EVALUATION TOOL OF CLIMATE POTENTIAL FOR VENTILATIVE COOLING

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ABSTRACT

The new initiatives and regulations towards nearly zero 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 passive cooling solution e.g. ventilative cooling. As buildings with different use patterns, envelope characteristics and internal loads level do not follow equally the external climate condition, the climate analysis cannot abstract from building characteristics and use.

Within IEA Annex 62 project, national experts are working on the development of a climate evaluation tool, which aims at assessing the potential of ventilative cooling by taking into account 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 data on hourly basis. The tool identifies the percentage of hours when natural ventilation can be exploited to assure minimum air change rates required by state of the art research, standards and regulations and the percentage of hours when direct ventilative cooling is useful to reduce overheating risk and improve thermal comfort. The tool also assesses the night cooling potential and highlights other useful climate performance indicators such as the day-night temperature swing.

Furthermore, the analysis method has also been devised to provide building designers with useful information about the level of ventilation rates needed to offset given rates of internal heat gain.

The paper also presents several analysis performed on a reference room in a case study (Aarhus town hall office in Denmark) in order to validate the analysis method development. Specifically we analysed the influence of using dynamic loads, building thermal mass and ventilation control in the heat transfer model and on the calculation method for the heating balance point temperature of the building.

Finally, the ventilative cooling potential tool outputs are compared with the predictions of a state of the art building performance simulation model of the reference room, highlighting several possible improvements in the evaluation criteria.

KEYWORDS

Ventilative cooling potential, climate analysis, early design stages, overheating, airflow rates

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. As buildings with different use patterns, envelope characteristics and internal loads level do not follow equally the external climate condition, the climate analysis cannot abstract from building characteristics and use.

Within International Energy Agency (IEA) Annex 62 project (IEA EBC Annex 62 - Ventilative cooling, 2014-2017), national experts are working on the development of a ventilative cooling potential tool (VC tool), which aims at assessing the potential of ventilative cooling by taking into account also building envelope thermal properties, internal gains and ventilation needs.

2 THE VENTILATIVE COOLING POTENTIAL TOOL

The ventilative cooling potential tool is an excel-based tool intended to be used during early design stages for estimating the potential of ventilative cooling.

2.1 Theory

The ventilative cooling potential tool refers to the method proposed by NIST (Axley J.W., Emmerich S.J., 2002) (Emmerich S. J., 2011), 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.

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

where:

T_{o-hbp} = heating balance point temperature [°C]
T_{i-hsp} = heating set point temperature [°C]
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 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 may 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 temperature limit of the comfort zone [°C]
T_{i-min} = lower temperature limit of the comfort zone [°C]
T_{rm} = outdoor running mean temperature [°C]

