University of Sopron

Roth Gyula Doctoral School of Forestry and Game Management

Theses of the doctoral (PhD) dissertation

Application of the Earth Air Heat Exchanger (EAHE) as sustainable technology for energy efficiency in building

Nadjat Kouki

Sopron
2026

Table of contents **Page**

1. INTRODUCTION

1.1 Background and Motivation of Research

Reducing greenhouse gas emissions is a primary objective for every country. 2018/844 European Union's Directive mandates the establishment of a sustainable, decarbonized, secure and competitive energy system by 2050 [1]. Member states must outline a strategic plan with actions directed at achieving the long-term objective of greenhouse gas emissions reduction between 80–95% by 2050, relative to 1990 levels. This aims to guarantee a national building stock that is both highly energy-efficient and decarbonized, while also enabling the cost-effective conversion of present structures into almost zero-energy buildings [1].

In Hungary, the residential sector represents the largest proportion (32%) of the country's energy consumption [2] and around 65% is used for heating [3]. Passive heating/cooling solutions have experienced notable progress during the previous decade. Among them, ground heating/cooling, especially earth-to-air heat exchangers (EAHE) has been highlighted as sustainable attractive technological research subjects. EAHE featured with its ability in the enhancement of the indoor thermal comfort; significant contribution to the reduction of heating/cooling energy loads and the improvement of the urban environment. Aligned with the European Union's decarbonisation goals, growing attention is being paid to the energy performance of non-residential structures, with a particular emphasis on educational institutions. These facilities must maintain adequate indoor air quality and thermal comfort while minimizing energy uses, as their Heating, Ventilation, and Air Conditioning (HVAC) systems generally function at high power levels.

Traditional research on the EAHE has mainly focused on its usage as standalone systems for pre-heating or pre-cooling a building through a comprehensive optimization of geometric and thermos-physical parameters to find the optimal system design depending on the location and the site of installation. However, when it comes to the integration of this system into standard mechanical ventilation systems such as Air Handling Unit (AHU), there is a remarkable lack of information, and the available literature remains limited. This knowledge gap is particularly evident in school buildings, which are featured by high ventilation rates, fixed occupancy schedules, strict indoor air quality requirements and significant peak ventilation loads. Consequently, school buildings serve as a significant yet insufficiently examined area for integration of EAHE and AHU, highlighting the importance of their potential effects on peak HVAC design loads and system sizing.

1.2 Research Problem

Building account for 38-40% of worldwide energy usage, with HVAC systems playing a significant role [4] . This contribution is particularly robust in educational institutions, owing to stringent outdoor air ventilation rates, indoor air quality (IAQ) standards, and occupancy schedules. According to ASHRAE Standard 62.1 and CEN EN 16798-1 [5], [6] , educational buildings require higher fresh-air flow rates per occupant than other building types, making ventilation a key HVAC system design issue. Consequently, standard Air Handling Units in educational institutions are required to continuously condition huge quantities of external air to ensure indoor comfort in regions with substantial seasonal fluctuations, resulting in high peak heating and cooling needs and increase reliance on mechanical conditioning. To the author's knowledge, the current situation in Hungary shows that many school buildings rely predominantly on natural ventilation through window opening to control indoor air quality, without widespread implementation of centralized mechanical ventilation systems [7] and the state- of-art lacks a global efficiency assessment of a hybrid HVAC system with an EAHE located upstream of the AHU. Giving this gap then, encouraging the integration of AHU-based ventilation system with passive system like EAHE would align with EU policy trends, improve indoor environmental quality and support energy-efficient building operation in new and renovated Hungarian schools.

1.3 Research Objectives

Within the research gap context, the main objective of this study is to evaluate the effectiveness of integrating an EAHE upstream of an AHU in a school building, by quantifying the reduction in peak heating and cooling coil loads required to condition outdoor ventilation air on design days. This evaluation is conducted through a psychrometric-based analysis of the thermal and hygrometric transformations of air, comparing a baseline AHU system without EAHE to a hybrid EAHE–AHU configuration under different climatic conditions. To achieve this objective, the study pursues the following specific aims: (i) to model the pre-conditioning effect of the EAHE on outdoor air in terms of temperature, humidity ratio, relative humidity, and specific enthalpy; (ii) to quantify the impact of EAHE integration on the sensible and latent loads handled by the AHU heating and cooling coils under summer and winter design conditions; and (iii) to compare the peak heating and cooling coil capacity requirements of the AHU for baseline and EAHE-assisted configurations, highlighting the associated reduction in peak HVAC power demand relevant to coil sizing in school-building applications.

