Ventilative cooling in a school building: evaluation of the measured performances

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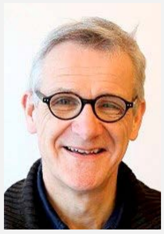

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The test lecture rooms of KU Leuven Ghent Technology Campus is a case study of IEA EBC Annex 62: Ventilative Cooling. The ventilative cooling system includes natural night ventilation and indirect evaporative cooling. This paper evaluates thermal comfort in this school building and the performances of its ventilative cooling.

Keywords: Ventilative cooling, nZEB, school building, measurements, thermal comfort, night ventilation, indirect evaporative cooling

One of the major new challenges in nearly Zero Energy Buildings (nZEB) is the increased need for cooling and risk on overheating not only during summer, but all year round (Heiselberg, 2018). Therefore, conceptual and building technical measures as well as energy efficient cooling systems are needed in these nZEB buildings to guarantee a good thermal comfort. Ventilative cooling is an example of an energy efficient cooling method and was extensively studied within IEA EBC Annex 62: Ventilative Cooling. The test lecture rooms of KU Leuven Ghent Technology Campus were one of the case studies of IEA EBC Annex 62 (see O'Sullivan and O'Donovan, 2018). This paper aims to evaluate thermal comfort in this nZEB school building and the performances of its ventilative cooling system.

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Building description

Building and use

The nZEB school building is realized at the Technology campus Ghent of KU Leuven (Belgium) on top of an existing university building. The building contains two large lecture rooms with a floor area of 140 m² and a volume of 380 m³ each (see zone 1 and 2 on **Figure 1**). The first floor has a medium and the second floor a light thermal mass according to EN ISO 13790. The window-to-wall ratio is 26.5% on both façades. The building is constructed according to the Passive House standard. The windows are provided with automatically controlled moveable external screens on the southwest façade. Design of the building is described more in detail in Breesch et al. (2016).

The lecture rooms are in use from Monday to Friday between 8:15 and 18:00 with a maximum occupancy of 80 persons or 1.78 m²/pers. **Figure 2** shows details of one typical week of occupancy.

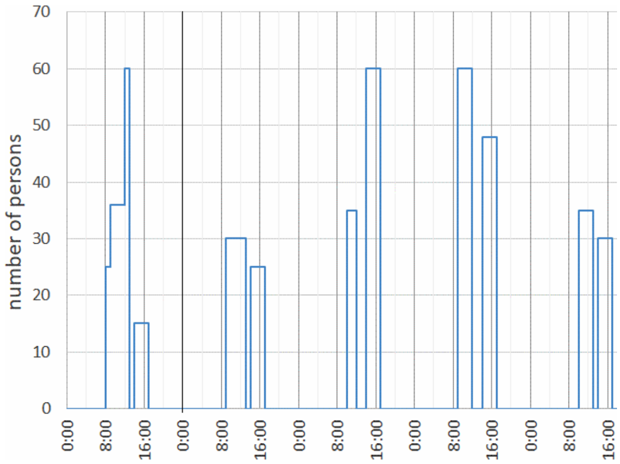

Figure 2. Typical occupancy profile in the lecture rooms during one course week (Monday to Friday).

Ventilative cooling

Two different principles of ventilative cooling are implemented in this building: (1) natural night ventilation (2) an air handling unit (AHU) that cools the supply air by controlling the modular bypass and by using indirect evaporative cooling (IEC). Night ventilation relies on cross ventilation through openable windows at both sides of the room (see **Figure 3**). The system includes 10 motorized bottom hung windows (1.29 x 1.38 m², maximum opening angle of 8.8°) with a chain actuator. There are 6 windows on the southwestern side and 4 on the northeaster side of the lecture room. The total effective opening area of these windows is 4.0% of the floor area. The modular bypass and IEC are part of the AHU. The maximum airflow rate is 4400 m³/h. The maximum capacity of IEC at maximum airflow is 13.1 kW.

Control strategy

Control strategy of the systems consists of two parts. First, the control strategy of the AHU (operation of bypass and IEC) during occupancy is based on internal and external temperatures (see **Figure 4** left). This strategy actuates the supply air temperature and the air flow rate. Second, control strategy that actuates the opening of the windows at night is based on internal temperature and relative humidity and external weather conditions (temperature, rain) measured on site (see **Figure 4** right).

