Journal of Physics:
Conference Series

PAPER • OPEN ACCESS

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To cite this article: C Otoo *et al* 2026 *J. Phys.: Conf. Ser.* **3302** 012073

Hybrid ventilation feasibility in Finnish schools - Case studies and outlook

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Abstract. Hybrid ventilation is uncommon in Finnish buildings, particularly in schools, owing to the cold climate and the predominance of mechanical ventilation systems. This study evaluates the indoor air quality (IAQ) and ventilation performance, as well as the feasibility of hybrid ventilation, in a selected classroom of four mechanically ventilated Finnish schools in Espoo, using a measurement-driven analytical framework. A year-long dataset of IAQ sensor data from the case schools and outdoor climate data were analysed, together with classroom and ventilation schedules, to estimate the Natural Ventilation Opportunity Index (NVOI) for each school. The findings indicate that hybrid ventilation was not necessarily needed to improve IAQ, as all classrooms recorded only a negligible period during which CO_2 levels exceeded 1000 ppm. However, Natural Ventilation Opportunity (NVO) based on outdoor climate triggers yielded 16.6%-18.7% potential air handling unit (AHU) fan-energy savings for the year across all four classrooms. The study concludes that integrating smart hybrid ventilation could reduce energy consumption in Finnish educational buildings. The study concludes with an outlook on the practical implications of adopting artificial intelligence (AI) hybrid ventilation control strategies in cold-climate educational buildings.

1. Introduction

Indoor environmental quality and energy performance are crucial considerations in educational buildings, particularly in cold-climate regions, where heating and mechanical ventilation demands are substantial. Finnish schools predominantly rely on constant or demand-controlled mechanical ventilation systems, which yield commendable IAQ but concurrently increase energy consumption for AHU fans and heating throughout the year. [1, 2]. Almost every school is designed with windows suitable for automated operability, but they remain vastly underutilised, primarily due to concerns about thermal discomfort, drafts, noise pollution, or uncontrolled air infiltration [3, 4]. This disparity between existing infrastructure and practical utilisation has spurred increased interest in smart hybrid ventilation systems, wherein natural ventilation complements mechanical systems under optimal conditions [5, 6].

Hybrid ventilation is widely acknowledged as a promising approach for enhancing IAQ, reducing operational energy consumption, and bolstering resilience by decreasing reliance on mechanical ventilation systems [7, 8]. Recent advancements in sensor networks, AI-assisted control mechanisms, and data-driven decision-making frameworks have created new opportunities for reassessing the viability of hybrid ventilation using empirical data from these buildings [9, 10].

This research contributes to this emerging approach by analysing one year of high-resolution IAQ and external weather data from four Finnish schools. We assessed the IAQ and ventilation energy use in a selected classroom at each school. We also evaluated the feasibility of hybrid ventilation during occupancy and off-hours for each school using a Natural Ventilation Opportunity Index (NVOI). The objective of this study is to determine the extent of safe hybrid ventilation throughout the year and quantify potential annual energy savings from AHU fans.

2. Methodology

This study employs a measurement-based comparative case-study methodology, combining one year of monitored IAQ and outdoor climate data with ventilation design and operation documentation from selected classrooms of four Finnish schools located in Espoo to conduct an analytical performance assessment of IAQ, hybrid ventilation feasibility and ventilation fan energy savings using a Natural Ventilation Opportunity Index (NVOI), without dynamic building simulations.

2.1 Case Study Buildings and Data Sources

The four schools are mechanically ventilated educational buildings representing typical Finnish cold-climate design practices. For each school, the analysis focuses on a single representative classroom within a ventilation zone served by a central AHU. Ventilation design and commissioning documents provided information on airflow rates, specific fan power (SFP), heat-recovery efficiencies, operating schedules, and classroom characteristics, including space volume, occupancy capacity, the number of windows, and their automated operability.

2.2 Data Pre-Processing

IAQ time-series sensor data were recorded at two-minute intervals. This dataset was converted to a 15-minute resolution, implausible readings and long data gaps were removed, while short gaps below one hour were interpolated. In addition, a one-year climate data of the Espoo area within the same time frame was obtained from the Finnish Meteorological Service platform, providing hourly temperature, humidity, wind speed and Air quality index readings, which are required for assessing climate adaptability for natural ventilation [11]. Classroom occupancy was represented using a binary occupancy flag derived from school timetables and verified against CO_2 patterns exhibiting characteristic rising profiles during teaching hours.

