EBC

Energy in Buildings and
Communities Programme

Ventilative Cooling potential tool

User guide

Version 1.0

IEA – EBC Programme – Annex 62 Ventilative Cooling

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Contents

1. Introduction

The new initiatives and regulation towards low energy buildings forces designers to exploit the cooling potential of the climate to reduce the overheating occurrence and to improve thermal comfort indoors. Climate analysis is particularly useful at early design stages to support decision making towards cost-effective ventilative cooling solutions. The first step to design ventilative cooling is to analyse the climate potential, in other words the natural forces that drives natural ventilation (outdoor temperature, humidity and wind velocities and direction).
As buildings with different use patterns, envelope characteristics and internal loads level react differently to the external climate condition, the climate analysis cannot abstract from building characteristics and use.
The ventilative cooling potential tool (VC tool) was developed within International Energy Agency (IEA) Annex 62 project with the aim to assess the potential effectiveness of ventilative cooling strategies by taking into account also building envelope thermal properties, occupancy patterns, internal gains and ventilation needs.

2. Theory

The ventilative cooling potential tool refers to the method proposed by (Emmerich J.S., 2001) further developed within the IEA Annex 62 activities.
This method assumes that the heating balance point temperature (T_{o-hbp}) establishes the outdoor air temperature below which heating must be provided to maintain indoor air temperatures at a defined internal heating set point temperature (T_{i-hsp}).
Therefore, when outdoor dry bulb temperature (T_{o-db}) exceeds the heating balance point temperature, direct ventilation is considered useful to maintain indoor conditions within the comfort zone. At or below the heating balance point temperature, ventilative cooling is no longer useful but heat recovery ventilation should be used to meet minimum air change rates for indoor air quality control and reduce heat losses.
The heating balance point temperature (T_{o-hbp}) can be calculated using Equation (*1*.

$$T_{o-hbp} = T_{i-hsp} - \frac{q_i''}{\dot{m}_{min} c_P + \sum hA} \tag{1}$$

where

q_i''	= total internal gains [W/m²]
c_p	= air capacity [J/kg-K]
$\dot{m}_{min}$	= minimum required mass flow rate [kg/s]
$\sum UA$	= envelope heat exchange [W/K]
U	= average U-value of the envelope [W/m²K]

The minimum required ventilation rate refers to indoor air quality standards (i.e. EN 15251:2007).
The equation derives from the energy balance of a well-mixed single-zone delimited by heat transfer surfaces and relies on the assumption that the accumulation term of the energy balance can be negligible. It is a reasonable assumption if either the thermal mass of the zone is negligibly small or the indoor temperature is regulated to be relatively constant. Under these conditions, the energy balance of the zone is steady state and can provide an approximate mean to characterize the ventilative cooling potential of a climate.

The comfort zone is determined according to the adaptive thermal comfort model proposed in the EN 15251:2007 standard. The upper and lower temperature limits of the comfort zone are calculated using Equations (2 and (3.

$$T_{i-max} = 0.33 \cdot T_{rm} + 18.8 + K \tag{2}$$

$$T_{i-min} = 0.33 \cdot T_{rm} + 18.8 - K \tag{3}$$

where

T_{i-max}	= upper operative temperature limit of the comfort zone [°C]
T_{i-min}	= lower operative temperature limit of the comfort zone [°C]
T_{rm}	= outdoor running mean temperature [°C]
K	= constant depending on required comfort Category: $K = 2$ if comfort cat. I, $K = 3$ if comfort cat. II, $K = 4$ if comfort cat. III.

Below an outdoor running mean temperature of 10°C, the upper temperature limit is set as the upper temperature limit for heating recommended by EN 15251:2007. Below an outdoor running mean temperature of 15°C, the lower temperature limit is set as the lower temperature limit for heating recommended by EN 15251:2007.