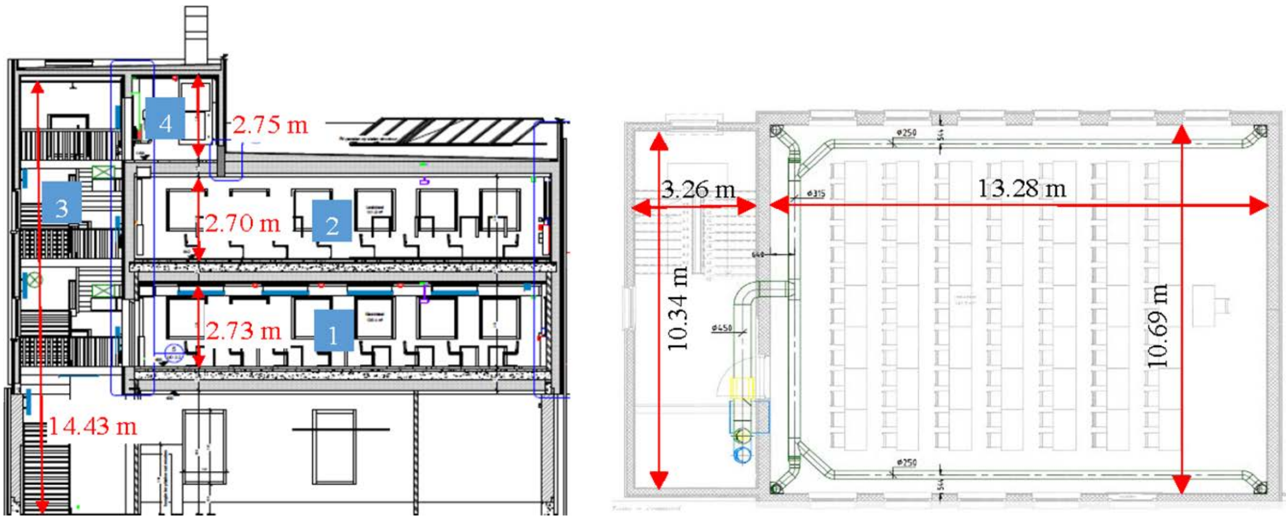

Figure 1. Section (left) and floor plan (right) of the test lecture rooms on KU Leuven Technology campus Ghent.

Measurement set up

Airflow rate

Air Changes Rates (ACR) as result of the opening of the windows were measured using a tracer gas concentration decay test method (EN 12569) in March and April 2017 by Decrock and Vanvalckenborgh (2017).

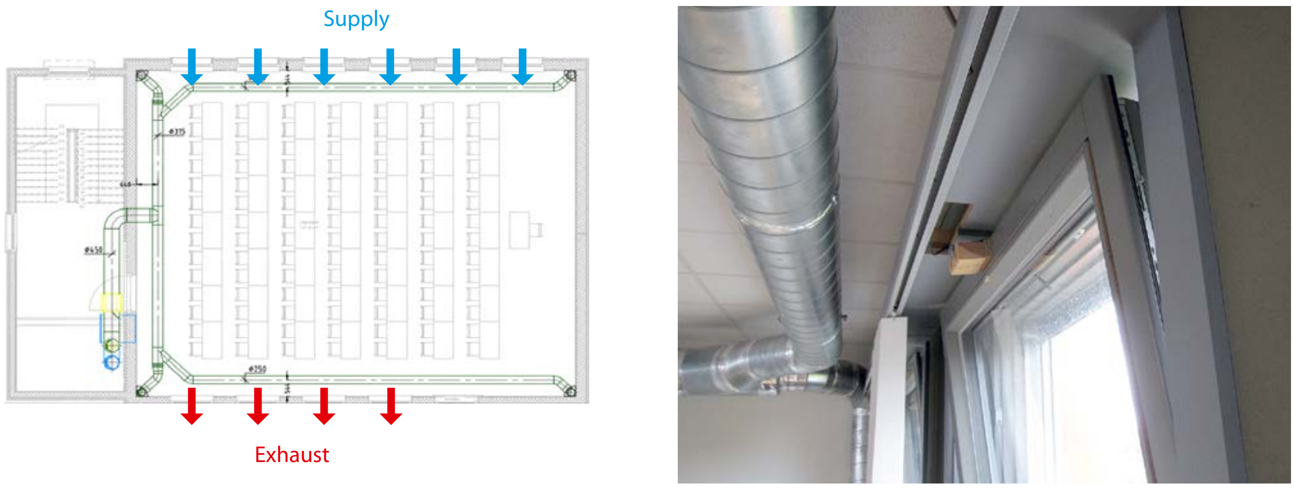

Figure 3. Principle of natural night ventilation (left) and detail of motorized window (right).