2.3 Indoor Air Quality and Energy Assessment

Design airflows and occupancy figures were used to compute the airflow rate per person (L/s per person) and Air Change Rate (ACH) for each classroom. ACH in this study context is the nominal or design air change rate calculated from the documented classroom supply airflow rate and the classroom volume, rather than direct measurement of infiltration or envelope leakage-driven air exchange. Building airtightness and infiltration were not measured within the scope of this work, and CO_2-decay-based ACH estimation was not performed because the study relies on long-term operational monitoring and climate-based feasibility screening rather than controlled decay or tracer-gas testing.

These metrics enable comparison of nominal ventilation capacity across the four schools and assessment of whether design conditions align with observed IAQ outcomes. Mean, median, and 95th percentile CO_2 concentration, together with the rate of CO_2 exceedance over 1000 ppm, the proportion of occupied hours within 20-25 °C and relative humidity within 30-60% were estimated for occupancy periods. AHU fan power was evaluated using analytical estimation based on Specific Fan Power, airflow rate, and operating hours. For each analysed classroom, the classroom-level share of ventilation energy use was estimated as the share of the total ventilation area served by that AHU.

2.4 Hybrid Ventilation Feasibility Assessment
The feasibility of hybrid ventilation was assessed based on both outdoor climatic conditions and IAQ characteristics. The natural ventilation opportunity index (NVOI) based on both outdoor and IAQ triggers was defined as the fraction of occupied hours meeting two conditions:

1. Indoor CO_2 concentration exceeded 1000 ppm, a proxy for potentially inadequate ventilation rate per person during occupancy.
2. Outdoor temperature was within a comfort range suitable for window opening (16–24 °C).

$$\text{NVOI} = \frac{\text{Hours sartisfying condition 1 and 2}}{\text{Total occupied hours}}$$

This index quantifies the conditions under which natural ventilation can plausibly supplement or partially replace mechanical ventilation without inducing thermal discomfort. We also assessed hybrid ventilation opportunities for both occupied and non-occupied AHU-ON hours, based solely on energy savings, using outdoor climatic conditions as the natural ventilation trigger, provided that the IAQ metrics remain within the acceptable range. These were defined as:

$$\text{NVOI}_{\text{occupied}} = \frac{(16°\text{C} \leq Tout \leq 24°\text{C})\ (U \leq 8m/s)\ (AQ \leq 2)}{\text{Total occupied AHU-ON hours}}\ ,\ \text{NVOI}_{\text{non-occupied}} = \frac{(14°\text{C} \leq Tout \leq 20°\text{C})\ (U \leq 8m/s)\ (AQ \leq 2)}{\text{Total non-occupied AHU-ON hours}}$$

$Tout$= Outdoor temperature (16°C-24°C for Occupied NVO) and (14°C-20°C for Non-occupied NVO)
U= maximum wind speed ($\leq 8m/s$)
AQ= Outdoor air quality Index between 1 and 5 ($AQ \leq 2$)

Consequently, the feasibility of hybrid ventilation was quantified primarily as a climate-driven opportunity for fan energy savings, evaluated separately for occupied and non-occupied hours during which the AHU was still scheduled ON. The NVOI trigger thresholds were selected as practical feasibility screening limits to identify time periods when window-based natural ventilation is likely to be acceptable in terms of thermal comfort, draft risk, and outdoor air quality in the Espoo area.

For occupied hours, the outdoor temperature band of 16–24 °C was applied to reflect a comfort-oriented range for sedentary classroom use, with typical indoor comfort targets generally between 20°C and 24°C and up to 26°C in warmer conditions. For non-occupied (AHU-ON) hours, a more conservative 14°C to 20°C range was applied to reduce the risk of pre-occupancy overcooling or overheating and because adaptive comfort actions are less likely when rooms are empty. Outdoor air quality was screened using the Finnish Meteorological Institute Air Quality Index (1–5), restricting NVO opportunities to index ≤ 2 (good/satisfactory) to avoid recommending window opening when outdoor air may be less suitable for health.

The NVOI framework identifies hours suitable for potential window opening based on indoor/outdoor condition screening. It does not model detailed window-control granularity such as opening fractions, airflow through windows, or room-to-room interactions.