2.1 Evaluation criteria

The analysis is based on a single-zone thermal model applied to user-input climatic data on hourly basis. For each hour of the annual climatic record of the given location, an algorithm splits the total number of hours when the building is occupied into the following groups:

1) **Ventilative Cooling mode [0]**: when the outdoor temperature is below the heating balance point temperature no ventilative cooling is required since heating is needed;

   If $T_{o-db} < T_{o-hbp}$ then $\dot{m} = 0$

2) **Ventilative Cooling mode [1]**: Direct ventilation with airflow rate maintained at the minimum required for indoor air quality can potentially ensure comfort when the outdoor temperature exceeds the balance point temperature, yet it falls below the lower temperature limit of the comfort zone;

   If $T_{o-hbp} \leq T_{o-db} < T_{o-hbp} + (T_{i-max} - T_{i-min})$ then $\dot{m} = \dot{m}_{min}$

3) **Ventilative Cooling mode [2]**: Direct ventilative cooling with increased airflow rate can potentially ensure comfort when the outdoor temperature is within the range of comfort zone temperatures.

   If $T_{o-hbp} + (T_{i-max} - T_{i-min}) \leq T_{o-db} \leq T_{i-max} - \Delta T_{crit}$ then $\dot{m} = \dot{m}_{cool}$

   The airflow rate required to maintain the indoor air temperature within the comfort zone temperature ranges is computed as in Equation (4. Direct ventilative cooling is not considered useful if the temperature difference between indoor and outdoor is below a ΔT_{crit} of 3 K;

$$\dot{m}_{cool} = \frac{q_i}{c_p(T_{i-max} - T_{o-db})} \tag{4}$$

4) **Ventilative Cooling mode [3]**: direct evaporative cooling (DEC) can potentially ensure comfort even if direct ventilation alone is not useful because the outdoor temperature exceeds the upper temperature limit. The evaporative cooling potential is considered when the expected temperature of the treated air is within the upper operative temperature limit minus 3 K. The expected outlet temperature of a DEC system is calculated according to (Chiesa & Grosso, 2015) and (Givoni, 1994). Moreover, an indirect limitation on DEC potential to prevent too high relative humidity values is also included fixing a maximum reference for the outdoor wet bulb temperature – see (Givoni, 1994) for residential buildings and (Chiesa, Huberman, Pearlmutter, & Grosso, 2016) for office ones.

   If $T_{o-db} > T_{i-max} - \Delta T_{crit}$ and $T_{DEC} < T_{i-max} - \Delta T_{crit}$ then $\dot{m} = \dot{m}_{cool}$
   Where
   T_{DEC} = expected outlet temperature of a DEC treated airflow [°C]

5) **Ventilative Cooling mode [4]**: Direct ventilative cooling is not useful when the outdoor temperature exceeds the upper temperature limit of the comfort zone and furthermore this limit is also overtaken from the expected DEC outlet temperature;
   If $T_{o-db} > T_{i-max} - \Delta T_{crit}$ then $\dot{m} = 0$

If direct ventilative cooling is not useful for more than an hour during the occupied time, the night-time climatic cooling potential (NCP) over the following night is evaluated using the method described in (Artmann N., 2007). Night-time ventilation is calculated by assuming that the thermal capacity of the building mass is sufficiently high and therefore all the exceeding internal gains can be stored in the building mass. Night-time cooling potential (NCP) over the following night is evaluated as the internal gains that may be offset for a nominal unit night-time air change rate have been computed as Equation 5.

$$NCP = \frac{H\rho c_P(T_{i-csp\_night} - T_{o-db})}{3600} \quad [\mathrm{W/m^2\text{-}ach}] \tag{5}$$

where
H = floor height [m]
ρ = air density [kg/m³]
T_{i-csp_night} = temperature cooling set point at night [°C]

The excel file also calculates the required ventilation rates need to cool the building during occupied hours, the monthly average temperature swing between day and night and the monthly average global horizontal radiation.

3. Input data

The tool requires basic information about a typical room of the building, the building use and the climate. Figure 1 reports the tool GUI with input and outputs visualization.