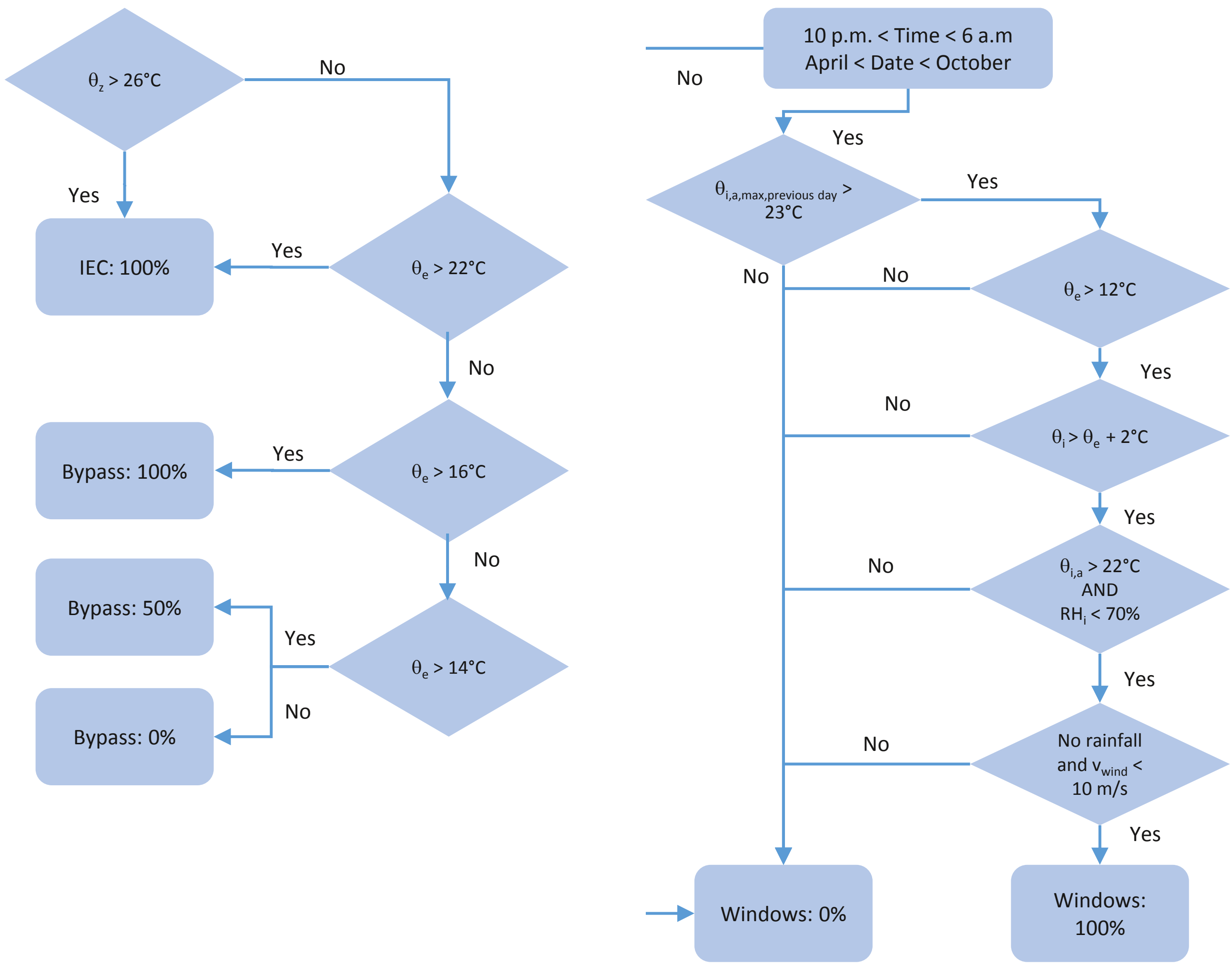

Figure 4. Control strategy flowchart of AHU during occupancy (left) and natural night ventilation (right).

The measurements were carried out in a representative zone with two opposing windows (see **Figure 5**). Tracer gas was injected and sampled in the middle of this small room and the concentration was increased to 200 ppm. Consequently, one or two opposing windows (depending on the test) were opened. The accuracy of the tracer gas equipment is 10% of the measured value.