3. Results

3.1 Overview of Schools
The study was conducted in four Finnish elementary and early childhood schools in Espoo, a city in the Helsinki metropolitan area in southern Uusimaa, Finland. The schools are in a warm-summer humid continental (Dfb) climate, with cold winters below 0 °C and cool summers up to

22°C. IAQ sensor data were obtained from selected areas of each school, including classrooms, dining areas, corridors, laboratories, and recreational areas. CO_2, humidity, temperature, and VOC data were recorded between October 2024 and September 2025.

The selected classrooms for this study vary in size, occupancy profile, and ventilation system configuration. Jousenkaari School (Classroom C2.14a) and Tiistilä School (Classroom 2282) represent lower-secondary teaching environments, whereas Tapiola School (Classroom D1169) and Monikko (Classroom 3052) represent upper-secondary teaching environments with older students and longer daily periods. All four schools are connected to district heating, and the classrooms are served by central air-handling units equipped with heat recovery with either time-programmed or demand-based operation. Architecturally, each selected classroom has two windows, enhancing its suitability for hybrid ventilation from a facade and usability perspective. Table 1 gives an overview of the classrooms studied.

Table 1. Overview of the four selected classrooms.

School (Classroom)	Class volume	Class size	Occupancy schedule	Supply airflow	Share of fan power	Ventilation control	Ventilation operating schedule
Jousenkaari (C2.14a)	201.6 m³	21	Mon.9:15-14:30 Tue. 9:15 -19:30 Wed.10:30 -20:0 Thu. 8:30-13:30 Fri. 8:30-10.00	0.256 m^3/s	0.5 kW	DCV (based on T and CO_2 measurement)	Mon–Fri: 08:00–18:00 Sat: 07:00–18:00
Monikko (3052)	179 m³	19	Mon. 8:30 -13:00 Tue. 8:30 -14:30 Wed. 8:30 -14:30 Thu. 8:30-13:30 Fri. 8:30 -14:30	0.212 m^3/s	0.41 kW	DCV (CO_2-based step/level control)	Flush 05:30–07:30 (Mon–Sun). Partial power 19:30–05:30
Tapiola (D1169)	227.2 m³	21	Mon–Fri 08:15–14:30	0.226 m^3/s	0.34 kW	DCV (based on T and CO_2 measurement)	Mon.5:00-21:00 Tue- Fri 6:00 -21:00 Sat -Sun 10:00-12:00
Tiistilä (2282)	272 m³	22	Mon–Fri, 08:15–15:15	0.245 m^3/s	0.39 kW	DCV (based on T and CO_2 measurement)	Mon–Fri: 08:00–17:00, Sat: 07:00–16:00

3.2 Annual IAQ and Ventilation Performance Assessment.

A consolidated annual analysis indicated that all classrooms maintained low CO_2 during teaching periods, with mean CO_2 ranging from 510 ppm to 604 ppm, and that very little time exceeded 1000 ppm in all four classrooms, as shown by Table 2. Tapiola (D1169) was the exception, with a rare but notable peak of 2760 ppm that occurred within an hour of occupancy in February, possibly due to a sudden reduction in ventilation rate. Other notable increases in CO_2 occurred in November, with a higher frequency, and peaked at 1177.6 ppm. Tapiola also had the highest fraction CO_2 concentration above 1000 ppm during occupancy.

Across the four classrooms, temperature control differed more than CO_2 control. Jousenkaari and Tiistilä maintained high compliance with the 20°C-25°C band, while Monikko and Tapiola showed more hours outside this comfort interval. Relative humidity followed the expected Nordic pattern of winter dryness, with no classroom maintaining RH in the 30-60% band for most of the year except Tapiola.

Table 2. Analysis of IAQ and ventilation performance of classrooms across a year.

IAQ Metric	Jousenkaari (C2.14a)	Monikko (3052)	Tapiola (D1169)	Tiistilä (2282)
Mean CO_2	510 ppm	589 ppm	604 ppm	556 ppm
Median CO_2	469 ppm	533 ppm	511 ppm	502 ppm
95th percentile	706 ppm	833 ppm	922 ppm	784 ppm
99th percentile	751 ppm	873 ppm	1022 ppm	859 ppm
Max CO_2	1101 ppm	1126 ppm	2760 ppm	1029.5 ppm
CO_2 Exceedance % > 1000 ppm	0.023%	0.26%	1.80%	0.04%
Temp (20-25) °C	99.7%	92.7%	78.2%	95%
30–60% RH	45.5%	48.5%	53.5%	41.1%
Vent. rate L.s/p	12.2	11.2	10.8	11.1
ACH (h^{-1})	4.57	4.26	3.58	3.24

