A design tool for night ventilation

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Dynamic multi-zone energy simulations are required to design and evaluate natural/hybrid night ventilation, but the additional costs are too high, especially for smaller construction projects. That is why Ghent University and consultancy Ingenium designed a simulation tool for ventilation manufacturer Duco Ventilation & Sun Control with which the components of a night ventilation system in an office (building) can be sized and the performance of the system can be evaluated. The tools processes the user input, carries out simulations with Trnsys-Trnflow and shows the performance.

In night ventilation, ventilation will use outside air to cool the building mass that during the day before has stored part of the heat gains. Applying night ventilation reduces the maximum inside temperature and delays the maximum inside temperature to later in the day. Comfort during summer is considerably increased and any cooling installations can be made smaller. That is why night ventilation is garnering quite some attention from clients in Belgium and the Netherlands. Recent projects with night ventilation, especially office buildings, prove this. Architects Stéphane Beel and Xavier De Geyter provided an inspiring example with their design of the University Forum (Ufo for short), a building of Ghent University with offices and an auditorium (**Figure 1**). Outside air enters the offices through open windows and flows back outside via the open stairwell. The new court building in Antwerp by Richard Rogers is another example. The building makes use of a hybrid night ventilation system. In spring and autumn, the ventilation grilles in the outside wall open at night, whilst in summer mechanical ventilation system blows in cold air through floor grates. Building designers who want to incorporate night ventilation in their design have a lot of choices to make. Does natural ventilation suffice or are ventilators required to guarantee the ventilation rate? Which ventilation concept is the best: single-sided ventilation, cross ventilation or stack ventilation? Do the windows have to be opened or will a small grate suffice? Which construction elements must remain thermally accessible? The degree to which designers succeed in coming up with an optimum design largely depends on the design tools used. In large projects, there is enough time and money to carry out advanced simulations. Designers of small buildings, however, have to make do with rules of thumb and conceptual design tools.

They do not always submit a good design and some of them do not even dare to propose night ventilation. That is why Ghent University and consultancy Ingenium designed a simulation tool for Duco Ventilation & Sun Control, a manufacturer of natural ventilation and sunscreen systems, with which the components of a natural/hybrid night ventilation system by this manufacturer can quickly and easily be sized and the performance of the system evaluated. This article describes the possibilities / shortcomings of the existing simple design tools, explains how the new design tool works, and explains by means of an example.

Development

Due to the larger size of building projects and the increasing complexity of construction, integral design has been on the rise since the beginning of the nineteen nineties. External specialists increasingly assisted the architect with the design. Partly as a result of this, sustainable technologies have become more popular. Various research projects have been launched with the aim of promoting natural ventilation as an alternative to mechanical ventilation and mechanical cooling. The European Pascool project and Annex 28 of the IEA about low-energy cooling were the first reference projects and were quickly followed by the European Joule project NatVent and IEA Annex 35 about hybrid ventilation. People who worked on these and other projects developed different types of design tools, varying from simple guidelines to numerical ventilation models. **Table 1** provides an overview of the main simple design tools that have been developed until now.

Graphic tools and spreadsheets

Chartered Institute of Building Services Engineers designed graphs and spreadsheets that helped to size the ventilation openings of wind-driven ventilation and/or ventilation on the basis of the stack effect [1]. Both the graphs and the spreadsheets were however based on explicit comparisons that did not take the interaction between flow paths into account. Another limitation resulted from the assumption that all the resistance along the flow path was situated at the supply and removal. Input parameters were the local wind speed, the estimated difference between the temperature inside and outside, the resistance along the flow path and the difference in height between the ventilation opening and the neutral pressure zone (the height at which the inside and outside pressure are the same). The graphs and spreadsheets showed the relation between the ventilation rate and the surface area of the opening as a function of the difference in temperature inside and outside and/or the wind speed. One of the results

