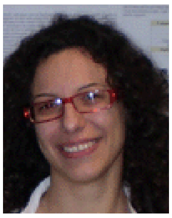
Natural ventilative cooling in school buildings in Sicily






M. CELLURA
University of Palermo
Dipartimento di Energia
Ingegneria dell'Informazione
e Modelli Matematici (DEIM)
maurizio.cellura@unipa.it

F. GUARINO
University of Palermo
Dipartimento di Energia
Ingegneria dell'Informazione
e Modelli Matematici (DEIM)
guarino@dream.unipa.it

S. LONGO
University of Palermo
Dipartimento di Energia
Ingegneria dell'Informazione
e Modelli Matematici (DEIM)
sonia.longo@unipa.it

M. MISTRETTA
University of Reggio Calabria
Dipartimento Patrimonio,
Architettura, Urbanistica (P.A.U)
marina.mistretta@unirc.it

The paper shows analysis of the impact on thermal comfort of natural ventilation in a non-residential Mediterranean case-study.

Results are based on the EN 15251 approach on adaptive comfort. Different scenarios are proposed, granting an improvement of up to 10% in the number of summer comfort hours.

Keywords: Ventilative cooling, natural ventilation, TRNSYS, building simulation, thermal comfort.

In the context of a renewed interest of the European Commission (the EPBD-recast 2012/27/EU directive) regarding the energy efficiency of buildings [1], energy retrofit actions in the public buildings sector are gaining interest [2-4]. One of the sectors that may benefit more from energy efficiency actions is the education one: in Sicily (Italy), more than 70% of schools have been built before the 1980s and therefore they often have energy performances that do not comply with the most up to date energy regulations. Moreover, due to high internal loads and a hot climate from May to October, cooling may be needed during large parts of the year, but air conditioning systems are rarely available: a solution may lie in ventilative cooling techniques that aim to reduce indoor temperature by simply using outdoor air.

The case study

The study shows an analysis aimed to increase the indoor summer comfort levels by means of natural ventilative cooling techniques in a school building in Sicily. The analysis is based on the thermal simulation of a real building and the development of scenarios where different ventilative cooling techniques are used; comfort levels are quantified by means of the EN 15251 adaptive comfort models. The zones investigated in the analysis are only classrooms and some administrative offices. The school building (**Figure 1** and **Figure 2**) is located in southern Sicily, 20 km away from Agrigento, facing the Sicilian channel.

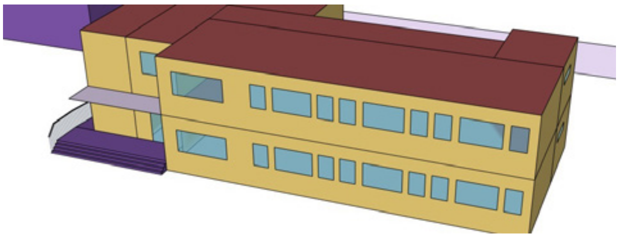


Figure 1. East Façade of the building, Google SketchUp.

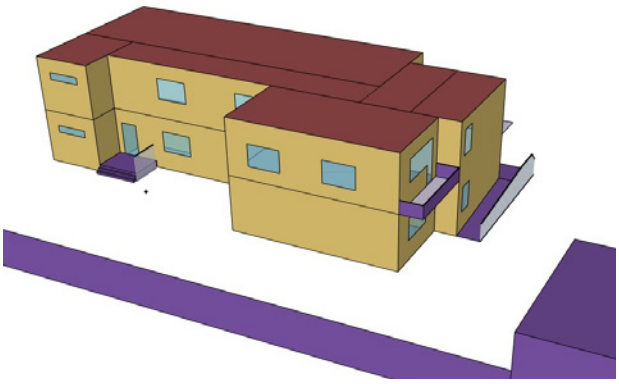


Figure 2. West Façade of the building, Google SketchUp.