The ventilation performance of all four examined classrooms demonstrated sufficient ventilation capacity. Even Tapiola, with the lowest per-person rate of 10.8 L/person, remains comfortably above standard minimums, and all ACH values ranged from 3.25 h^{-1} to 4.6 h^{-1}, indicating strong classroom ventilation. This is consistent with the annual IAQ results, in which the mean occupied CO_2 concentration remains within a narrow band of 510-604 ppm across schools. The differences in CO_2 stability are driven more by control or operation than by designed airflow.

3.3 Hybrid Ventilation Feasibility Analysis

The opportunity for natural ventilation during teaching hours was initially estimated using the IAQ-triggered concept, with CO_2 exceedance combined with a mild outdoor temperature window. However, because CO_2 exceedances above 1000 ppm were not substantial in all classrooms, hybrid ventilation is not required for CO_2 compliance during lessons.

Table 3. Natural Ventilation Opportunity (NVO) Estimation.

School (classroom)	AHU Schedule	AHU ON occupied hours	AHU ON non-occupied	NVO - occupied hours	NVOI occupied	NVO non-occupied hours	NVOI non-occupied
Jousenkaari (C2.14a)	Time program (Mon–Fri 08–18; Sat 07–18)	983	2199	128	11.3%	466	21.2%
Monikko (3052)	Continuous (Flush + Partial power → treated ON 24/7)	759	8001	66	8.7%	1,451	18.1%
Tapiola (D1169)	Time program (Mon 05–21; Tue–Fri 06–21; Sat–Sun 10–12)	1316	2859	118	9.0%	604	21.1%
Tiistilä (2282)	Time program (Mon–Fri 08–17; Sat 07–16)	1316	1501	107	8.1%	360	24%

The analysis results, as indicated in Table 3, show two consistent patterns across the four schools. Firstly, the occupied-hour NVO is modest (8.1%-11.3%), reflecting the relatively limited fraction of teaching hours that coincide with suitable outdoor conditions in Espoo.

Secondly, the Non-occupied AHU-ON NVO is higher (18.1%-24.0%), indicating a substantial opportunity for pre-occupancy or off-hour natural-ventilation strategies to substitute for mechanical operation without compromising thermal comfort [12]. Monikko stands out due to its near-continuous ventilation schedule, resulting in the largest absolute pool of non-occupied AHU-ON hours

3.4 Potential Hybrid Ventilation Energy Savings
Potential fan energy savings were estimated analytically by using each classroom's allocated share of fan electricity consumption and the calculated NVO hours (occupied and non-occupied AHU-ON). This yielded an annual estimate of the potential reduction in fan energy consumption that would be achievable if the mechanical supply for these classrooms were reduced or disabled during NVO periods and replaced by a controlled natural ventilation system.

Table 4. Annual Potential Hybrid Ventilation Fan Energy Savings.

School (Classroom)	Share of fan power (kW)	NVO - occupied savings (kWh)	NVO non-occupied savings (kWh)	Total Annual potential savings (kWh)	Annual total AHU-ON hours	Annual total AHU-ON consumption (kWh)	Potential savings percentage
Jousenkaari (C2.14a)	0.5	64	233	297	3182	1591	18.7%
Monikko (3052)	0.41	27.1	594.9	622	8760	3591.6	17.3%
Tapiola (D1169)	0.34	40.1	205.4	245.5	4175	1419.5	17.2%
Tiistilä (2282)	0.39	41.7	140.4	182.1	2817	1098.6	16.6%

As shown in Table 4, the dominant energy-savings potential occurs during non-occupied AHU-ON periods rather than during teaching hours. This is driven by long daily time-program operations extending beyond classroom use, as shown by Jousenkaari, Tapiola, and Tiistilä, and by continuous or overnight operations in Monikko. In absolute terms, Jousenkaari exhibited the highest fan energy-saving potential, as a percentage of the total AHU fan energy consumption, for classroom C2.14a. Tiistilä exhibited the lowest total energy-saving potential, consistent with its non-occupied AHU-ON hours, despite having the highest percentage of non-occupied NVOI.