of the NatVent project was the graphic design tool by Van Paassen e.a., that enabled designers to dimension ventilation openings for night ventilation in Dutch buildings (**Figure 2**) [2]. The tool was based on a large number of dynamic simulation results. The simulation model consisted of a three-zone model: two offices with a corridor in the middle. The design tool took the following input parameters into account: two building orientations, three thermal capacities, five levels of internal heat gains, three window surface area to floor surface area ratios, three ventilation strategies, different ventilation opening to floor surface ratios and three settings for night ventilation. Using the tool, designers were able to estimate the necessary surface area of the ventilation openings.
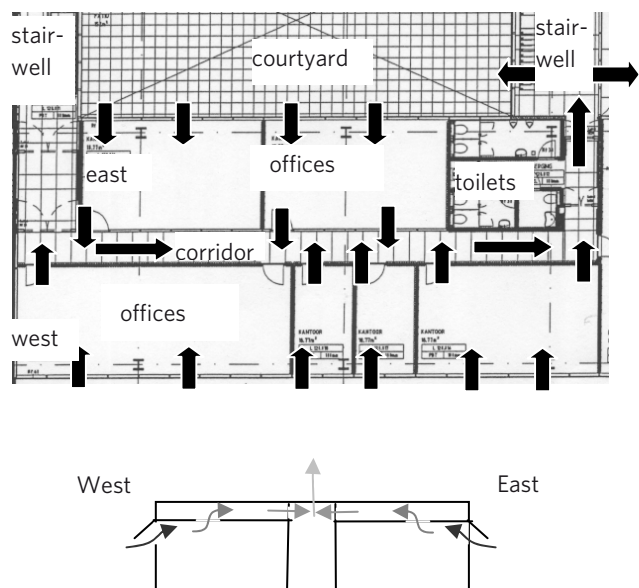

Figure 1. University Forum with natural night ventilation (supply via windows, removal via the stairwell).

Table 1. Overview of design tools for night ventilation

Tool	Tool	Calculation model	Building model	Output
Graphic tools and spreadsheets	CIBSE method	Explicit equations	1 zone	Snapshot
	Graph by Van Paassen ea	Thermal and ventilation model	1 zone	Dimension of ventilation openings
Simulation models	Lesocool	Thermal and ventilation model	Maximum 9 zones (single flow path)	Day profile
	Nitecool	Thermal and ventilation model	1 zone	Week profile
	NatVent	Thermal and ventilation model	1 zone	Year profile
	LoopDA (CONTAM)	Thermal and ventilation model	Multiple zones	Dimensions ventilation openings
	Coolvent	Thermal and ventilation model	Multiple zones	Year profile

Selection Natural Ventilation Cooling System

Figure 2. Graphic design tool by Van Paassen e.a.
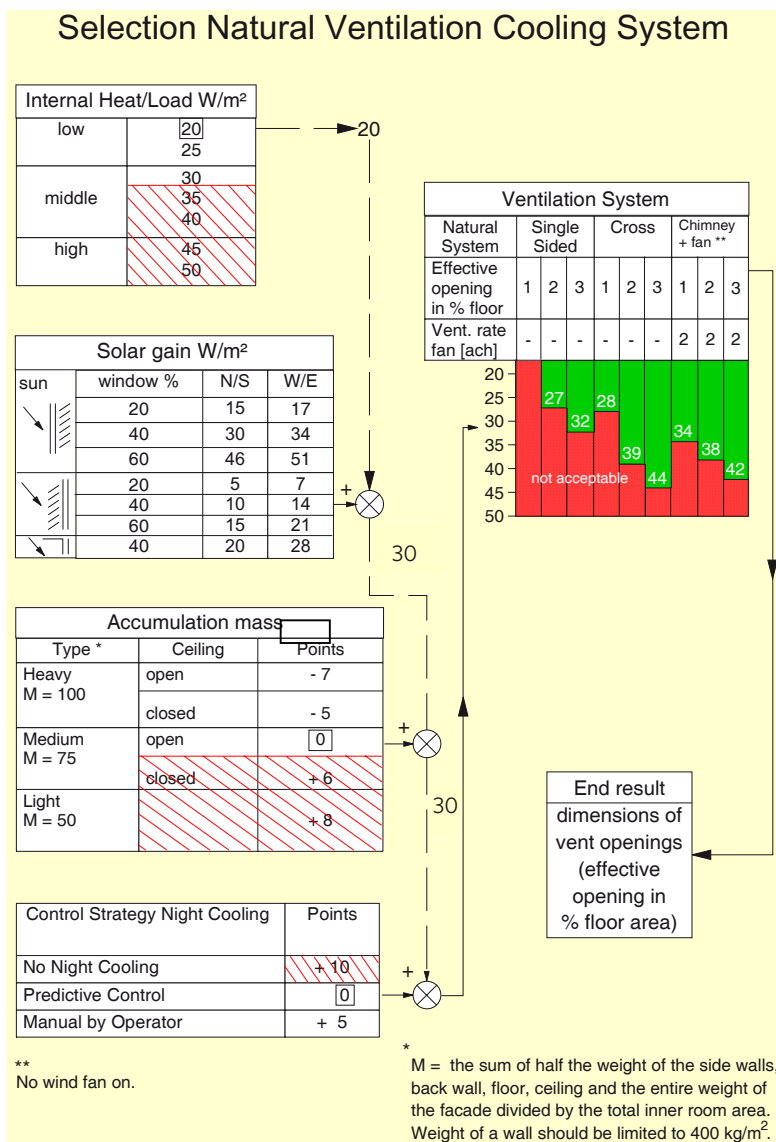
Simulation models