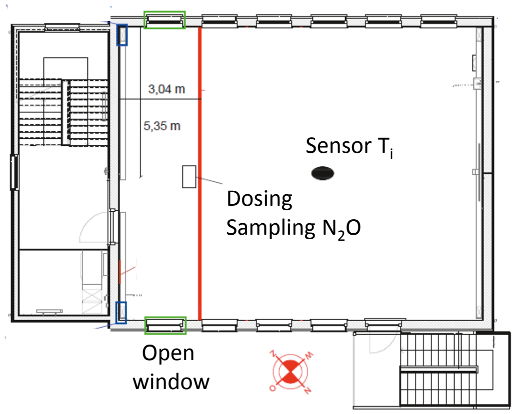

Figure 5. Test set up tracer gas measurement.

Indoor climate and operation ventilative cooling

A set of sensors has been installed to continuously monitor indoor conditions (temperature, CO_2-concentration, relative humidity, occupancy), operational data (of AHU, night ventilation, IEC, heating systems, etc.) and weather data (temperature, humidity, rain, global horizontal solar radiation, wind speed and direction) and is described in Andriamamonjy and Klein (2015). The time step is 1 minute. **Table 1** shows type and accuracy of the sensors used in this study.

Table 1. *Properties of the sensors.*

Parameter	Type sensor	Accuracy
Room temperature	SE CSTHR PT1000	± 0.1°C
Supply temperature	SE CSTHK HX	± 0.4°C
Occupancy	Acurity Crosscan Camera	± 5%
Outdoor temperature	Vaisala HMS82	± 0.3°C at 20°C
Wind velocity	Ultrasonic 2D Anemometer	± 0.1 m/s (0-5 m/s)
Wind direction	Ultrasonic 2D Anemometer	± 1°

In this paper, internal temperatures and operation of ventilative cooling are studied during the cooling season in 2017 in the lecture room on the first floor, i.e. from May 22th to September 30th, 2017. As there was no occupancy in July and only limited in August, these months are excluded from the analysis.

Results

Airflow rate

Table 2 presents the results of the tracer gas decay tests for single sided and cross ventilation including the local weather conditions (wind velocity and direction) and the average indoor-outdoor temperature difference during the test. For cross and single-sided ventilation, the 95% confidence interval for ACR is respectively 1.21 to 2.12 and 2.17 to 4.64 h-1.

Table 2. *Measured ACR with tracer gas decay during spring 2017.*

Ventilation mode	ACR (h^{-1})	Wind velocity (m/s)	Wind direc-tion	ΔT (°C)
Cross ventilation	4,18 ± 0,42	1,9	WNW	4,3
Cross ventilation	3,76 ± 0,38	2,1	ESE	1,6
Cross ventilation	3,04 ± 0,30	2,2	ESE	2,4
Single sided	2,05 ± 0,21	2,3	SSW	No data
Single sided	2,00 ± 0,20	2,68	S	No data
Single sided	1,17 ± 0,12	1,45	SSW	5,1
Single sided	1,56 ± 0,16	1,78	S	8,6

Operation of ventilative cooling

Figure 6 presents the ratio of operation time of the windows to the possible total opening hours by night (22h tot 6h) and the ratio of the operation of the IEC to the operation hours of the AHU by day. IEC and night-time ventilation are in use during 66% respectively 45% of the time.

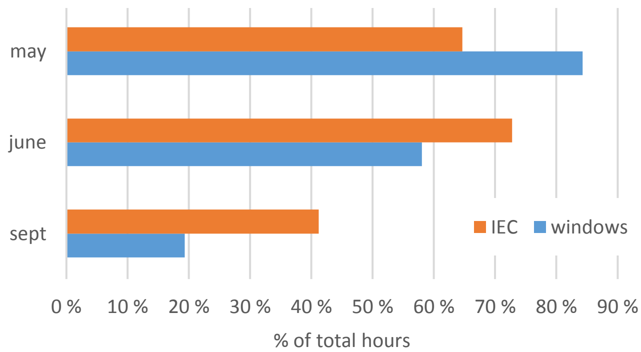

Figure 6. Percentage of hours of operation of windows by night and IEC by day from May to September 2017.