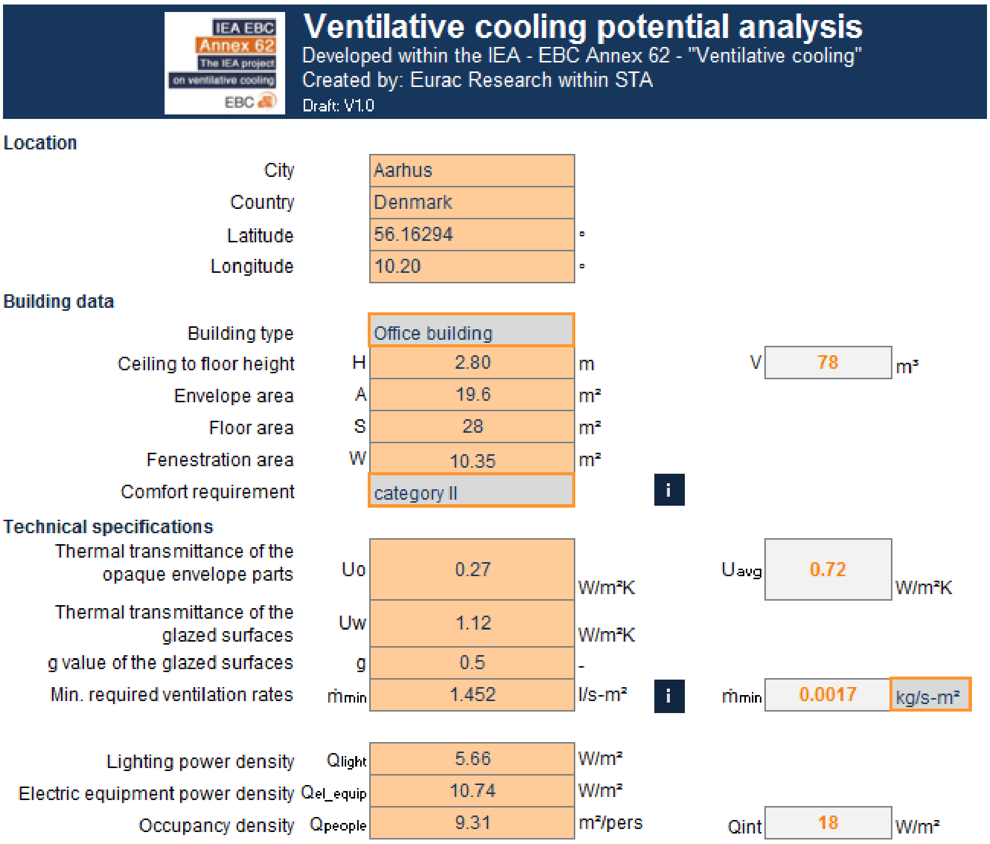
K = constant depending on required comfort Category: $K = 2$ if comfort cat. I, $K = 3$ if comfort cat. II, $K = 4$ if comfort cat. III.

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 (Table A.3). 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 (Table A.3).

2.2 Input

The tool requires basic information about a typical room of the building, the building use and the climate.

Figure 1 shows a screenshot of the input data sheet. Orange cells should be fulfilled by the user. Grey cells provide different options for the user (e.g. type of the building). The tool automatically calculates data in grey cells.



Ventilative cooling potential analysis
Developed within the IEA - EBC Annex 62 - "Ventilative cooling"
Created by: Eurac Research within STA
Draft: V1.0

Location						
City		Aarhus				
Country		Denmark				
Latitude		56.16294	°			
Longitude		10.20	°			
Building data						
Building type		Office building				
Ceiling to floor height	H	2.80	m	V	78	m³
Envelope area	A	19.6	m²			
Floor area	S	28	m²			
Fenestration area	W	10.35	m²			
Comfort requirement		category II				
Technical specifications						
Thermal transmittance of the opaque envelope parts	Uo	0.27	W/m²K	Uavg	0.72	W/m²K
Thermal transmittance of the glazed surfaces	Uw	1.12	W/m²K			
g value of the glazed surfaces	g	0.5	-			
Min. required ventilation rates	ṁmin	1.452	l/s-m²	ṁmin	0.0017	kg/s-m²
Lighting power density	Qlight	5.66	W/m²			
Electric equipment power density	Qel_equip	10.74	W/m²			
Occupancy density	Qpeople	9.31	m²/pers	Qint	18	W/m²

Figure 1: Input data sheet of the ventilative cooling potential tool

Within the building data section, the user is required to input basic internal geometry data of the reference room as well as the type of the building and the comfort category.

Comfort requirements refer to the comfort categories defined by the EN 15251:2007 standard (K parameter Equation (2 and (3). Recommended input values given for each of the different comfort categories are included in the tool and automatically selected.

Various thermal and technical properties specifications about the envelope features are required to determine the transmission losses and the solar gains. Minimum required air change rates (l/s-m^2) determine the ventilation losses within the energy balance of the reference room.

The tool includes a database of standard load profiles of occupancy (Table 3), lighting (Table 4) and electric equipment (Table 5) for different building typologies, which are under publication by REHVA organization. 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.
The tool determines internal gains for each hour of the year according to the load profile, the lighting and electric equipment power density and the occupancy density input by the user.