The building has two levels, it has an overall 675 m² surface and, in the classrooms, the window to wall ratio is around 25%. The building develops mostly on the East-West direction; the overall U value of opaque external surfaces is around 1.2 W/(m² K) and it is around 3 W/(m² K) for the glazed surfaces (single) used.

Cooling systems are not available; no specific use of natural ventilation is reported during the day or the night.

The thermal building simulation is modelled in TRNSYS 17 environment, natural ventilation modelling involves the use of the empirical equations specified by ASHRAE in [5], where the ventilation air flow rate is function of wind speed, thermal stack effect, opening area of windows and their opening factors. Windows are considered close, if wind speed is higher than 3 m/s.

The thermal zoning performed in the analysis is represented in **Figure 3**. Zones Classrooms 1 and 2 have an overall area of around 165 m² while the zones Classrooms 3 and Administration office are nearly 66 m² large. The other zones including corridors, halls, technical locals, have been modeled but they are not analyzed as comfort zones.

The building use takes place mostly from 8:30 to 14:30 (all zones in **Figure 3**) in the morning but it is often occupied also during the afternoon from 16:30 due to some evening classes (only the classrooms 2 zone). This is particularly relevant since the whole comfort analysis is performed on the occupied hours only and will have quantitative impacts on the results as well.

As specified in the regulation, running mean temperatures (Θ_{rm}) are calculated as function of recurring average temperature values ($\Theta_{ed\text{-}i}$) calculated during previous week (*) while the comfort temperature is calculated through Eq.1.

$$\Theta_c = 0{,}33\,\Theta_{rm} + 18{,}8\ °C \qquad (1)$$

The comfort temperature ranges adopted for the study are respectively reported in Eq.2 and 3.

$$\Theta_c - 2 < \Theta_{indoor} < \Theta_c + 2\ °C \qquad (2)$$

$$\Theta_c - 3 < \Theta_{indoor} < \Theta_c + 3\ °C \qquad (3)$$

* $\Theta_{rm} = (1 - \alpha)\cdot\{\Theta_{ed\,-1} + \alpha\,\Theta_{ed\,-2} + \alpha^2\,\Theta_{ed\,-3} + \ldots\}$

Where: Θ_{rm} = External Running mean temperature for the considered day (°C).

Θ_{rm-1} = running mean external air temperature for previous day

α = constant between 0 and 1 (recommended value is 0.8)

$\Theta_{ed\text{-}i}$ = daily mean external air temperature for the *i*-the previous day

prEN 16798-1 (replacing the EN15215) states the following:

The following approximate equation shall be used where records of daily running mean external temperature are not available:

$\Theta_{rm} = (\Theta_{ed\,-1} + 0{,}8\,\Theta_{ed\,-2} + 0{,}6\,\Theta_{ed\,-3} + 0{,}5\,\Theta_{ed\,-4} + 0{,}4\,\Theta_{ed\,-5} + 0{,}3\,\Theta_{ed\,-6} + 0{,}2\,\Theta_{ed\,-7})\ /\ 3{,}8$

The case study model was run in non-steady state by using Meteonorm weather data, all the temperature data for each of the occupied thermal zones analyzed and compared to results of Eq.1 to verify whether each simulated hour for every thermal zone would fall inside the thermal comfort ranges.

The study has determined the percentage of comfort hours for the existing building including no natural ventilation strategies and in the case of daily ventilation, night ventilation and continuous natural ventilation during the whole 24 hours of the day in a period including May, June, early July, September, early October.

Results and discussion

The comfort hours percentages for each of the analyzed thermal zones are shown in **Figure 4**, calculated according to eq.2 and 3 temperature ranges for the existing building with no natural ventilation strategies applied.

Classrooms 3 and the administration locals show results very close to each other. Classrooms 1 and 2 instead, although being geometrically very similar, show results significantly different: this can be explained with the already described differences in occupation levels. Adding more occupation hours in the afternoon to a thermal zone (Class 2) that has undergone high internal gains and a high solar radiation during the morning, will surely cause an increase in thermal discomfort.

