

Night Ventilation as a Key Strategy for Enhancing HVAC Energy Efficiency in Educational Buildings: A Case Study of Energy Savings

Ventilarea de noapte ca strategie cheie pentru creșterea eficienței energetice a sistemelor HVAC în clădirile educaționale: Un studiu de caz privind economiile de energie

Marius Adam¹, Adriana Tokar¹, Alexandru Dorca¹, Dănuț Tokar¹

¹ Politehnica University of Timisoara

Victoriei Square, Nr.2, Timisoara, Romania

E-mail: marius.adam@upt.ro, adriana.tokar@upt.ro, alexandru.dorca@upt.ro, danut.tokar@upt.ro

DOI: 10.37789/rjce.2026.17.3.9

Abstract: Educational buildings frequently face issues with overheating and high energy consumption associated with HVAC systems, amid rising global temperatures and increasing demands for thermal comfort. Night Ventilation (NV) has been recognized as an effective passive or semi-passive cooling technique that utilizes cooler outdoor air to discharge the building's thermal mass during the night, thereby creating a 'cool reservoir' for the following day. This article presents a case study on the implementation of night ventilation strategies in an educational building, aiming to evaluate energy efficiency and the impact on thermal comfort. The study analyzes the interaction between night ventilation rates, building thermal inertia, and the energy consumption of HVAC equipment during occupancy periods. The results demonstrate that an optimized night ventilation strategy can significantly reduce peak cooling loads and the number of thermal discomfort hours. Furthermore, the paper explores the economic cost-benefit ratio by comparing the energy consumption of fans during the night with the savings generated by the reduced use of HVAC systems during the day. The study emphasizes that, although night ventilation cannot always independently ensure full thermal comfort, its integration as part of a hybrid cooling system is a feasible and energy-efficient solution for educational buildings.

Key words: Night ventilation; HVAC efficiency; educational buildings; thermal mass; energy savings; thermal comfort

1. Introduction and theoretical basis

The link between thermal inertia, night ventilation (also known as free cooling or night cooling) and the electrical energy consumption of HVAC equipment represents one of the most effective design principles for sustainable buildings[1,5].

Night Ventilation as a Key Strategy for Enhancing HVAC Energy Efficiency in Educational Buildings:
A Case Study of Energy Savings

The operating principle is based on the ability of massive building elements (such as concrete or brick) to absorb heat generated internally or from solar radiation during the day, a phenomenon described as thermal inertia. At night, when the outside air is colder, the ventilation system introduces this air to “unload” the structure thermally. Thus, the building starts the next day with a lower internal temperature, drastically reducing the need for the compressors of the cooling systems [2].

The heat transfer mechanism is governed by the following mathematical equations:

- *thermal mass storage capacity:*

$$Q_{masă} = m \cdot c_p \cdot \Delta T_{structură} \quad (1)$$

- *energy extracted through night ventilation:*

$$Q_{vent} = L \cdot \rho_{aer} \cdot c_{p,aer} \cdot (T_{int} - T_{ext}) \cdot t \quad (2)$$

- *theoretical energy savings on HVAC equipment:*

$$E_{răcire_evitată} = \frac{Q_{vent}}{SEER} \quad (3)$$

- *energy consumption of fans:*

$$E_{ventilatoare} = SFP \cdot L \cdot t \quad (4)$$

where:

Q_{mass} – thermal energy stored in the mass of the building (J);

m – mass of thermally active building elements (kg);

c_p – specific heat capacity of building materials (J/kg·K);

$\Delta T_{structure}$ – temperature difference of the thermal mass between day and night regime (K);

Q_{vent} – extracted thermal energy (J);

L – fresh air volume flow rate (m³/s);

ρ_{air} – air density (kg/m³);

$c_{p,air}$ – specific heat of air (J/kg·K);

$T_{int} - T_{ext}$ – temperature difference between the exhaust indoor air and the introduced outdoor air (K);

t – operating time of night ventilation (s);

$SEER$ – seasonal energy efficiency of the VRV system.

For night ventilation to be considered energy efficient, the energy saved by not using the cooling compressor must be strictly greater than the energy consumed by the fans to move the air during the night [3,4]:

$$E_{economie_netă} = E_{răcire_evitată} - E_{ventilatoare} > 0 \quad (5)$$

2. Experimental setup: ventilation laboratory

The case study was carried out in an educational experimental room (fig.1), with the following geometric characteristics: length 10.3 m, width 6.6 m, height 3.75 m, resulting in a useful surface area of 68 m² and an air volume of 255 m³.