Climatic data

Annual record of climatic data is user-input on hourly time steps. The climatic data used on this tool are the dry bulb temperature and the global horizontal solar radiation. The weather data should be representative of the examined location's typical meteorological year for the given location.
Several sources for typical meteorological year weather files are available: Meteonorm software (Meteonorm, 2015), International Weather for Energy Calculations (IWEC) data set (ASHRAE, 2001), Typical Meteorological Year (TMY) data set (Wilcox S., 2008) and many others (Energylus Energy Simulation software: Weather Data sources, 2015).

2.3 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]**: ventilative cooling is not required when the outdoor temperature is below the heating balance point temperature no ventilative cooling can be used since heating is needed;

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

2. **Ventilative Cooling mode [1]**: Direct ventilative cooling with airflow rate maintained at the minimum required for indoor air quality when the outdoor temperature exceeds the balance point temperature, yet 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 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. A ΔT_{crit} of 3 K is introduced in order to prevent unrealistic airflow rates;

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

4. **Ventilative Cooling mode [3]**: Direct ventilative cooling is not useful when the outdoor temperature exceeds the upper temperature limit of the comfort zone;

   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 cooling potential over the following night is evaluated as the internal gains that may be offset for a nominal unit night-time air change rate (Equation (5).

$$NCP = \frac{H\rho c_P (T_{i-max} - T_{o-db})}{3600} \quad (5)$$

where:

NCP = night-time cooling potential [W/m²-ach]
H = floor height [m]
ρ = air density [kg/m³]

Compared to the climate suitability analysis method developed by NIST, the ventilative cooling potential analysis tool presented in this research includes two main new features:

- Dynamic load profiles and heating balance point temperature calculation;
- Adaptive thermal comfort based control.

2.4 Outputs

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. 2.32.3;
  - direct ventilative cooling with airflow rate maintained at the minimum is required (VC mode [1]) according to the evaluation criteria described in par. 2.3;
  - direct ventilative cooling with increased airflow rate is required (VC mode [2]) according to the evaluation criteria described in par. 2.3;
  - direct ventilative cooling is not useful (VC mode [3]) according to the evaluation criteria described in par. 2.3;
- the night-time cooling potential over the night following the days when direct ventilative cooling is not useful (VC mode [3]) for at least an hour;
- 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]);
- the night-time Cooling Degree Hours (CDH);
- the monthly average temperature swing between day and night;
- the monthly average global horizontal radiation.

From climate classification point of view, the outputs are useful to compare the ventilative cooling potential in different climates for different building typologies.

From design point of view, the outputs 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 analyse the effect of other energy efficiency measures, like internal gains reduction, solar gains control and envelope performance, on ventilative cooling effectiveness.

3 CASE STUDY: AARHUS TOWN HALL OFFICE (DENMARK)

The case study used for the validation of the analysis is an office room located in the Aarhus municipality building in Denmark.

3.1 Ventilative Cooling potential tool

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.

Since the solar gain calculation is still under development, we input to the VC tool the solar gains calculated by the building energy simulation model in EnergyPlus (see par. 3.2).

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 85% of the time during the period May - September.