1.4 Research Questions

In order to comprehend the operation of the hybrid HVAC system associated with EAHE placed before the AHU in different European climates, many study inquiries were formulated. These inquiries comprise:

1. How does the incorporation of EAHE upstream an AHU modify the thermal and hygrometric outdoor air properties under summer and winter design conditions in school building?
2. What is the impact of EAHE on the thermal loads handled by AHU coil when conditioning the ventilation outdoor air on design days?
3. What is the reduction achieved by the hybrid EAHE-AHU configuration in peak heating and cooling coil capacity requirements compared to a conventional baseline AHU in education building?
4. Can the integration of EAHE as passive pre-conditioning technology be a feasible and energy-efficient retrofit approach for educational facilities that need regulated mechanical ventilation?

2. RESEARCH METHODS

2.1 Methodological Approach

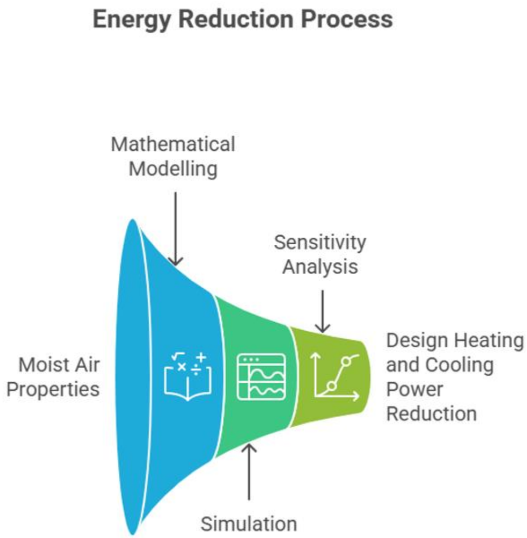


Figure 1. Research Methodology diagram (Source: Author's idea, developed by Napkin)

2.2 Methodological Framework

The main analytical steps adopted in this study are the following:

- Calculation of the required outdoor air flow rate based on floor area and number of occupants in accordance with EN 16798-1.
- Configuration of a hybrid ventilation system with an Earth–Air Heat Exchanger (EAHE) installed upstream of the Air Handling Unit (AHU).
- Psychrometric analysis of outdoor, EAHE-conditioned, and supply air states using the psychrometric chart.

- Mathematical modelling of heat and moisture transfer within the EAHE and calculation of AHU heating and cooling coil capacities for configurations with and without EAHE.
- Quantification of sensible and latent ventilation load reductions and assessment of EAHE performance under different climatic conditions.

3. RESULTS AND NEW SCIENTIFIC FINDINGS

3.1 Computed input parameters and boundary conditions

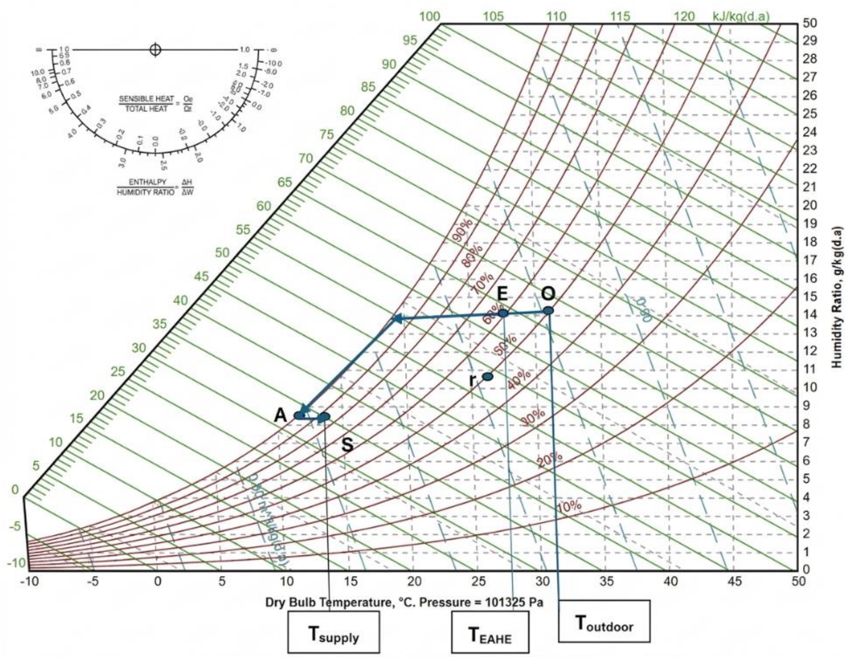
3.1.1. Ventilation flow rate

The ventilation requirements were determined in accordance with EN 16798-1, accounting for both floor area and occupancy levels and it equivalent to 10692 m^3/h. The calculated outdoor air flow rates satisfied indoor air quality criteria for all examined scenarios and served as the baseline for subsequent system sizing and performance comparison.