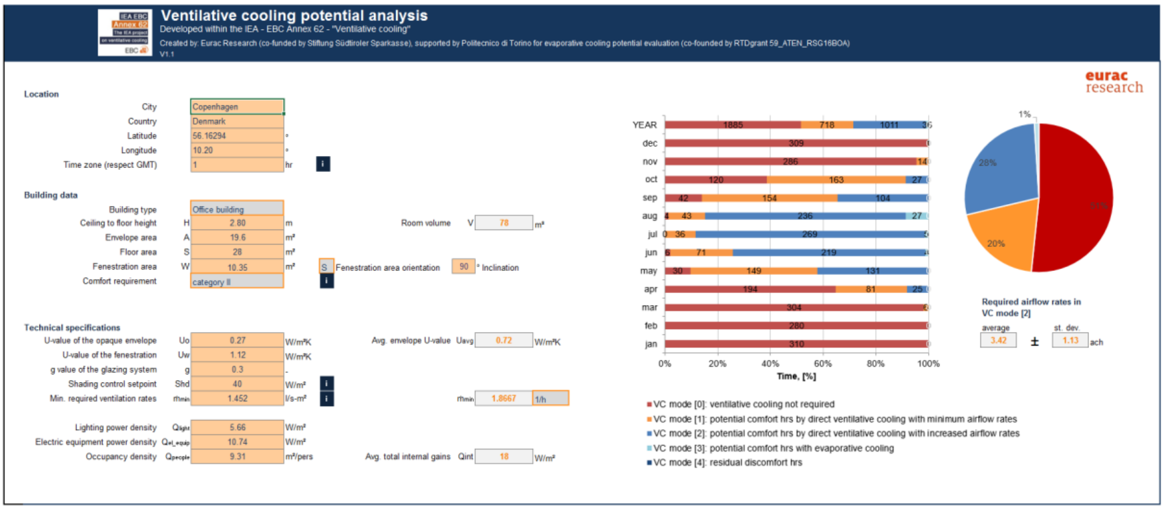

Figure 1. Tool GUI with input data and output visualization.

Spreadsheet cells are formatted according to the following rules:

	input value about the building
	input value about weather data*
calc	cells used for calculation (do not modify them)
output	output data

*the grey cells in the weather data input file refer to not mandatory data (i.e. wet bulb temperature can be also calculated by the tool depending on dew point and relative humidity) or not used data (i.e. wind speed and direction are not used in the calculations but they would be needed for future developments).

3.1 Weather data

Annual record of climatic data is user-input on hourly time steps by copy-paste the weather data from the weather file to the respective columns in the "Weather data" sheet. The weather data should be representative of the typical meteorological year for the given location. Available weather data sources could be found at:

- Meteonorm software: http://www.meteonorm.com/
- EnergyPlus website: https://energyplus.net/weather
- NOAA website: https://www.ncdc.noaa.gov/cdo-web/

The climatic data used on this tool version are the dry bulb temperature, dew point temperature, relative humidity, wet bulb temperature (in case there is no input, wet bulb temperature is derived from dew point temperature and relative humidity), the extra-terrestrial horizontal radiation and the global horizontal solar radiation.
The tool calculates the global radiation incident on the specified tilted surface using the isotropic model (Liu B.Y.H., 1960).

3.2 Building data

The user is required to input basic internal geometry data of a reference room as well as the type of the building and the comfort category. Table 1 describes in detail the building data required.

Table 1. Building data description.

Input name		**Description**
Building type		The tool includes a database of standard load profiles of occupancy, lighting and electric equipment for different building typologies, which are included in the new standard on energy performance of buildings (PrEN 16798-1, 2016-02-07 under approval). According to the selected building type, the tool sets automatically the typical corresponding occupied time and load profiles on hourly basis due to occupancy, lighting and electric equipment.
Ceiling to floor height	H	The net room height. The tool calculates the air volume of the room as V = H * S.
Envelope area	A	The sum of walls, windows, ceiling and floor area with outdoor boundary conditions. This area, multiplied by the average thermal transmittance, is used to estimate the transmission losses. The tool simplifies building heat losses calculation by considering a total envelope area and an average U value and outdoor temperature from weather data.
Floor area	S	The net floor area of the room. The tool calculates the air volume of the room as V = H * S.
Fenestration area	W	The glazing area used for the estimation of solar gains. Fenestration area orientation needs to be selected from the drop down menu. Fenestration area inclination refers to the angle between horizontal and the glazing outward normal (0° means horizontal, 90° means vertical).
Comfort requirement		Comfort requirements refer to the comfort categories defined by the EN 15251:2007 standard. Recommended input values given for each of the different comfort categories are included in the tool and automatically selected.

3.3 Technical specifications

Various thermal and technical properties specifications about the envelope features are required to determine transmission losses, ventilation losses, as wells as internal and solar gains. Table 2 describes in detail the technical specifications required.