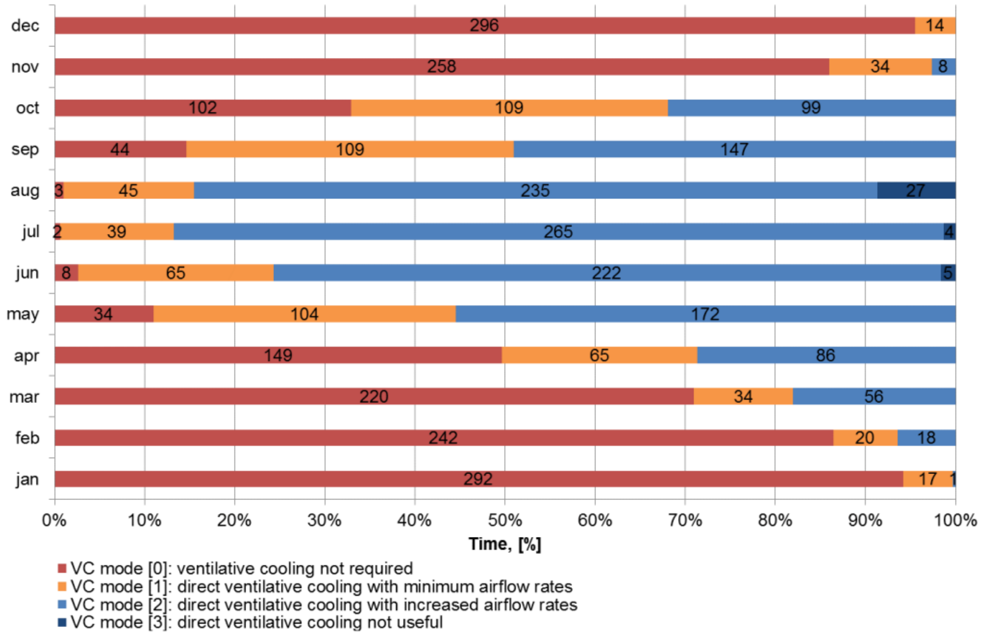


Figure 2: Tool output: percentage of working hours when ventilative cooling is not required, direct ventilative cooling is useful or not useful.

Table 1: 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]).

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Average airflow rate	2.68	2.63	2.98	3.73	4.30	4.47	4.68	4.82	3.59	3.17	2.89	0
Standard deviation	0	0.17	0.41	1.08	1.58	1.94	2.22	2.75	0.99	0.61	0.38	0
Nr of hours when VC mode [2] is on	1	18	56	86	172	222	265	235	147	99	8	0

Table 1 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 4.82 ± 2.75 h^{-1} is expected to assure that indoor temperatures are within the comfort zone during August for more than 80% 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, 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.

3.2 Building Energy Simulation model

In order to validate the ventilative cooling potential tool outputs, we modelled the reference office room in EnergyPlus simulation software and compared the simulation results with the tool outputs.

The zone settings are the same as the reference office room described in par. 0. The schedules of internal gains are defined in order to perfectly match the load profiles used by the tool.

The design flow rates are input as hourly values in a schedule file that reports the required airflow rates, both minimum and increased, calculated by the ventilative cooling potential tool. The simulation is run in free-floating mode.

The predicted indoor temperatures on hourly frequency were compared with the comfort ranges set in the tool according to the following assumptions:

- If the predicted indoor temperature is lower than the lower temperature limit of the comfort zone and the airflow rates are set at the minimum, then direct ventilative cooling is not useful (VC mode [0]);
- If the predicted indoor temperature is within the comfort zone and the airflow rates are set at the minimum, then direct ventilative cooling is useful if airflow rates are maintained at the minimum required (VC mode [1]). Also time steps when the predicted indoor temperature is lower than the lower temperature limit of the comfort zone and the airflow rates are set at an increased value, are classified as VC mode [1];
- If the predicted indoor temperature is within the comfort zone and the airflow rates are set at an increased value, then direct ventilative cooling is considered useful (VC mode [2]);
- Finally, if the predicted indoor temperature is higher than the higher temperature limit of the comfort zone and the airflow rates are set at an increased value, then direct ventilative cooling is not enough to cool down the reference zone (VC mode [3]).

3.3 Building Energy Simulation model predictions vs VC tool outputs

The graph in Figure 3 shows the percentage of working hours when ventilative cooling is not required, direct ventilative cooling is useful or not useful based on the analyses of building energy simulation model (EnergyPlus) predictions as described above. The results are directly compared with the ventilative cooling potential tool outputs.

