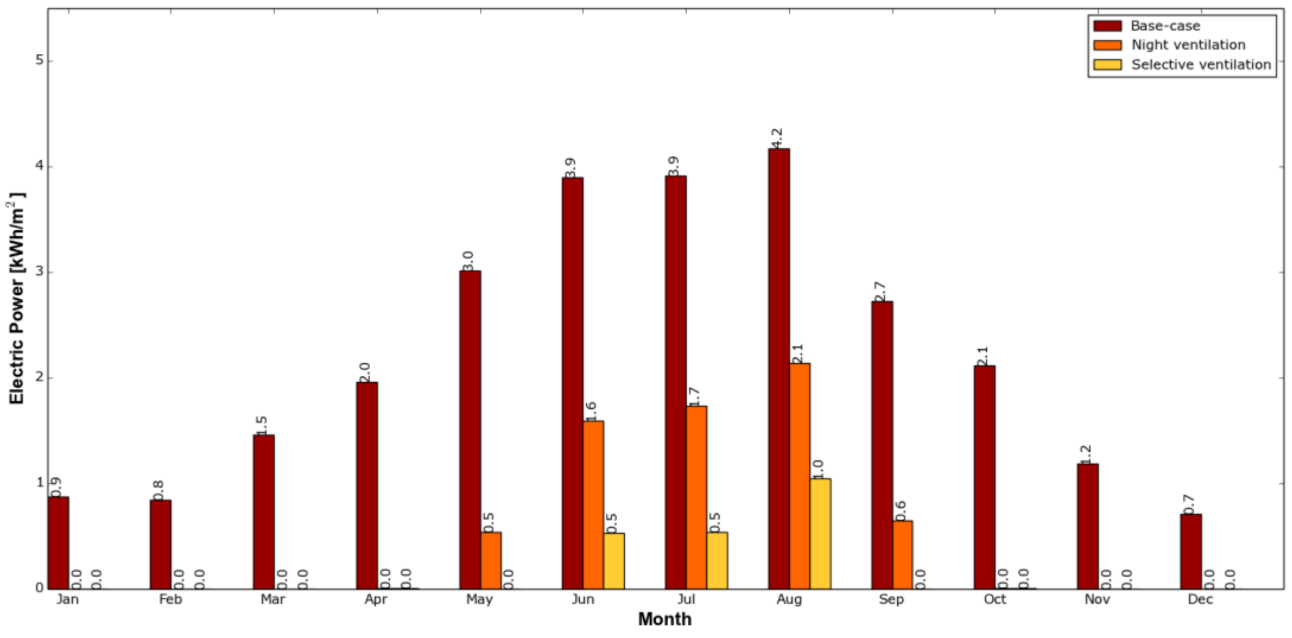


Fig. 7: Monthly air conditioning use for the room in Hamburg

Table 3 - Peak cooling sensible heat gain.

	HVAC input sensible air cooling (kW) and date + time of the peak load		
Room	Base-case	Night ventilation	Selective ventilation
HCU	-1.87 08/03 15:00	-1.60 08/03 15:10	-1.45 08/07 15:10
IFCH	-4.87 10/13 09:03	-4.20 10/12 09:03	-4.21 10/12 09:03

4.2 Temperature profile

According to the weather profile of Campinas, the highest outdoor temperatures occur between January and February. Analyzing the temperature during working hours, better results were found when using passive strategies in January 16th. Therefore this was the period to be analyzed for summer conditions (Figure 8, left). The same criterion is adopted for the climate of Hamburg. Better results are achieved with natural ventilation exemplary in July 9th.