The space has a significant thermal mass, necessary for heat storage. The floor and the floor are made of 20 cm of concrete, 5 cm of screed and 1 cm of sandstone. The east-facing exterior wall, made of 25 cm solid brick masonry, contains a large glazed surface (25 m²), while the south-facing wall is also made of 25 cm solid brick. These heavy materials act as a thermal flywheel, quantitatively evaluated by the thermal inertia index. Two systems are used for air conditioning:

Ventilation system (CTA): a GEA CAIRplus SX air handling unit, with a nominal flow rate of 8000 m³/h and a specific fan power indicator $SFP = 1.37 \text{ kW}/(\text{m}^3/\text{s})$.

Air conditioning system (VRV): a Daikin RSX inverter system, necessary to cover a maximum cooling load calculated at 9501.49 W.

According to literature recommendations for schools and medium-sized spaces, the ideal air change rates (ACH) for night ventilation are between 5 and 15 ACH.

2.1. Viewing the 3D model of the experimental room

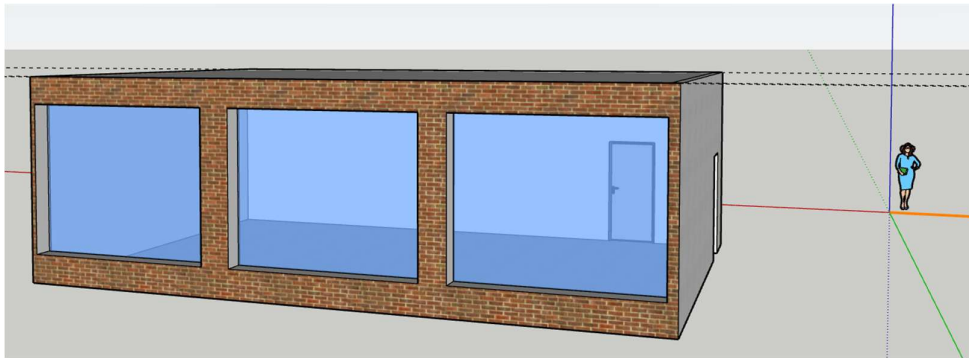


Fig. 1. 3D model of the experimental room – the ventilation laboratory

The 3D model of the ventilation laboratory clearly highlights the orientation and composition of the walls. The East wall features a major glazed area of 25 m², framed by 25 cm solid brickwork. This architectural configuration allows for massive diurnal solar heat gain. The heat radiated into the interior is efficiently stored throughout the day in the thermal mass of the floor, concrete floor and interior walls.

3. Case study and in situ measurements

To validate the efficiency of the strategy, comparative measurements were carried out on two consecutive days in June 2025, simulating similar occupancy conditions (10 people present during the day).

Scenario A (without night ventilation) – 06.06.2025: the building did not benefit from night free cooling. The VRV system was started at 08:00 (meter index 44.45 kWh) and operated until 16:00 (meter index 62.61 kWh). The indoor temperature was maintained around 26.5°C, but the thermal mass warmed up significantly, with the floor temperature reaching 24.8°C at 16:00.

Scenario B (with night ventilation) – 07.06.2025: a night ventilation strategy was implemented between 04:00 and 07:30, operating the AHU at a constant flow rate of 1500 m³/h. Subsequently, the VRV system was used from 08:00 (index 63.65 kWh) to 15:30 (index 75.11 kWh).

Tabelul 1

Sinteza parametrilor în timpul ventilației de noapte (07.06.2025, extrase)

Ora	Contor CTA (kWh)	Text (°C)	Tint (°C)	Efect asupra camerei
04:00	7.00	21.0	26.4	Pornire NV
06:00	8.22	21.0	25.0	Răcire progresivă
07:30	8.93	21.3	23.4	Oprire NV

At the end of the free cooling cycle, the indoor air temperature dropped from 26.4°C to 23.4°C.

4. Data analysis and application of mathematical formulas

Using measurements, we can validate the theoretical mathematical model.

- **Evaluating the air exchange rate (ACH)** at a flow rate $L=1500$ m³/h and a room volume of 255 m³, we have: $ACH = 5.88$ hourly changes. This value falls perfectly within the optimal range of 5-15 ACH recommended for educational buildings.