This comparison allows us to validate the VC tool outputs as well as to analyse the effect of thermal mass on output results.

Table 2 reports the differences in terms of number of days between the EnergyPlus predictions and the ventilative cooling potential tool outputs.

Highest differences occur during middle seasons for the time when ventilative cooling is not useful (VC mode [0]) and the time when ventilative cooling with increased airflow rates is useful (VC mode [2]). Generally, the VC tool underestimates the number of hours when

ventilative cooling is not useful (apart from June, July, August) and overestimates the number of hours when ventilative cooling with increased airflow rates is useful (apart from July). This underestimation exceeds 5 working days per month during spring and fall time, but does not exceed 3 working days per month during summer and winter time.
The differences are mainly related to the evaluation criteria and the simplifications in the heating balance point temperature calculation. According to the indoor temperature prediction of the EnergyPlus model, the average heating balance point temperature is around 15°C. The VC tool calculates an average heating balance point temperature of 12°C.

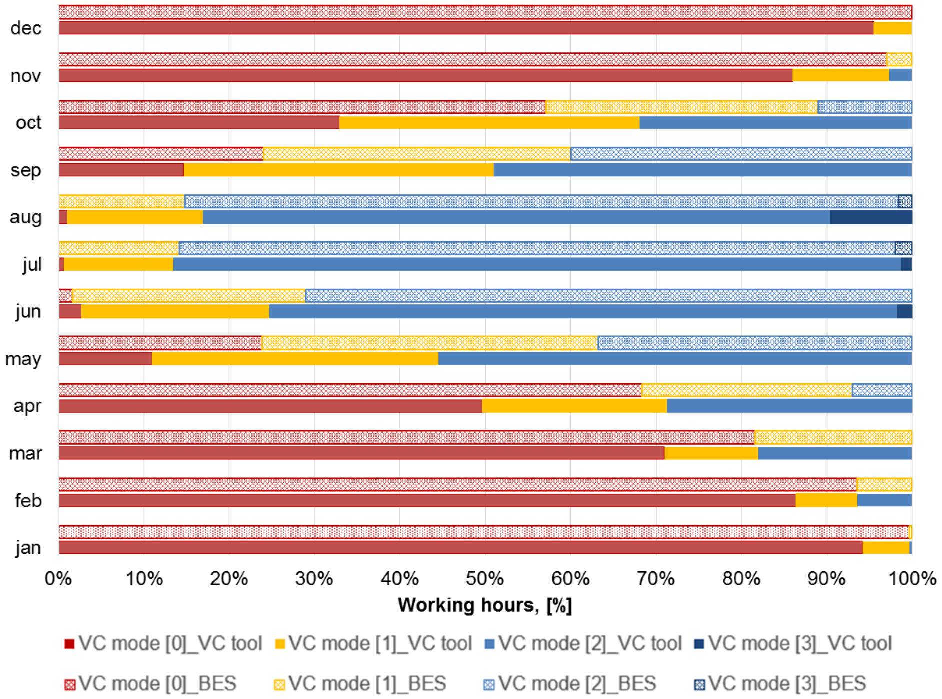


Figure 3. EnergyPlus model output (BES) analysed according to the tool evaluation criteria compared to the ventilative cooling potential tool (VC tool) outputs.

Table 2: Number of days (considering 10hrs/day) difference between EnergyPlus model predictions and ventilative cooling potential tool outputs.

	Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Total**
VC mode [0]	-1.7	-2	-3.3	-5.6	-4	0.3	0.2	0.3	-2.8	-7.5	-3.3	-1.4	-30.8
VC mode [1]	1.6	0.2	-2.3	-0.9	-1.8	-1.7	-0.5	-0.1	0.1	1	2.5	1.4	-0.5
VC mode [2]	0.1	1.8	5.6	6.5	5.8	0.4	0.1	-5.1	2.7	6.5	0.8	0	25.2
VC mode [3]	0	0	0	0	0	0.5	-0.2	2.2	0	0	0	0	2.5

Furthermore, we analysed the effect of the new features introduced in the VC tool compared to the original method developed by NIST (Emmerich S. J., 2011), namely:

1. Adaptive thermal comfort based control instead of standard comfort zone;
2. Constant loads and heating balance point temperature.