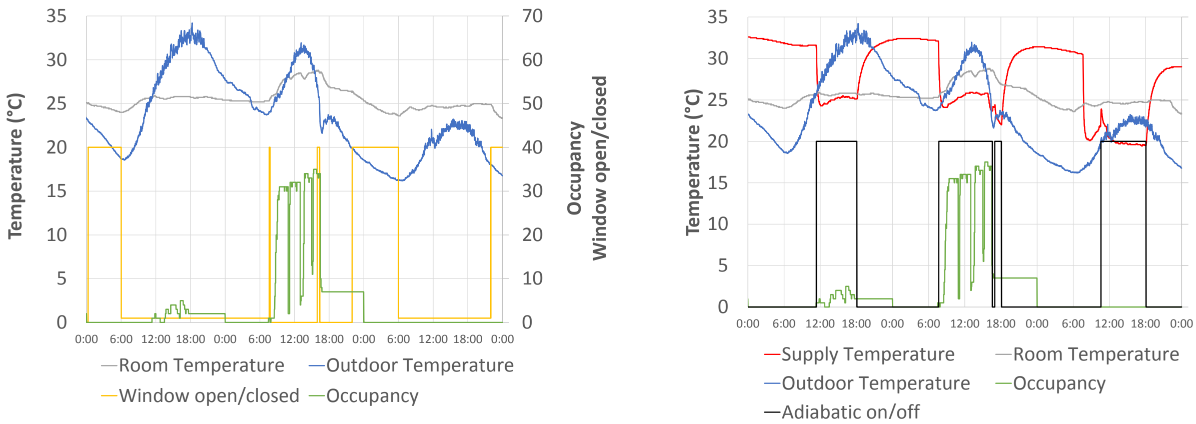

Figure 7. Operation of windows (above) and IEC (below) during an extremely warm period (21-23 June 2017).

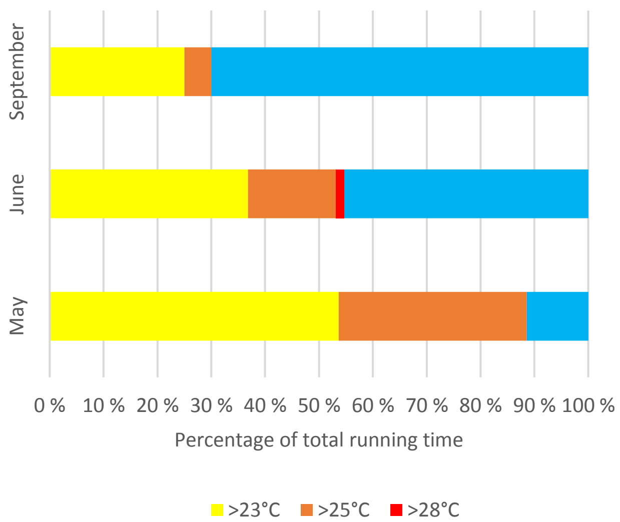

Figure 8. Percentage of hours above threshold values for internal temperatures in lecture room on 1st floor May-September 2017.

Figure 7 shows the operation of the windows for night ventilation respectively IEC during extremely warm days in June 2017. In that period, IEC operates the whole day and can lower the supply temperature significantly compared to the outdoor temperature. Natural night ventilation only operated very short time the second night in between two hot summer days because the requirement that the outdoor temperature has to more than 2°C lower than the room temperature was not fulfilled.

Thermal comfort

Figure 8 presents hourly indoor operative temperature in this lecture room, as a percentage of hours of exceedance per month above 23°C, 25°C and 28°. During operation of the AHU, 5.1% and 0.3% of the hours in 2017 exceeded 25°C respectively 28°C. This means a good thermal comfort according to EN 15251.

Thermal comfort in this lecture rooms is also evaluated as a function of the running mean outdoor temperature as defined by the Dutch adaptive temperature limits indicator (van der Linden et al., 2006) (see **Figure 9**).

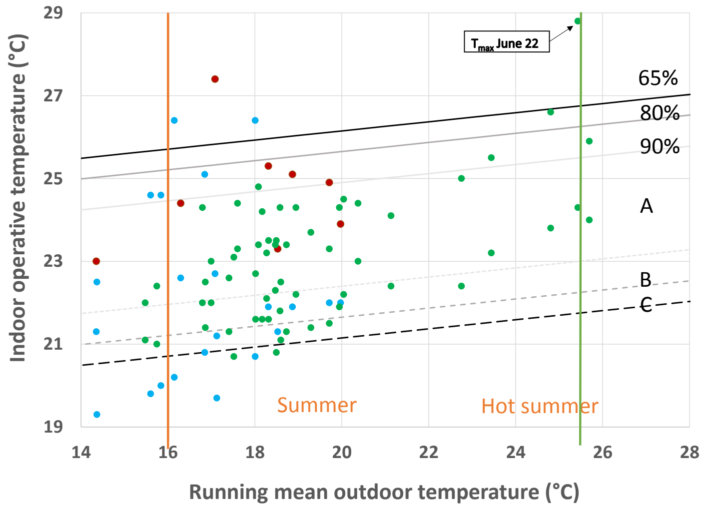

Figure 9. Thermal comfort evaluation according to the Adaptive Temperature Limits Method (van der Linden et al., 2006).