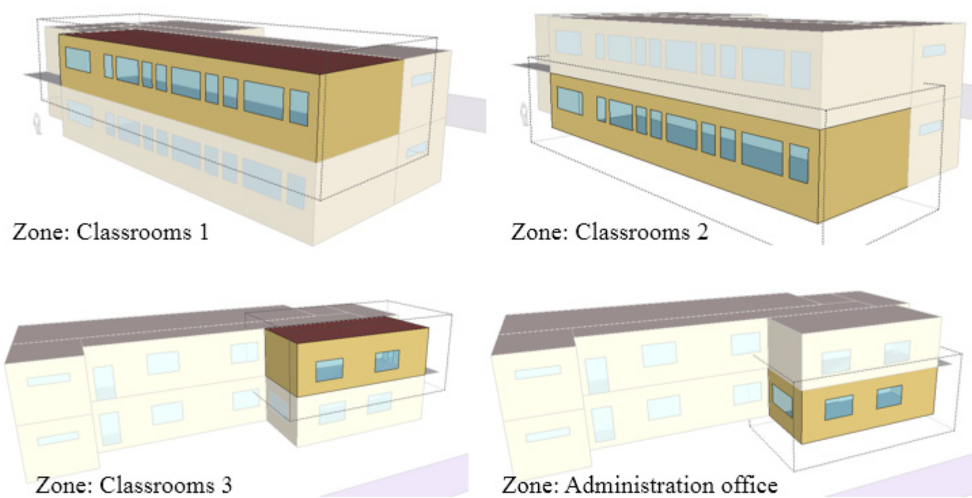


Figure 3. Thermal zones modeled and included in the study.

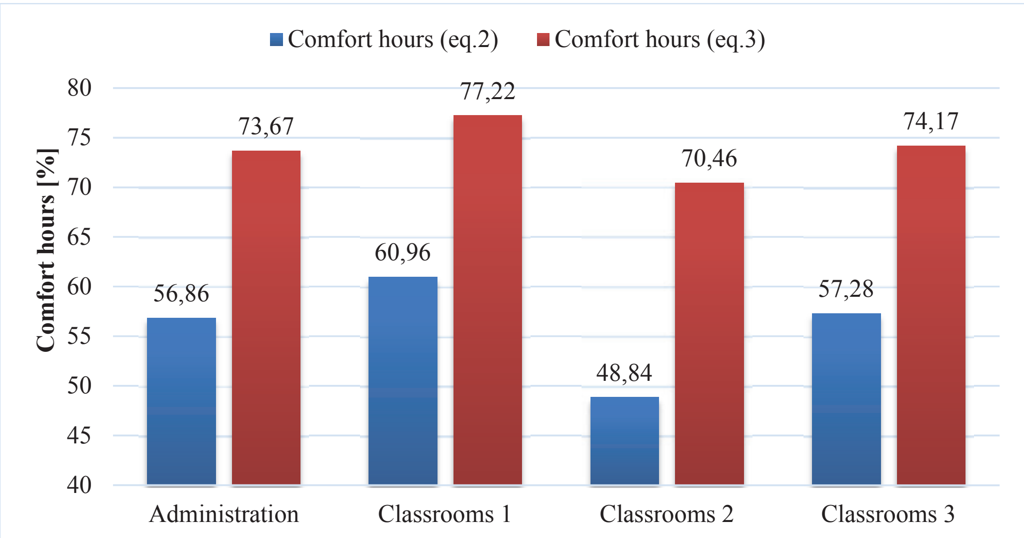


Figure 4. Comfort hours percentages.