One of the research results of the Pascool project was Lesocool, a simulation tool that made it possible to evaluate the effect of (natural) night ventilation [2].

The calculation model comprised a stationary thermal model combined with a storage model and a ventilation model for a single ventilation flow through a maximum of nine zones. Lesocool users could adapt the following parameters: the type of ventilation (natural or mechanical), the properties of the openings (e.g. position, size, removal coefficient), the setting (on the basis of temperature or time), the thermal mass of the zone (four standard levels), the construction surface areas, the internal heat gains (three standard levels) and the surface area and U-value of the glazing. The tool offered the variation in the ventilation rate, the inside temperature, the average surface temperature and the cooling capacity for a typical day. The UK Department of the Environment sponsored the development of Nitecool [3]. This simulation tool had to enable the designers of British offices to quickly determine the impact of a

number of important parameters on the performance of the night ventilation. The program simulated heat transport in a typical, individual office with a resistance capacity model and air transport with a simple ventilation model. Users could enter the following parameters: site location, building orientation, thermal mass, infiltration rate, glass surface area, internal heat gains, occupancy duration, and sunscreens. In addition, they had a choice of nine cooling system for operation during the day and/or night and three types of setting for the night ventilation system. The results were limited to a week profile of the temperature and the peak capacity / energy consumption for cooling that had been economized. The NatVent tool was developed in the research project of the same name. The thermal calculation model was a first-order system; the ventilation model was a single-zone model that represented an entire building. Users could adapt four categories of input parameters: location, building, ventilation, and windows. Location included the climate and orientation of the building. The building category included the geometrics, the degree of insulation and the airtightness. The ventilation category allowed the size of the openings, the internal heat gains, the ventilation strategy, and the properties of any ventilators to be entered. The windows category comprised the properties of the windows and sunscreens. The result of the tool was the ventilation rate and the inside temperature in summer, winter or during a year. The National Institute of Standards and Technology developed the Loop Design Analysis tool (LoopDA) and integrated it into the multi-zone ventilation model Contam [4].

The accompanying Loop Equation Design Method described the steps required to arrive at a correctly dimensioned ventilation system with the simulation program. The calculation model comprised a stationary heat and mass balance that were calculated successively. Users of the tool had to enter the following parameters: the building's characteristics (such as geometrics, average U-value), the properties of the ventilation system (such as minimum ventilation requirements) and the design preconditions (target inside temperature, wind speed). The tool first provided a rough estimate of the ventilation openings before using the additional preconditions (such as the maximum air speed through the opening) in further calculations with Contam. Coolvent, a multi-zone energy simulation model for natural ventilation in buildings, was developed at the Massachusetts Institute of Technology. It was a user-friendly and robust tool that had an advanced thermal model and ventilation model as its template. In contrast to, for example, LoopDA, it calculated the heat and

mass balance simultaneously. The input parameters were limited to those with the most impact and were divided into two categories: general information and detailed building information. The general information included the ventilation concept, building orientation, user profiles, terrain information, and climate data. The building information comprised the size of the building, the size of the windows and openings, the thermal mass and strategies for opening windows. The result of the tool was a profile of the inside temperature and the ventilation rate during the period studied.