4. Discussion and Conclusion

4.1 Discussion
Across the four selected classrooms, the occupied-hours IAQ results show consistently low CO_2 levels (mean 510-604 ppm) and negligible time above 1000 ppm, indicating that the mechanical ventilation system air delivery is generally sufficient. Consequently, hybrid ventilation is not required to improve IAQ. This aligns with the ventilation design metrics as all classrooms have high nominal rates of 10.8 to 12.2 L/s·person and 3.25 to 4.57 h^{-1}, suggesting that most differences in CO_2 stability are not capacity-limited. The key exception is Tapiola (D1169), where rare but pronounced CO_2 peaks (max 2760 ppm; 1.8% >1000 ppm) occurred despite adequate nominal ventilation capacity. The ventilation information indicates that although sensors are present, the system appears to be dominated by a time program, and sensor signals do not seem to affect the ventilation rate in practice. In contrast, Tiistilä achieves strong CO_2 outcomes even

with the lowest ACH, consistent with the documented demand-controlled strategy applied at a block level.

The NVO analysis was structured to reflect two distinct control intents. During occupancy, NVO represents when mild outdoor conditions make window operation feasible without thermal discomfort (Tout 16-24°C). During non-occupancy while AHU is ON, a tighter window (T out 14°C-20°C) was used to avoid pre-occupancy overcooling or overheating while targeting fan energy savings. The unified analysis results showed that occupied-hours NVO is modest (8.1-11.3%), while non-occupied AHU-ON NVO is higher (18.1-24.0%). This difference is significant because the climate in Espoo offers limited comfortable window-opening hours during teaching periods but provides greater opportunities to replace mechanical ventilation during off-hours, when the AHU is operating unnecessarily relative to classroom use.

Using classroom-level shares of fan power and NVO hours, the estimated annual fan energy-saving potential ranges from 182 kWh to 622 kWh per classroom-zone share, representing 16.6% to 18.7% of the total AHU fan energy consumption. This result indicates that fan-energy savings are dominated by non-occupied AHU-ON periods, consistent with the NVO results and the ventilation schedules. These potential energy savings are interpreted as upper-bound, runtime-based fan-energy savings and may be lower, because demand-controlled systems often operate below nominal fan power.

4.2 Practical implications for AI-driven hybrid control in Finnish schools

Results for the selected classrooms suggest a prioritised control roadmap aligned with the study objectives. The priority is to improve ventilation control and classroom schedule alignment. In buildings where sensor inputs do not appear to influence ventilation, such as Tapiola, improving the Demand-controlled Ventilation (DCV) function or schedule logic is likely to yield immediate improvements in IAQ robustness and energy efficiency before introducing window-based hybrid ventilation strategies.

The second priority is to implement off-hour hybrid control (pre-ventilation or night purge). The non-occupied AHU-ON NVO results indicate a substantial safety margin for shifting the ventilation task from AHU fans to windows under screened conditions, particularly in systems with long daily schedules or continuous night modes.

The third priority is to use occupied-hour hybrid ventilation as an occasional supplement, rather than a baseline requirement.

4.3. Limitations of the Study

Occupancy was derived from timetables and cross-checked conceptually against CO_2 dynamics. However, deviations such as room changes, partial occupancy, and events can affect occupancy hours and NVO percentages.

Also, building air leakage/infiltration was not directly measured, and no CO_2 decay or tracer-gas tests were conducted. Therefore, the reported ACH values represent nominal/design ventilation capacity rather than measured air exchange under operational conditions.

Additionally, Energy savings were estimated for fan energy only (fan power share). Heat-recovery impacts are not included; therefore, net fan energy savings may be lower or, in some seasons, higher if pre-cooling reduces cooling demand. Lastly, Block-level or shared-zone DCV can prevent classroom level fan-off actions even when NVO conditions exist, particularly in systems like Tiistilä, where the worst condition in the ventilation zone logic governs airflow.

4.4. Conclusion

This study's analysis indicates that IAQ sufficiency is generally high under existing mechanical ventilation. The selected classrooms maintained low occupied-hour CO_2 and recorded negligible time above 1000 ppm. It appears that the designed ventilation capacity is adequate and operational, as the control dynamics explain the differences. All classrooms have high nominal ventilation rates, supporting the conclusion that differences in CO_2 stability are more closely related to schedule dominance, zoning, and DCV effectiveness than to insufficient airflow design.