The parametric analysis performed includes different scenarios that have been compared to assess the potential for comfort improvement through natural ventilation in the case-study:

- Scenario A, the state of the art of the building, with no natural ventilation strategies implemented,
- Scenario B1, daily ventilation (8:00, 20:00) with an opening area of the windows equal to 50% of the total windowed area,
- Scenario B2, daily ventilation (8:00, 20:00) with an opening area of the windows equal to 100% of the total windowed area,
- Scenario C1, night ventilation (20:00 – 8:00) with an opening area of the windows equal to 50% of the total windowed area,
- Scenario C2, night ventilation (20:00 – 8:00) with an opening area of the windows equal to 100% of the total windowed area,
- Scenario D1, whole-day ventilation with an opening area of the windows equal to 50% of the total windowed area,
- Scenario D2, night ventilation with an opening area of the windows equal to 100% of the total windowed area.

As example to the already discussed features of the case study and of the parametric analysis performed, **Figure 5** presents hourly results (3rd and the 4th of June, chosen as hot summer days in Sicily) for the transient model, representing air temperatures and air change per hour for the zone Classroom 2 for both the A and D2 scenarios.

The calculated comfort temperature is around 27.5°C and in **Figure 5** the eq.3 comfort zone is reported.

The air temperature in the classrooms in scenario A is never included in the comfort zone: it is always higher than 31°C and peaks in the morning and in the afternoon reach 35°C.

The internal loads drive the energy balance of the classrooms. Although external temperature reaches its peak between 14 and 16 during the day, indoor temperature drops by a couple of degrees before raising again in the afternoon following occupation: this clarifies the need for a careful ventilation to disperse excess heat from the rooms.