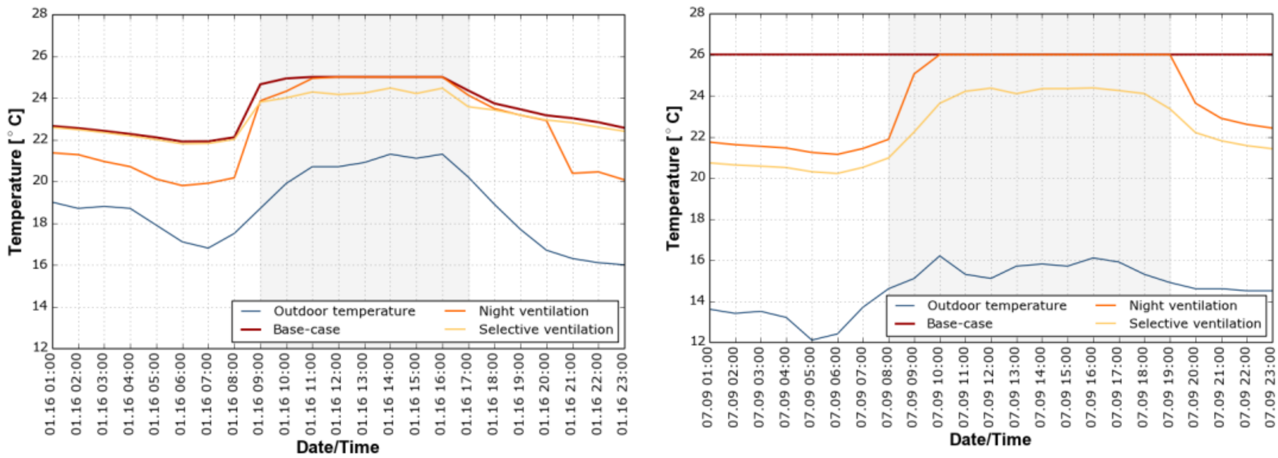


Fig. 8: Indoor temperatures during occupation of the rooms in summer for the three cases in Campinas, January 16th (on the left) and Hamburg, July 9th (on the right).

The temperature behavior demonstrates the need of natural ventilation for energy efficient buildings in Hamburg. With only night ventilation the room air temperature will be the same as the defined cooling temperature setpoint due to high thermal insulation of the university building in Hamburg which prevents thermal losses. The idea of static night cooling is a simple window opening control algorithm to use natural ventilation during the night in a predefined time interval. During the day the windows are closed to prevent the room against overheating on hot days. For moderate outdoor temperatures as shown in figure 8 right, the use of natural ventilation the whole day long will decrease indoor temperatures without energy consumption for air conditioning. The discharge coefficient c_d and the effective area for ventilation A_{eff} of windows are limiting factors for the air exchange rate. When the heat losses by infiltration are lower than the internal gains, high indoor temperatures will occur even with moderate outdoor temperatures.

For retrofitting the room of the HafenCity University Hamburg the ventilation cross section area shall be increased in order to obtain higher air exchange rates. Heat convection from indoor to outdoor will increase.

The use of natural ventilation does not bring significant contributions on reducing indoor temperatures for the room in Brazil. One reason is the small difference between indoor and outdoor temperatures during the night. The glazing area is also an important contributor for heat gains as it can be seen in the next section. In Brazil, the single glazing causes heat transmission during the night. As a result, for hot climate conditions the retrofitting strategy should consider additional aspects besides nighttime natural air ventilation.

4.3 Sensible heat

Heat dissipation occurs mainly through air conditioning (during the day in all cases), opaque surfaces (probably during the night) and infiltration (in the ventilated cases). During the night, for the base-case (without natural ventilation) the main way to dissipate heat is by conduction through opaque and transparent surfaces. For the natural ventilated cases the main way becomes infiltration, decreasing the heat removal by conduction through surfaces. In all cases the indoor temperature during the night is much higher than the outdoors, what leads to high rates of heat either by conduction through opaque surfaces or air exchange through infiltration.