The tool includes a database of standard load profiles of occupancy, lighting and electric equipment for different building typologies, which are included in the new standard on energy performance of buildings (PrEN 16798-1, 2016-02-07 under approval). According to the selected building type, the tool sets automatically the typical corresponding occupied time and load profiles on hourly basis due to occupancy, lighting and electric equipment. Internal gains are calculated according to the lighting and electric equipment power density and the occupancy density input by the user in terms of average number of people per square meters (person/m^2). Thanks to this input, users can inquire for ventilative cooling potential in case of different levels of internal gains (i.e. what’s the ventilative cooling potential of a retail building I am designing/retrofitting in case of LED lamps installation instead of less efficient lamps?).

Table 2. Technical specifications description.

Input name		Description
U-value of the opaque envelope	U_o	Average thermal transmittance of the opaque surfaces (wall, roof, floor) with outdoor boundary conditions. The tool simplifies building heat losses calculation by considering a total envelope area and an average U value and outdoor temperature from weather data. If the reference room is located at ground floor, this U-value shall take into account of the different temperature boundary conditions.
U-value of the fenestration	U_w	Thermal transmittance of the window (or average thermal transmittance of windows if the room has more than one window), considering both glazing system and frame.
g value of the glazing system	g	Solar energy transmittance of the glazing system
Shading control setpoint	Shd	Shading is on if the specific beam plus diffuse solar radiation incident on the window exceeds this setpoint value (generally it is between 40 and 150 W/m²). If there are no shadings this value shall be greater than the maximum global solar radiation over the annual record of climatic data. If there are fixed shading, this value shall be set to 0.
Min. required ventilation rates	$\dot{m}_{min}$	Minimum required air change rates (l/s-m^2) calculated according to IAQ standards (EN 15251:2007, ASHRAE 62.1) or design requirements determine the ventilation losses within the energy balance of the reference room.
Lighting power density	Q_{light}	The maximum lighting level per floor area. Internal gains due to lighting are calculated by multiplying the lighting power by the pre-defined load profiles.
Electric equipment power density	Q_{el_equip}	The maximum electric equipment level per floor area. Internal gains due to electric equipment are calculated by multiplying the lighting power by the pre-defined load profiles.
Occupancy density	Q_{people}	The maximum floor area per person. Internal gains due to people are calculated by multiplying the maximum number of person by the pre-defined occupancy profiles.

4. Output data

The VC tool calculates the following performance indicators:

- the percentage of time within each month when the building is occupied and:
  - ventilative cooling is not required (VC mode [0]) according to the evaluation criteria described in par. 2.1;

- direct ventilative cooling with airflow rate maintained at the minimum is required (VC mode [1]) according to the evaluation criteria described in par. 2.1;
- direct ventilative cooling with increased airflow rate is required (VC mode [2]) according to the evaluation criteria described in par. 2.1;
- direct evaporative cooling is required (VC mode [3]) according to the evaluation criteria described in par. 2.1;
- direct ventilative cooling is not useful (VC mode [4]) according to the evaluation criteria described in par. 2.1;

- the night-time cooling potential over the night following the days when direct ventilative cooling is not useful (VC mode [4]) for at least an hour;

- the required ventilation rates (average and standard deviation) to cool the building during occupied hours when direct ventilative cooling with increased airflow rate is required (VC mode [2]);

- the night-time Cooling Degree (CD);

- the monthly average temperature swing between day and night;

- the monthly average global horizontal radiation.

5. Example 1: office building in Copenhagen

The case study used as example is an office room located in the Aarhus municipality building in Denmark.

5.1 Input data

The reference office is 3.99 m x width x 7 m large x 2.8 m height (volume 78 m³) and is occupied by three persons. Lighting and electric equipment power density amounts at 5.7 W/m² and 10.7 W/m² respectively.
The room has only one external wall (facing south) with 53% Glass to Wall Ratio (GWR). Considering the external wall (U_{wall} = 0.27 W/m²K) and window constructions (U_{window} = 1.12 W/m²K) and assuming adiabatic conditions for the other envelope components, the average U-value of the external walls is 0.72 W/m²K.
The examined required comfort level is category II (new or renovated buildings). According to the EN 15251:2007 standard, the minimum required air change rates to assure an indoor air quality within category II are 1.452 l/s-m² (1.9 h^{-1}).
The weather file used for the analysis refers to the city of Copenhagen and derives from the International Weather for Energy Calculations (IWEC) database (ASHRAE, 2001). The climate of Denmark is temperate with small differences from city to city.