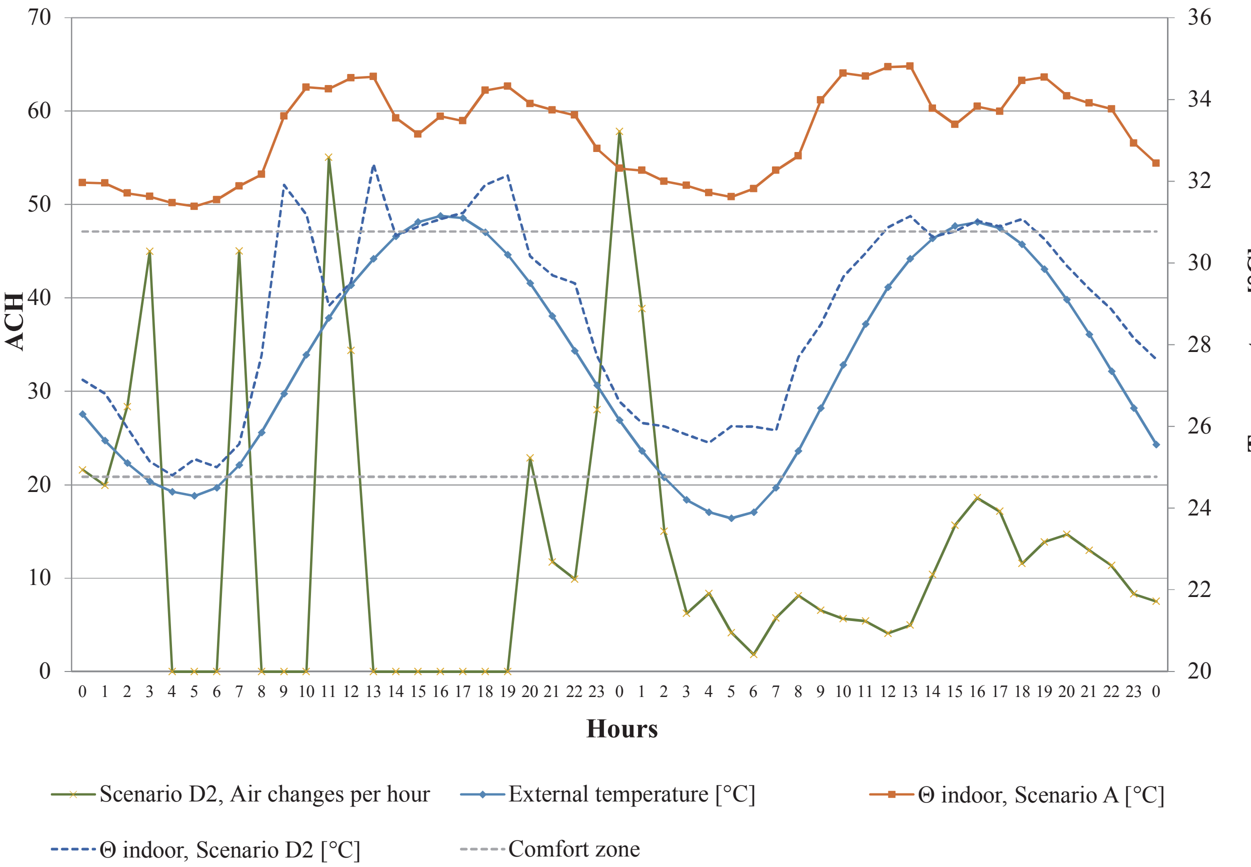


Figure 5. Hourly transient results for the thermal zone classrooms 2.

The D2 scenario proves suitable since during the selected days the external temperature is for most of the hours inside the comfort range.

It may be argued that during the daytime a finer control of the windows opening (e.g. closing windows if exterior temperature rises above 28°C) would slow the increase of indoor temperature (T indoor, Scenario D2) from hours 32 to 36 and thus night and early morning ventilation could be more appropriate.

It is easy instead to verify the positive impact of daytime ventilation even at higher temperatures: as soon as ventilation rates drop, indoor temperature rises immediately even by two degrees in the following hour due to high internal loads, if the zone is occupied (e.g. at 9 or at 13 hours).

Table 1. Results of the parametric analysis: percentage of comfort hours.

	±(2°C)	±(3°C)	±(2°C)	±(3°C)	±(2°C)	±(3°C)	±(2°C)	±(3°C)
Scenario	Administration		Classrooms1		Classrooms2		Classrooms 3	
A	56.86	73.67	60.96	77.22	48.84	70.46	57.28	74.17
B1	61.07	78.51	65.48	82.87	53.38	75.35	61.72	79.23
B2	62.43	80.29	66.64	83.98	54.96	76.92	61.98	79.82
C1	63.03	81.03	66.98	84.34	55.80	78.92	62.35	80.08
C2	65.08	82.08	67.59	85.03	56.75	80.25	62.97	80.60
D1	66.11	83.65	69.05	86.07	57.89	81.63	64.45	82.50
D2	66.38	84.03	69.37	86.46	59.18	81.91	65.04	83.20

Global results for all the scenarios discussed are following in **Table 1**.

Results identify improvements in all the classrooms of up to nearly 10% in the D2 comfort scenario that reports the highest increases.

Conclusions

The paper proposes the quantification of thermal comfort improvement obtainable in a school building in Sicily through the use of natural ventilation. The building is characterized by overheating from May to October due to high internal loads and solar gains: natural ventilative cooling is a potential solution to improve the thermal comfort of the occupants.

Natural ventilation scenarios include daytime ventilation, night-time ventilation as well as whole-day ventilation: all the solutions investigated allow for an increase in the percentage of hours of comfort on the total of occupied hours.

Of the scenarios proposed, the best proves to be the 24 hours natural ventilation strategies (D1 and D2) in all the thermal zones: although the features of the summer external temperature trend would probably suggest not to ventilate much during peak hours, the features of the spaces – characterized by high internal loads – require ventilation during most occupied hours. ■

References

[1] Directive 2010/31/EU of the European parliament and of the council of 19 May 2010 on the energy performance of buildings (recast).

[2] M. Cellura, F.Guarino , M. Mistretta, S. Longo, Energy life-cycle approach in net zero energy buildings balance: operation and embodied energy of an Italian case study. Energy & Buildings n°72, pp 371-381, April 2014 - DOI: 10.1016/j.enbuild.2013.12.046.

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[5] 2013 ASHRAE handbook of fundamentals, Chapter 16 Ventilation and infiltration.