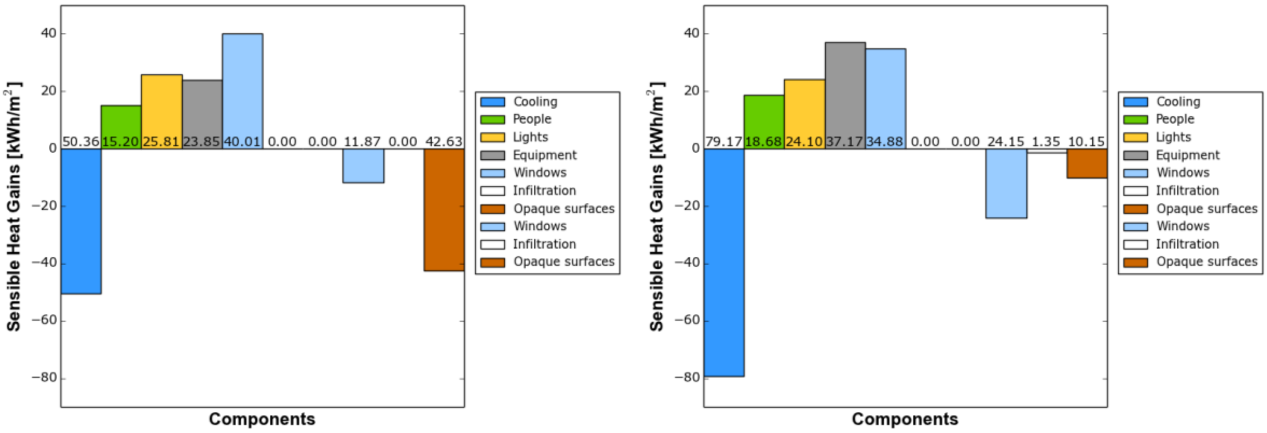


Fig. 9: Annual heat gains of the room for the base-cases in Campinas (a) and in Hamburg (b)

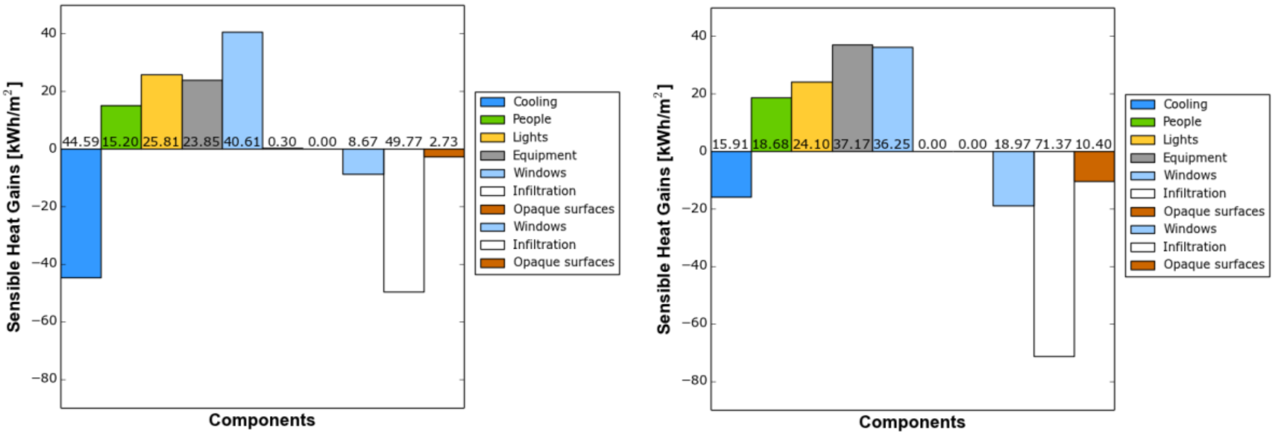
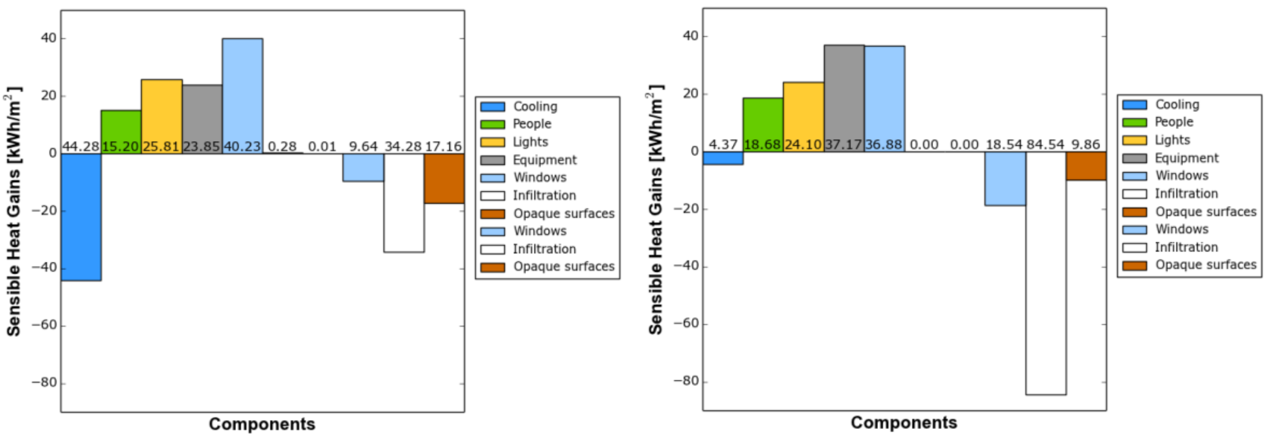