Hybrid ventilation was not required to meet CO_2 compliance during lessons in all studied classrooms, but there is energy-saving potential, particularly during non-occupied hours. Occupied-hour NVO under mild outdoor temperatures is limited, whereas non-occupied AHU-ON NVO is higher due to the ventilation system schedules. The results indicate that the most practical hybrid ventilation strategy is to target non-occupied hours, when the AHU is operational, in addition to the minimal NVO periods during occupancy.

An AI-driven hybrid ventilation application for Nordic schools must include robust control strategies. It should prioritise streamlining DCV to ensure that IAQ sensors influence air supply as required, optimise ventilation schedules to match real-time space usage, and implement dynamic climate-screening occupied and off-hour window-opening strategies to reduce fan runtime without compromising thermal comfort.

The analysis in this study was limited to one classroom per school and to an analytical feasibility framework. Therefore, the results are in no means overgeneralised to all Finnish schools or all classrooms within the case buildings. Future work should cover broader validation through multi-room analysis and the evaluation of practical window-control implementation, including staging and modulating window-opening and classroom-zone interactions, using monitored trials and detailed airflow-control simulations.

Funding: This research was supported by the Research Council of Finland for the projects Sustain-School (Grant No. 359189) and DISCAS (Grant No. 362751).

References

[1] Ruusala A, Laukkarinen A, and Vinha J 2018 Energy consumption of Finnish schools and daycare centres and the correlation to regulatory building permit values Energy Policy vol. 119, pp. 183–195, Aug. 2018, doi 10.10 16/j.enpol

[2] Ahmed K, Hasu T, and Kurnitski J 2022 Actual energy performance and indoor climate in Finnish NZEB daycare and school buildings *Journal of Building Engineering* **vol. 56** doi: 10.1016/j.jobe.2022.104759.

[3] Turunen M, Toyinbo O, Putus T, Nevalainen A, Shaughnessy R, and Haverinen-Shaughnessy U 2014 Indoor environmental quality in school buildings, and the health and wellbeing of students *Int J Hyg Environ Health* **vol. 217** no. 7, pp. 733–739 doi: 10.1016/j.ijheh.2014.03.002.

[4] Vornanen-Winqvist C et al. 2018 Effects of ventilation improvement on measured and perceived indoor air quality in a school building with a hybrid ventilation system *Int J Environ Res Public Health* **vol. 15, no. 7** doi: 10.3390/ijerph15071414.

[5] Peng Y, Lei Y, Tekler Z D, Antanuri N, Lau S K, and Chong A 2022 Hybrid system controls of natural ventilation and HVAC in mixed-mode buildings: A comprehensive review *Elsevier Ltd*. doi: 10.1016/j.enbuild.2022.112509.

[6] Lestinen S, Kilpeläinen S, Kosonen R, Valkonen M, Jokisalo J, and Pasanen P 2021 Effects of night ventilation on indoor air quality in educational buildings - a field study *Applied Sciences (Switzerland)* **vol. 11, no. 9** doi: 10.3390/app11094056.

[7] Brager G S, Ring E, and Powell K UC Berkeley HVAC Systems Title Mixed-mode ventilation: HVAC meets mother nature Available: https://escholarship.org/uc/item/0285m0h1

[8] Otoo C, Lu T, and Lü X, 2024 Application of Mixed-Mode Ventilation to Enhance Indoor Air Quality and Energy Efficiency in School Buildings *Multidisciplinary Digital Publishing Institute (MDPI)*. Doi: 10.3390/en17236097.

[9] Chen Y, Norford L K, Samuelson H W, and Malkawi A 2018 Optimal control of HVAC and window systems for natural ventilation through reinforcement learning *Energy Build* **vol. 169** pp. 195–205 doi: 10.1016/j.enbuild.2018.03.051.

[10] Ala'raj M, Radi M, Abbod M F, Majdalawieh M, and Parodi M, 2022 Data-driven based HVAC optimisation approaches: A Systematic Literature Review *Elsevier Ltd*. doi: 10.1016/j.jobe.2021.103678.

[11] Causone F 2015 Climatic Potential for Natural Ventilation *Architectural Science Review* doi:10.1080/00038628.2015.1043722.

[12] Faggianelli G A, Brun A, Wurtz E, and Muselli M, 2014 Assessment of natural ventilation potential for summer comfort in buildings on mediterranean coastal zones." https://doi.org/10.1016/J.enbuild.03.042.