- **Modeling the Consumption of Fans (E_{fans})**, according to formula (4) and using the values for $SFP = 1.37$ KW/(m³/s), $L=0.416$ m³/s and the time of 3.5 hours, resulted in: $E_{ventilatoare} = 1,37 \cdot 0,416 \cdot 3,5 = 1,99$ kWh.

This theoretical result is extremely accurate validated by the actual meter index: 8.93 kWh-7.00 kWh = 1.93 kWh actually consumed.

- **Energy balance and net savings ($E_{\text{net_savings}}$)** the consumption of VRV equipment to provide air conditioning during the day has changed drastically due to the pre-cooling of the thermal mass:

VRV consumption without NV (06.06.2025, 8h operation): 62.61-44.45=18.16 kWh

VRV consumption with NV (07.06.2025, 7.5h operation): 75.11-63.65=11.46 kWh.

Gross savings on cooling equipment, $E_{\text{avoided_cooling}}=18.16-11.46=6.70$ kWh.

Net energy savings (5) is: $E_{\text{net_savings}}=6.70-1.93=4.77$ kWh/day.

- **Impact on thermal inertia**, the effect is directly observed at the level of the building elements. At the end of the program on 07.06.2025 (with NV), the concrete floor reached 23.6°C, compared to 24.3°C recorded on the day without night ventilation. The same mass cooling phenomenon is also visible on the inner surface of the sheet metal wall (decrease from 25.7°C to 24.2°C).

5. Conclusions and future research directions

The case study demonstrates mathematically and empirically that night ventilation is a viable strategy for Romanian educational buildings, managing, in a typical summer scenario, to reduce the electrical energy consumption of the VRV system by almost 37% (from 18.16 kWh to 11.46 kWh). By reducing the adjacent consumption of ventilation equipment (1.93 kWh), a clear net energy saving results, perfectly fulfilling the theoretical condition: $Q_{\text{vent}}/SEER > SFP \cdot L \cdot t$. Beyond the energy savings, the unloading of the thermal mass of the concrete prevents sudden jumps in radiated temperature, directly improving the comfort of the students.

Based on the findings from recent literature and previous theoretical discussions, the following directions for developing this topic are proposed:

Assessing the resilience of night ventilation to future climate change: analyzing how the future increase in ambient temperatures during the night will diminish the potential of the Q_{vent} equation, imposing either much higher flow rates (with a penalty on the SFP), or creating exclusively hybrid systems.

Optimizing operating parameters using predictive algorithms (machine learning): avoiding "supercooling" and optimizing the time, t , in formula (4) by coupling sensors with predictive weather models, so that the energy consumed by the AHU is exactly the minimum necessary to discharge the thermal mass.

Correlating acoustic interfaces with thermal inertia: considering that the educational environment requires acoustic ceilings (which often cover the concrete floor, blocking storage), future studies can analyze the integration of radiant panels or diffuse ceilings with slots, so as not to sacrifice the thermal flywheel effect.

Night Ventilation as a Key Strategy for Enhancing HVAC Energy Efficiency in Educational Buildings:
A Case Study of Energy Savings

References

- [1] Rui Guo, Yue Hu, Per Heiselberg, Hicham Johra, Chen Zhang, Pei Peng, “Simulation and optimization of night cooling with diffuse ceiling ventilation and mixing ventilation in a cold climate”, *Renewable Energy* 179 (2021) 488-501.
- [2] Donal P. Fin, Darragh Connolly, Paul Kenny, “Sensitivity analysis of a maritime located night ventilated library building”, *Solar Energy* 81 (2007) 697–710.
- [3] Wenhui Ji, Houhua Wang, Tao Du, Zili Zhang, “Parametric study on a wall-mounted attached ventilation system for night cooling with different supply air conditions”, *Renewable Energy* 143 (2019) 1865-1876
- [4] Miguel Lança, Pedro J. Coelho, João Viegas, “Numerical simulation of a night cooling strategy in an office room”, *Energy & Buildings* 252 (2021) 111359.
- [5] Marius Adam, Adriana Tokar, Alexandru Dorca, Dănuț Tokar, Alexandru Filipovici, “A general review on night ventilation systems used to reduce energy consumption in buildings”, *Romanian Journal of Civil Engineering*, Volume 16 (2025), Number 3.