Fig. 10: Annual heat gains of the room for night ventilation in Campinas (a) and in Hamburg (b)



5. Conclusions

The use of natural ventilation for summer night cooling is an efficient method either for reducing indoor temperatures, increasing energy conservation and air quality. Besides local climate conditions the design of window openings is a key factor for natural ventilation.

Static night cooling (windows are open in a defined time period) decreases the energy consumption for air conditioning in both countries. Night cooling in Brazil was not as effective as in Hamburg, as the air temperature drop by night is lower. An intelligent facade controlled by the difference of temperature between outdoors and indoors to allow natural ventilation for cooling when needed can further noticeably reduce the energy consumption in moderate climate regions like Germany. Dynamic simulations of airflow should consider an appropriate description of the window geometry (discharge coefficient, effective area for ventilation) in order to reduce the uncertainty of the model. The study demonstrates the application of a model to represent bottom pivoted windows (Hamburg) and a simplified approach for horizontal eccentric pivoted windows with lateral barriers (Campinas).

6. Outlook

For the verification of the above used air flow resistance data (discharge coefficient, effective area) a joint research project will start in 12-2015. To determine discharge coefficients for commonly used window systems (bottom pivoted, side pivoted) wind tunnel test with these window types will be done at the laboratory of the State University of Campinas, Brazil. Additional tracer gas measurements with these window systems will be done at the façade test laboratory of the HafenCity University Hamburg, Germany. Based on these tests computational fluid dynamic (CFD) models can be verified and the field of window systems can be extended by a numerical parameter study. In the next project step the energetic and comfort performance of typical buildings with natural ventilation will be analyzed by EnergyPlus to develop design nomograms for the prediction of the air exchange rate in buildings by natural ventilation. Recommendations for the geometry of the window openings with maximum discharge coefficients can be given based on the successive testing and numerical analysis.

7. References

[1] DOE. U. S. Department of Energy – Energy Efficiency & Renewable Energy. Available at: http://apps1.eere.energy.gov/buildings/energyplus/.

[2] DIN 4108-2:2013-02, Wärmeschutz und Energie-Einsparung in Gebäuden – Teil 2: Mindestanforderungen an den Wärmeschutz

[3] ASHRAE. American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc. ASHRAE Handbook of Fundamentals, Atlanta, 2009

[4] IDELCHICK, I.E. et al., *Handbook of Hydraulic Resistance*, page 225, 3rd Edition, Mumbai, 2003

[5] HULT et al., *Using CFD Simulations to Improve the Modelling of Window Discharge Coefficients*, Fifth National Conference of IBPSA-USA, Wisconsin, 2012