The graph in Figure 4 shows the analysis results over the whole for the following cases:

- *BES (EnergyPlus)*: building energy simulation model results;
- *BES (EnergyPlus) with increased thermal mass*: results of the building energy simulation model with additional 8200 kg of thermal mass (corresponding to the mass of a 20cm concrete slab with area equal to the floor area);
- *VC tool*: output of the ventilative cooling potential tool;

- *VC tool: standard comfort zone*: output of the ventilative cooling potential tool considering the standard comfort zone, with lower temperature limit of 20°C and upper temperature limit of 24°C;
- *VC tool: no dynamic load and T_{hbp}*: output of the ventilative cooling potential tool considering constant internal gains (18 W/m²) and heating balance point temperature (12°C).

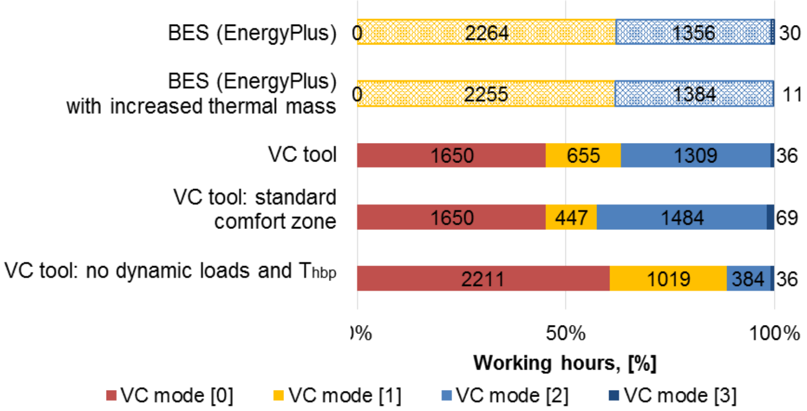


Figure 4. EnergyPlus and VC tool output according to different evaluation criteria.

No significant differences are observed between the original EnergyPlus model and the one with increased thermal mass, meaning that in this case the effect of thermal mass can be neglected.

The use of a standard comfort zone within the evaluation criteria of the VC tool causes an additional overestimation of the ventilative cooling with increased airflow rate mode compared to the case with adaptive thermal comfort based control. Since the upper temperature limit does not vary according to the outdoor temperatures, the time when ventilative cooling is not considered useful is overestimated as well because of the high temperatures.

Higher differences occur when internal gains and heating balance point temperature are considered constant over the whole time. The ventilative cooling potential is up to three times under estimated.

4 DISCUSSION

The steady-state assumptions seem to be acceptable in this case. The Aarhus municipality building town hall office does not have massive constructions. The assumptions validity needs to be further tested on other building types located in different climates (hot, temperate).

Highest differences between EnergyPlus model predictions and VC tool outputs occur during middle season. The evaluation criteria allow direct ventilative cooling with increased rates even when the outdoor temperatures are too low. Analysing the EnergyPlus model results on thermal comfort, we observed when ventilative cooling with increased rates is activated at low outdoor temperatures, the model predicts discomfort due to too cold temperatures, meaning that the increased airflow rates have a too high cooling effect.

The introduction of an outdoor temperature limit condition for VC mode [2] would prevent this issue.

Since the current European standard on thermal comfort does not provide for any recommendation on relative humidity, the evaluation criteria adopted by the tool does not include consideration about relative humidity. According to the Copenhagen weather file, less than 1% of the time the dew point temperature exceeds the 17°C limit proposed by the NIST methodology (Emmerich S. J., 2011). Therefore, the introduction of a control based on air humidity would not affect the results for the present case study. The relative humidity based control is still under discussion within the IEA Annex 62 experts and will be introduced in the next versions of the tool.