Overall, good thermal comfort is concluded. Only in hot summer and/or periods with high occupancy, high indoor temperatures are monitored. In addition, very low temperatures are noticed in September in the morning.

Conclusions and lessons learned

Thermal comfort and the performances of ventilative cooling in the test lecture rooms of KU Leuven Ghent Technology Campus was monitored during cooling season of 2017.

A good thermal summer comfort was measured in the test lecture rooms. Only during heat waves and/or periods with high occupancy rates, high indoor temperatures were monitored. Both night-time ventilation and indirect evaporative cooling operate very well. IEC can lower the supply temperature by day significantly compared to the outdoor temperature. IEC is in use during more than half of the occupied hours in the cooling season due to high internal heat gains in the lecture rooms.

The ACR of the night-time ventilation is rather low and, in case of cross ventilation, depends a lot on wind direction and velocity. The ACR in these lecture rooms can be increased and made more reliable and stable by adding mechanical exhaust. However, this measure will also increase the fan energy.

The extensive data monitoring system was of great value to detect malfunctions, to improve the control of the building systems and optimize the whole building performance. Monitoring showed e.g. that the windows for night ventilation opened and closed a lot at night during the first weeks. This was due to (1) bad translation of the signal of the rain sensor and (2) peaks in the wind velocity. These parameters are part of the control of the windows. This malfunctioning was discovered and solved by analysing the monitoring results.

Furthermore, attention must be paid to the users. A lot of different teachers give classes in these lecture rooms. Most of them are not used to automated blinds, ventilation and ventilative cooling. They open the door to the corridor and the windows even when it is warm outside and consequently cause a decrease in thermal comfort. It is important to educate and inform the users about the operation of the automated system to come to a comfortable and energy efficient building. ■

References

Andriamamonjy, R., Klein, R. (2015), *A modular, open system for testing ventilation and cooling strategies in extremely low energy lecture rooms*, in 36th AIVC Conference, Madrid, 22-23 September 2015.

Breesch H., Wauman B., Klein R., Versele A. (2016) Design of a new nZEB test school building, *REHVA European HVAC Journal*, 53 (1), pp.17-20.

Decrock, D., Vanvalckenborgh G. (2017). *Evaluation of the cooling potential of natural night ventilation in the test lecture rooms* (in Dutch), M. Sc. Thesis, KU Leuven.

EN ISO 13790 (2008) Energy performance of buildings - Calculation of energy use for space heating and cooling. (Withdrawn and replaced by EN ISO 52016-1:2017 Energy performance of buildings — Energy needs for heating and cooling, internal temperatures and sensible and latent head loads —Part 1: Calculation procedures).

EN ISO 12569 (2001) Thermal insulation in buildings – Determination of air change in buildings – Tracer gas dilution method.

EN 15251 (2007) Indoor environmental input parameters for design and assessment of energy performance of buildings addressing indoor air quality, thermal environment, lighting and acoustics. (Withdrawn and replaced by EN 16798-1:2019 Energy performance of buildings — Part 1: Indoor environmental input parameters for design and assessment of energy performance of buildings addressing indoor air quality, thermal environment, lighting and acoustics — Module M1-6).

Heiselberg, P. (ed.) (2018). *Ventilative Cooling Design Guide*, IEA EBC Annex 62, Aalborg University, Aalborg, Denmark, http://www.iea-ebc.org/Data/publications/EBC_Annex_62_Design_Guide.pdf.

O'Sullivan, P., O'Donnovan, A. (ed.) (2018). *Ventilative Cooling Case Studies*, IEA EBC Annex 62, Aalborg University, Aalborg, Denmark, http://venticool.eu/wp-content/uploads/2016/11/VC-Case-Studies-EBC-Annex-62-May-2018-Final.pdf.

van der Linden, A.C., Boerstra, A.C., Raue, A.K., Kurvers, S.R., de Dear, R. (2006). Adaptive temperature limits: a new guideline in The Netherlands A new approach for the assessment of building performance with respect to thermal indoor climate. *Energy and Buildings*, 38 (1) 8-17.