5.2 Output data

The graph in Figure 2 reports the ventilative cooling mode distribution in terms of the percentage of time when the building is occupied.
Direct ventilative cooling is useful for more than 65% of the time during the period May - September.

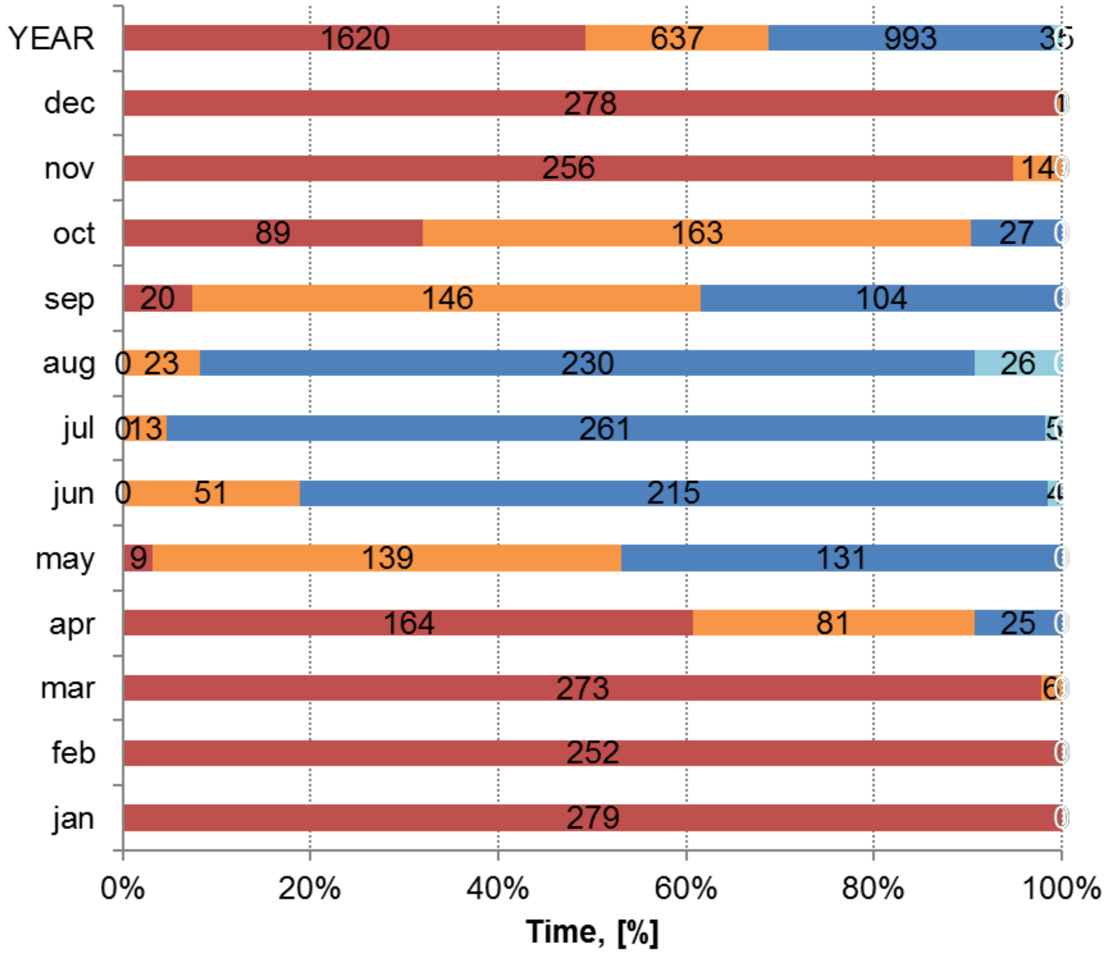

Figure 2. Tool output: ventilative cooling mode distribution in terms of the percentage of time when the building is occupied. Data refer to example 1: office building in Copenhagen.