Furthermore, as mentioned before, a simplified solar radiation model for solar gains calculation is under implementation.

5 CONCLUSIONS

The paper presents the ventilative cooling potential tool (VC tool) which is under development within the IEA Annex 62 project. The tool analyse 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.

As validation of results, the ventilative cooling potential tool outputs are compared with the predictions of a building energy simulation model of the reference room, highlighting the following aspects:

- The steady-state assumptions seem to be acceptable in case of no massive constructions and cold climates, but their validity needs to be further tested on other case studies located in different climates;
- Dynamic internal loads and calculation of the heating balance point temperature need to be considered in order to have realistic results;
- The introduction of an outdoor temperature limit condition for ventilative cooling mode with increased airflow rates would improve further the tool outputs reliability.

Further improvements of the tool such as internal calculation of solar gains and evaluation criteria based on relative humidity are under discussion within the Annex 62 national experts.

6 ACKNOWLEDGEMENTS

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8 APPENDIX

Table 3: Occupancy load profile. Source: REHVA (under publication)

Time	Residential building	Department store	Hospital	Hotel	Office building	Restaurant	School	Sport, terminal, theatre
00:00-01:00	1	0	0.4	0.9	0	0	0	0
01:00-02:00	1	0	0.4	0.9	0	0	0	0
02:00-03:00	1	0	0.4	0.9	0	0	0	0
03:00-04:00	1	0	0.4	0.9	0	0	0	0
04:00-05:00	1	0	0.4	0.9	0	0	0	0
05:00-06:00	1	0	0.4	0.9	0	0	0	0
06:00-07:00	0.5	0	0.4	0.7	0	0.1	0	0
07:00-08:00	0.5	0	0.5	0.4	0.2	0.4	0	0
08:00-09:00	0.5	0.1	0.6	0.4	0.6	0.4	0.6	0.6
09:00-10:00	0.1	0.3	0.8	0.2	0.6	0.4	0.7	0.6
10:00-11:00	0.1	0.3	0.8	0.2	0.7	0.2	0.6	0.6
11:00-12:00	0.1	0.7	0.8	0.2	0.7	0.5	0.4	0.6
12:00-13:00	0.1	0.6	0.8	0.2	0.4	0.8	0.3	0.6
13:00-14:00	0.2	0.5	0.8	0.2	0.6	0.7	0.7	0.6
14:00-15:00	0.2	0.6	0.8	0.2	0.7	0.4	0.6	0.6
15:00-16:00	0.2	0.6	0.8	0.3	0.7	0.2	0.4	0.6
16:00-17:00	0.5	0.9	0.8	0.5	0.6	0.25	0.2	0.6
17:00-18:00	0.5	0.9	0.6	0.5	0.2	0.5	0	0.6
18:00-19:00	0.5	1	0.5	0.5	0	0.8	0	0.6
19:00-20:00	0.8	0.9	0.5	0.7	0	0.8	0	0.6
20:00-21:00	0.8	0.7	0.4	0.7	0	0.8	0	0.6
21:00-22:00	0.8	0	0.4	0.8	0	0.5	0	0.6
22:00-23:00	1	0	0.4	0.9	0	0.35	0	0
23:00-00:00	1	0	0.4	0.9	0	0.2	0	0

Table 4: Lighting load profile. Source: REHVA (under publication)