Dynamic multi-zone energy simulation

The above overview shows that most of the existing tools are greatly simplified. Either the results of simulations were moulded into a design tool with a limited number of input parameters, or a greatly simplified calculation model was developed that calculated the heat and air flows. The main reason was the limited calculation power of computers. However, for natural/hybrid night ventilation the driving forces vary over time, which makes the performance of such a system highly uncertain. In addition, the temperature differences and ventilation rates depend on each other. The inside temperature affects the natural ventilation rate and the ventilation rate has an impact on the inside temperature. That is why dynamic multi-zone energy simulation programs that are based on linked thermal and ventilation model are required to properly design natural/hybrid night ventilation and correctly evaluate its performance. However, various obstacles hinder the general use of dynamic multi-zone energy simulation programs. It takes a lot of know-how and time to carry out simulations. The calculation algorithms can become very complex and the user environment is not always user friendly. What's more, a simulation model is determined by a large number of parameters, that all have to be entered. Often it is also difficult to convince parties that the higher initial study costs will quickly be recovered, especially if it concerns smaller projects. If a fast assessment of the performance of natural/hybrid ventilation is required there are two possibilities. A simulation expert can carry out an extensive parameter study to then compile the results in a design graph or table. Or a simple, applied interface for controlling an energy simulation program can be developed. The direct control of a template does have advantages over a derived graph/table. The choice of parameter values is not limited to a number of discrete values but can be any numerical value. This makes practically every combination of parameters possible. Ghent University and Ingenium, in consultation with Duco
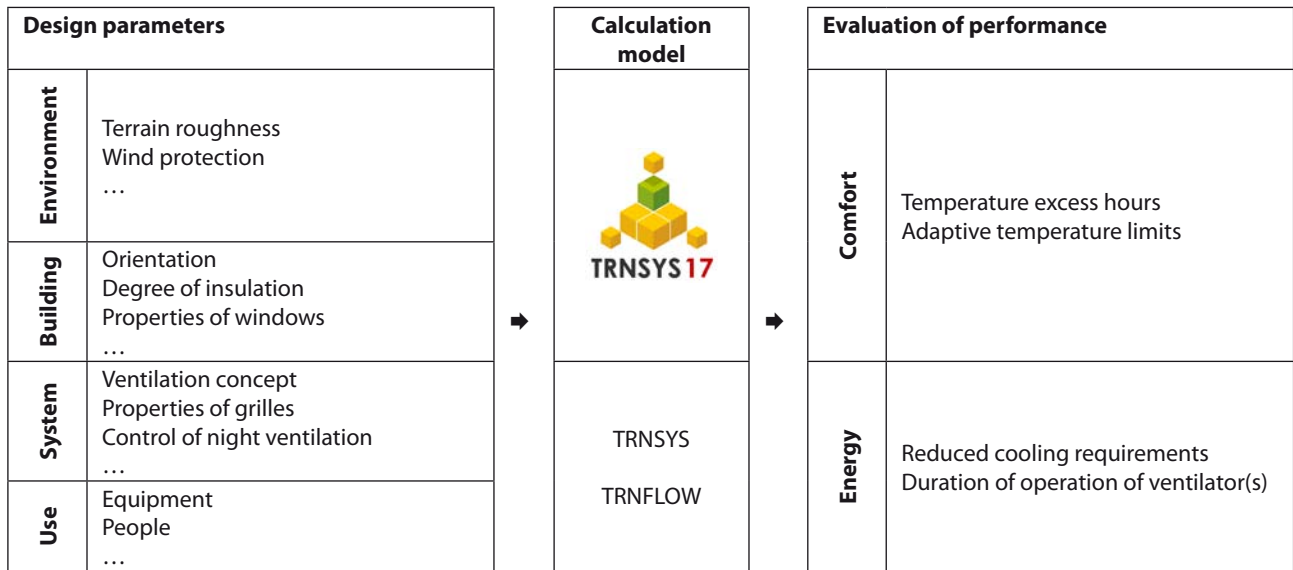
Design parameters		Calculation model	Evaluation of performance	
Environment	Terrain roughness Wind protection …	TRNSYS 17	**Comfort**	Temperature excess hours Adaptive temperature limits
Building	Orientation Degree of insulation Properties of windows …			
System	Ventilation concept Properties of grilles Control of night ventilation …	TRNSYS TRNFLOW	**Energy**	Reduced cooling requirements Duration of operation of ventilator(s)
Use	Equipment People …			

Figure 3. Configuration of the new design tool.