Table 3. Required ventilation rates (average and standard deviation over each month) to cool the building during occupied hours when direct ventilative cooling with increased airflow rate is required (VC mode [2]). Data refer to example 1: office building in Copenhagen.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Average airflow rate	-	-	-	2.91	3.22	3.53	3.69	3.58	2.85	2.68	-	-
Standard deviation	-	-	-	0.37	0.76	1.11	1.22	1.38	0.33	0.21	-	-
Nr of hours when VC mode [2] is on	0	0	0	25	131	215	261	230	104	27	0	0

ventilative cooling mode distribution in terms of the percentage of time when the building is occupied. Data refer to example 1: office building in Copenhagen.

Table 3 reports the required ventilation rates (average and standard deviation over each month) to cool the building during occupied hours when direct ventilative cooling with increased airflow rate is required (VC mode [2]). These statistics provide design guidance for preliminary considerations about the ventilation system and the control strategy. For example, according to the results for Copenhagen, an average airflow rate of 3.58 ± 1.38 h^{-1} is expected to assure that indoor temperatures are within the comfort zone during August for more than 90% of the time. Furthermore, by decreasing the solar and internal loads level,

the airflow rate required to provide ventilative cooling would decrease as well and therefore the passive cooling of the building might be possible or more effective using commonly available ventilation strategies.
During wintertime, outdoor temperatures are too cold and a direct ventilative cooling strategy would cause higher heating demand and/or draught problems due to too low indoor temperatures.
Direct ventilative cooling is not useful due to too high outdoor temperature for only 2%, 1% and 9% of the time in June, July and August respectively. In these cases, direct evaporative cooling would be effective. Furthermore, the Night-time Cooling Potential is around 8 $W/m^2\text{-}h^{-1}$, which means that an airflow of one air change per hour can offset 8 W/m^2 of internal gains produced during the previous day. The average monthly diurnal temperature swing is around 3K during summer.

6. Example 2: apartment building in Madrid

The case study used as example is a living room of an apartment building located in Madrid, Spain.

6.1 Input data

The reference room is 3.99 m x width x 7 m large x 2.7 m height (volume 75 m^3) and is occupied by three persons. Lighting and electric equipment power density amounts at 2.86 W/m^2 and 3.58 W/m^2 respectively.
The room has only one external wall (facing south) with 40% Glass to Wall Ratio (GWR). Considering the external wall (U_{wall} = 0.27 W/m^2K) and window constructions (U_{window} = 1.12 W/m^2K) and assuming adiabatic conditions for the other envelope components, the average U-value of the external walls is 0.72 W/m^2K.
The examined required comfort level is category II (new or renovated buildings). According to the EN 15251:2007 standard, the minimum required air change rates to assure an indoor air quality within category II are 1 $l/s\text{-}m^2$ (1.3 h^{-1}).
The weather file used for the analysis refers to the city of Madrid and derives from the International Weather for Energy Calculations (IWEC) database (ASHRAE, 2001).

6.2 Output data

The graph in Figure 3 reports the ventilative cooling mode distribution in terms of the percentage of time when the building is occupied.
Direct ventilative cooling is useful for up to 57% of the time during the whole year. Direct evaporative cooling is useful for up to 14% of the time, mainly occurring during summertime when outdoor temperatures are too hot for direct ventilative cooling.
Table 4 reports the required ventilation rates (average and standard deviation over each month) to cool the building during occupied hours when direct ventilative cooling with increased airflow rate is required (VC mode [2]).
During wintertime, outdoor temperatures are too cold and a direct ventilative cooling strategy would cause higher heating demand and/or draught problems due to too low indoor temperatures.
Neither direct ventilative cooling nor direct evaporative cooling are useful due to too high outdoor temperature for 15% of the time in July and August respectively. In these cases, the tool outputs a graph (Figure 4) with the Night-time Cooling Potential. The graph shows for each month, the internal heat gains that can be offset for a nominal unit night-time ventilation. In this case the Night-time Cooling Potential is around 8 $W/m^2\text{-}h^{-1}$, which means that an airflow of one air change per hour can offset 8 W/m^2 of internal gains produced

during the previous day. The average monthly diurnal temperature swing is around 5K during summer.