Time	Residential building	Department store	Hospital	Hotel	Office building	Restaurant	School	Sport, terminal, theatre
00:00-01:00	0	0	0.5	0.22	0	0	0	0
01:00-02:00	0	0	0.5	0.17	0	0	0	0
02:00-03:00	0	0	0.5	0.11	0	0	0	0
03:00-04:00	0	0	0.5	0.11	0	0	0	0
04:00-05:00	0	0	0.5	0.11	0	0	0	0
05:00-06:00	0	0	0.5	0.22	0	0	0	0
06:00-07:00	0.15	0	0.5	0.44	0	0.1	0	0
07:00-08:00	0.15	0	0.5	0.56	0.2	0.4	0	0
08:00-09:00	0.15	1	0.9	0.44	0.6	0.4	0.6	0.6
09:00-10:00	0.15	1	0.9	0.44	0.6	0.4	0.7	0.6
10:00-11:00	0.05	1	0.9	0.28	0.7	0.2	0.6	0.6
11:00-12:00	0.05	1	0.9	0.28	0.7	0.5	0.4	0.6

12:00-13:00	0.05	1	0.9	0.28	0.4	0.8	0.3	0.6
13:00-14:00	0.05	1	0.9	0.28	0.6	0.7	0.7	0.6
14:00-15:00	0.05	1	0.9	0.28	0.7	0.4	0.6	0.6
15:00-16:00	0.05	1	0.9	0.28	0.7	0.2	0.4	0.6
16:00-17:00	0.2	1	0.5	0.28	0.6	0.25	0.2	0.6
17:00-18:00	0.2	1	0.5	0.28	0.2	0.5	0	0.6
18:00-19:00	0.2	1	0.5	0.67	0	0.8	0	0.6
19:00-20:00	0.2	1	0.5	0.89	0	0.8	0	0.6
20:00-21:00	0.2	1	0.5	1	0	0.8	0	0.6
21:00-22:00	0.2	0	0.5	0.89	0	0.5	0	0.6
22:00-23:00	0.15	0	0.5	0.67	0	0.35	0	0
23:00-00:00	0.15	0	0.5	0.41	0	0.2	0	0

Table 5: Electric equipment load profile. Source: REHVA (under publication)

Time	**Residential building**	**Department store**	**Hospital**	**Hotel**	**Office building**	**Restaurant**	**School**	**Sport, terminal, theatre**
00:00-01:00	0	0	0.5	0.22	0	0	0	0
01:00-02:00	0	0	0.5	0.17	0	0	0	0
02:00-03:00	0	0	0.5	0.11	0	0	0	0
03:00-04:00	0	0	0.5	0.11	0	0	0	0
04:00-05:00	0	0	0.5	0.11	0	0	0	0
05:00-06:00	0	0	0.5	0.22	0	0	0	0
06:00-07:00	0.15	0	0.5	0.44	0	0.1	0	0
07:00-08:00	0.15	0	0.5	0.56	0.2	0.4	0	0
08:00-09:00	0.15	1	0.9	0.44	0.6	0.4	0.6	0.6
09:00-10:00	0.15	1	0.9	0.44	0.6	0.4	0.7	0.6
10:00-11:00	0.05	1	0.9	0.28	0.7	0.2	0.6	0.6
11:00-12:00	0.05	1	0.9	0.28	0.7	0.5	0.4	0.6
12:00-13:00	0.05	1	0.9	0.28	0.4	0.8	0.3	0.6
13:00-14:00	0.05	1	0.9	0.28	0.6	0.7	0.7	0.6
14:00-15:00	0.05	1	0.9	0.28	0.7	0.4	0.6	0.6
15:00-16:00	0.05	1	0.9	0.28	0.7	0.2	0.4	0.6
16:00-17:00	0.2	1	0.5	0.28	0.6	0.25	0.2	0.6
17:00-18:00	0.2	1	0.5	0.28	0.2	0.5	0	0.6
18:00-19:00	0.2	1	0.5	0.67	0	0.8	0	0.6
19:00-20:00	0.2	1	0.5	0.89	0	0.8	0	0.6
20:00-21:00	0.2	1	0.5	1	0	0.8	0	0.6
21:00-22:00	0.2	0	0.5	0.89	0	0.5	0	0.6
22:00-23:00	0.15	0	0.5	0.67	0	0.35	0	0
23:00-00:00	0.15	0	0.5	0.41	0	0.2	0	0