Ventilation & Sun Control, opted to make an interface for an existing commercial simulation program, namely Trnsys-Trnflow [5]. With this tool it was possible to adapt a number of input parameters in order to arrive at a properly predicted performance of the natural/hybrid ventilation system. For example by adapting the type of grate, the intended comfort in summer is achieved. The focus was on office buildings since night ventilation is interesting in this type of building.

Configuration

The design tool processes the data entered by the user, carries out simulations with Trnsys-Trnflow and presents the results of the simulations (**Figure 3**). The environment that the user uses is a spreadsheet, Microsoft Excel. The spreadsheet contains codes in Visual Basic for Applications (VBA) and Visual Basic .NET (VB. NET) that carry out the majority of the actions. Excel actions take care of a small part of processing the user data entered and the results. VBA codes do the rest of the user data input; they also make computer files, set up the simulation environment (such as climate data, user profiles) and process the results. The VB.NET codes provide the complex building model. The input parameters are subdivided into properties of the environment, building properties, system properties and building use. The environment in particular determines the wind pressure on the façades. That is why properties such as the roughness of the terrain (countryside, suburb, city) and the degree of screening (open, half screened and completely screened off) must be determined. However, the shape of the building also has an impact, more in particular the height of the

building and the relationships of the façades. The latter parameters however fall under the building properties. Other building parameters include: orientation of the building (8 orientations), the geometrics of the room(s) (numerical values), the storey the room is on (numerical value), the degree of insulation (5 insulation levels), the air-tightness (numerical value), the thermal capacity (4 levels), the glazing (numerical values for surface area and g value). System properties include: the ventilation concept (single-sided ventilation, cross or stack ventilation in a room or stack ventilation for an office building with three floors that each consist of two offices with a corridor between them), the properties of the air supply grilles and the extraction ventilator for hygienic ventilation (inc. ventilation rate and heights of the supply grate and extraction ventilator), the properties of the night ventilation grilles and any extraction ventilator (inc. surface area, K factor and height of the supply grate) and the control of the night ventilation system and finally the control of the sunscreens. The use of the building is determined by the internal heat burden (numerical values) and the possibility of extra ventilation during the day. To evaluate the summer comfort, the temperature overshoots and the adaptive temperature limits are selected. In accordance with the temperature limit excess method, the inside temperature may not exceed 25.5°C and 28°C for more than 100 h and 20 h of the occupancy period respectively. The method of the adaptive temperature limits states that a certain ceiling, that varies in function of the outside temperature, may not be exceeded for more than 3% of the occupancy period (in this case in accordance with class B). The viability of the night ventilation system

Figure 4. Supply of fresh air through skylights housed in casing.

is assessed on the basis of the cooling requirement economized and the operating period of the ventilation system. The cooling requirement economized follows from two simulations: one with night ventilation and mechanical cooling and another with only mechanical cooling. The processing time of a ventilation system supported by an extraction ventilator is derived from a simulation with only night ventilation.

Application

Televic, a producer of highly technological communication systems, wanted night ventilation to limit the cooling burden in its new office. The building was designed in such a way that the outside air was brought in through skylights and inside air was removed by natural or mechanical means (**Figure 4**). Televic engaged Duco to dimension and detail various the components. They used the tool to simulate two situations in a typical office space with cross ventilation. In the first situation, night ventilation was only natural. The predetermined number of air exchanges per hour was 7. In the second situation, there was an additional extraction ventilator with a capacity of 2 air exchanges per hour. **Figure 5** shows the parameter input of the ventilation in the tool. Both the natural and the mechanically supported night ventilation yielded a considerable reduction in the cooling requirement: up to 7.5 kWh/m². After all, the building had sufficient thermal mass and the sun-loaded façades had sunscreens. **Figure 6** shows the

Figure 5. Illustration of the input ventilation in the tool.

COMFORT		
TE-METHOD		
boundary	**h**	**%**
> 25.5 °C	313	13%
> 28 °C	19	1%
ATG-method		
class	**h**	**%**
> A	358	11%
> B	84	3%
> C	12	0%