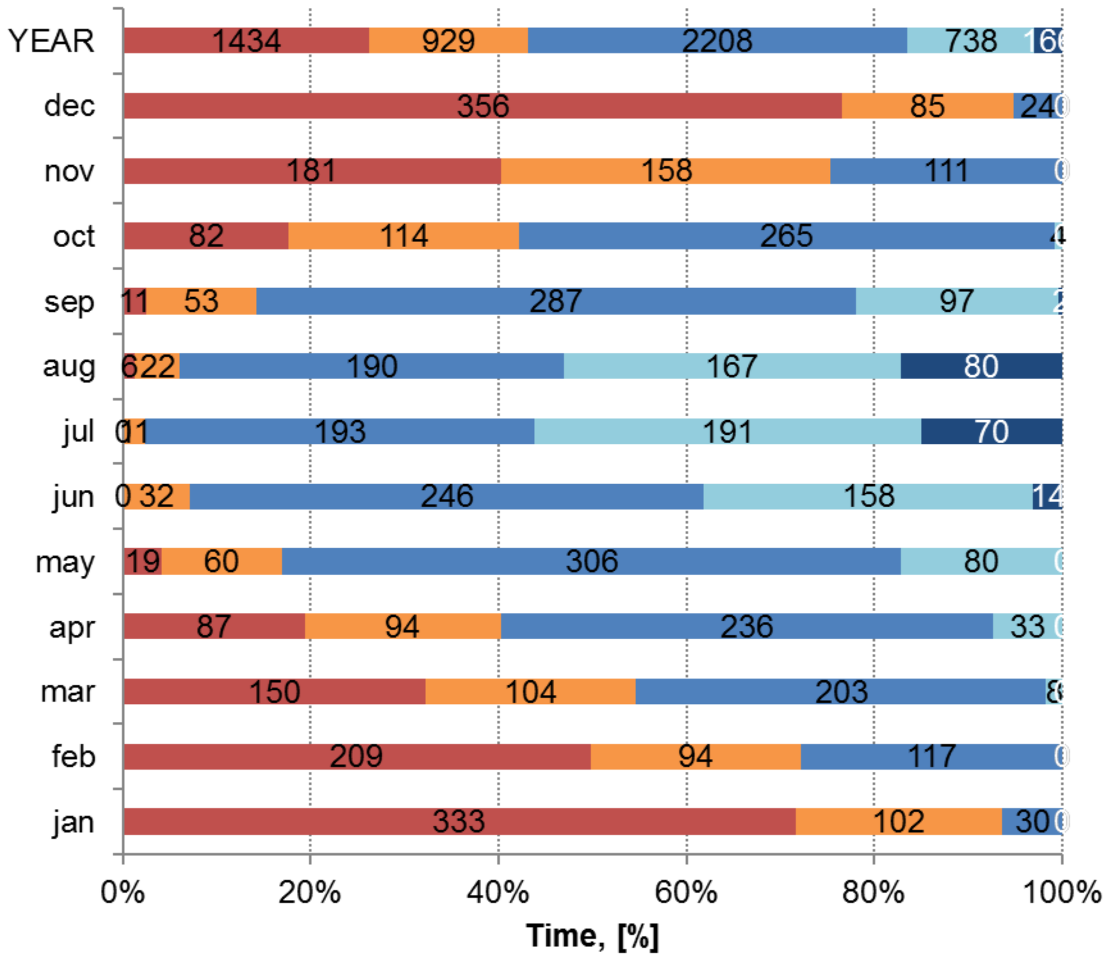

Figure 3. Tool output: ventilative cooling mode distribution in terms of the percentage of time when the building is occupied. Data refer to example 1: apartment building in Madrid.

Table 4. Required ventilation rates (average and standard deviation over each month) to cool the building during occupied hours when direct ventilative cooling with increased airflow rate is required (VC mode [2]). Data refer to example 1: apartment building in Madrid.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Average airflow rate	2.20	2.38	3.00	3.23	3.90	4.16	3.64	3.50	3.94	3.30	2.69	2.05
Standard deviation	0.29	0.51	1.15	1.23	1.82	2.25	2.21	1.80	2.08	1.34	0.79	0.21
Nr of hours when VC mode [2] is on	30	117	203	236	306	246	193	190	287	265	111	24