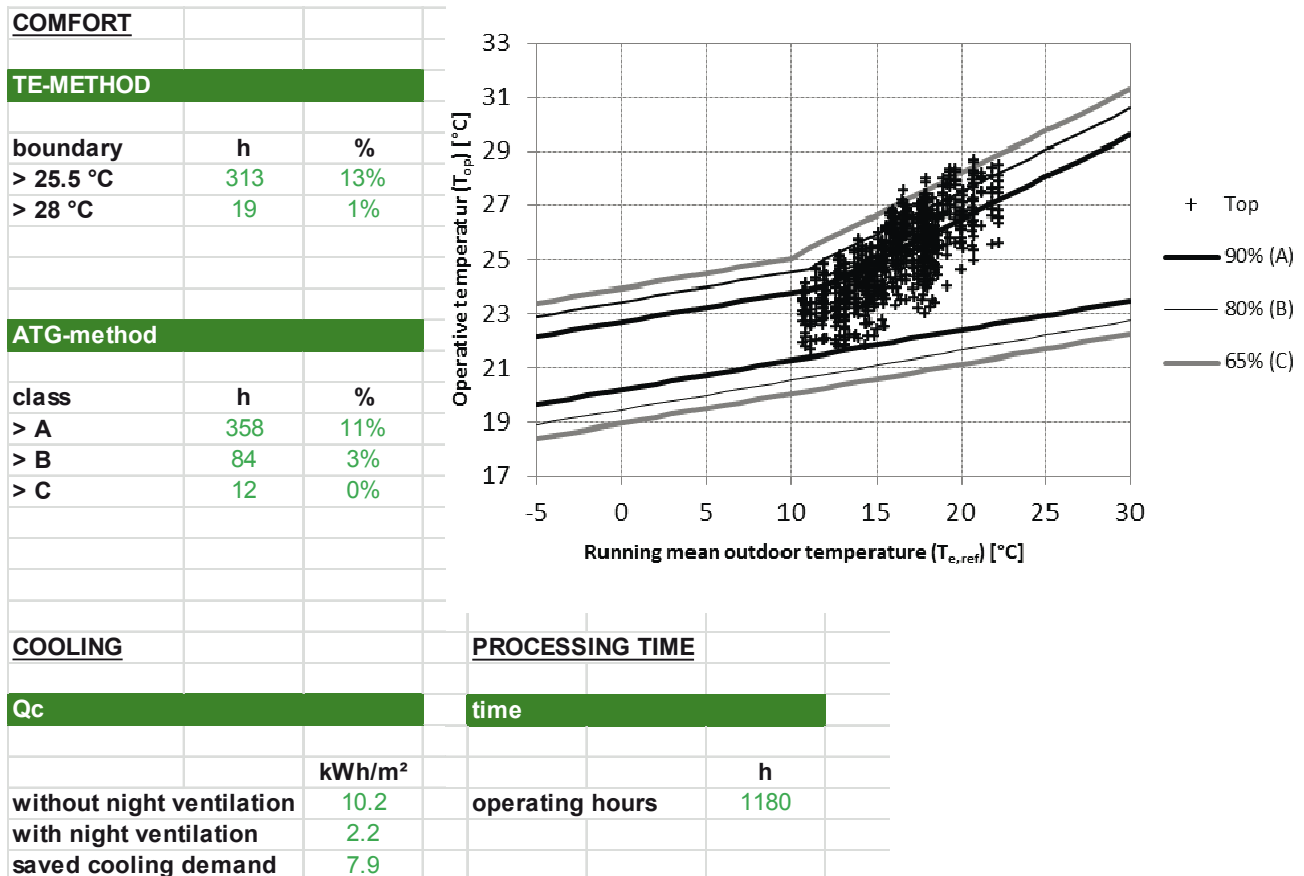| COOLING		PROCESSING TIME	
Qc		**time**	
	kWh/m²		**h**
without night ventilation	10.2	operating hours	1180
with night ventilation	2.2		
saved cooling demand	7.9		

Figure 6. Result of the tool

result of the situation with only natural night ventilation. Televic opted for a hybrid night ventilation system. Generally, the outside flowed into the offices through façade grilles to then move on through the (open) doors to the central stairwell. In the stairwell skylights and/or ventilators removed the air.

Conclusion

Night ventilation is a technique with a lot of potential, especially in offices. However, the design is generally so complex that basic know-how or experience is not adequate to evaluate design measures (such as the impact of dimensioning grilles). In these cases, simulations may help, as long as they can be used efficiently. The tool developed by Ghent University and consultancy Ingenium for Duco Ventilation & Sun Control permits to quickly and simply calculate a number of design variants of a night ventilation system in an office (space) using the Trnsys-Trnflow template. This tool has already successfully been used a number of times. ■

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