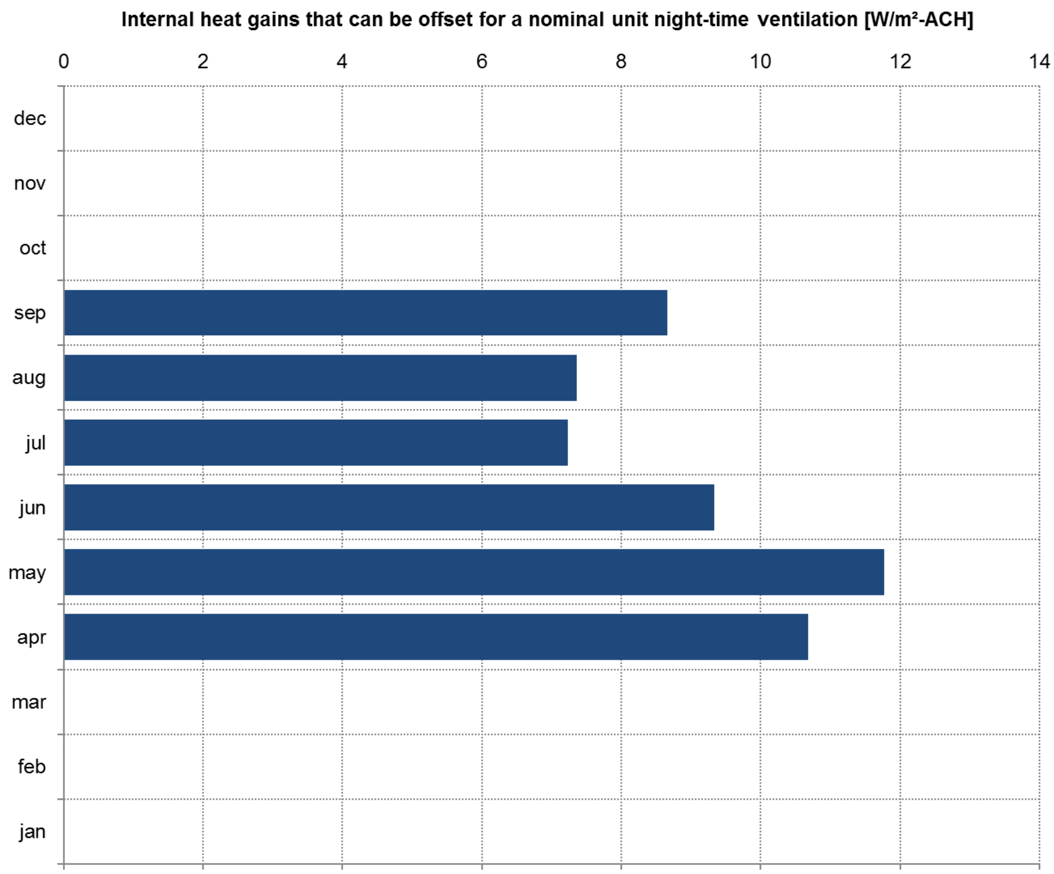

Figure 4. Internal gains that can be offset for a nominal unit night-time ventilation in Madrid.

7. Conclusion

The tool analyses the potential of ventilative cooling by taking into account not only climate conditions, but also building envelope thermal properties, internal gains and ventilation needs.

The analysis is based on a single-zone thermal model applied to user-input climatic (hourly) basis and thermal data. For each hour of the annual climatic record of the given location, an algorithm identifies over the occupied time the number of hours when ventilative cooling is useful and estimates the airflow rates needed to prevent building overheating.

The tool is particularly suitable for early design phases, as it requires only basic information about a typical room of the building, the building use and an annual climatic record.

Furthermore, the tool provide building designers with useful information about the level of ventilation rates needed to offset given rates of internal heat gains.

Previous research works (Belleri A. P. T., 2015) (Belleri A. A. M., 2016) compared the ventilative cooling potential tool outputs with the predictions of a building energy simulation model of a reference room in two different climates (Rome and Copenhagen) and highlighted the following aspects:

- the outputs are useful to compare the ventilative cooling potential in different climates for different building typologies;
- the outputs also support the decision making by selecting the most efficient ventilative cooling strategy and by providing rough estimation of the airflow rates

needed to cool down the building in relation to internal gains, comfort requirements and envelope characteristics;

- the tool enables also to analyze the effect of other energy efficiency measures, like internal gains reduction, solar gains control and envelope performance, on ventilative cooling effectiveness.

8. References

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