3.2. Transformation of Humid Air

3.2.2. Psychrometric Properties of Humid Air

Psychrometric analysis showed a clear shift in air state conditions due to the EAHE. Compared to untreated outdoor air, EAHE-conditioned air exhibited reduced temperature fluctuations and partial moisture moderation. Consequently, the supply air state approached comfort conditions with reduced reliance on mechanical heating and cooling.


100
105
110
115
120
kJ/kg(d.a)
SENSIBLE HEAT / TOTAL HEAT = Qs/Qt
ENTHALPY / HUMIDITY RATIO = ΔH/ΔW
90%
80%
70%
60%
50%
40%
30%
20%
10%
E
O
r
A
S
0.80
0.90 m³/kg(d.a)
Humidity Ratio, g/kg(d.a)
Dry Bulb Temperature, °C. Pressure = 101325 Pa
Tsupply
TEAHE
Toutdoor

Summer

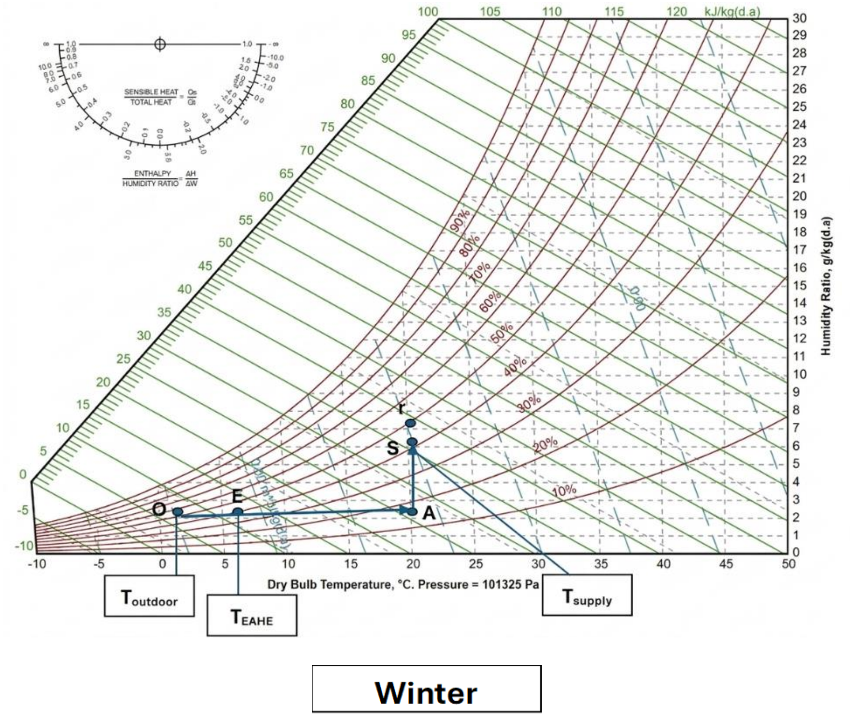


Figure 2. Representation on the psychrometric chart of the humid air treatment processes in the air handling unit for heating and cooling modes

3.3. Thermal performance and the impact of EAHE

Mathematical modelling of heat and moisture transfer within the EAHE demonstrated effective thermal interaction between the air and surrounding soil.

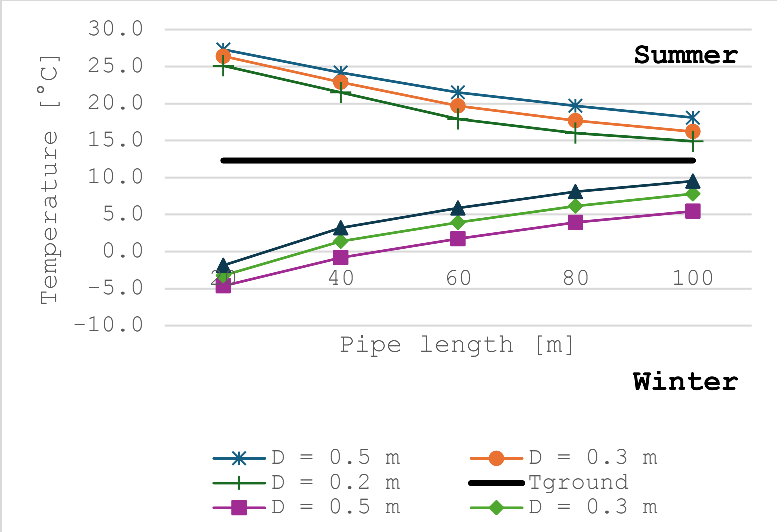
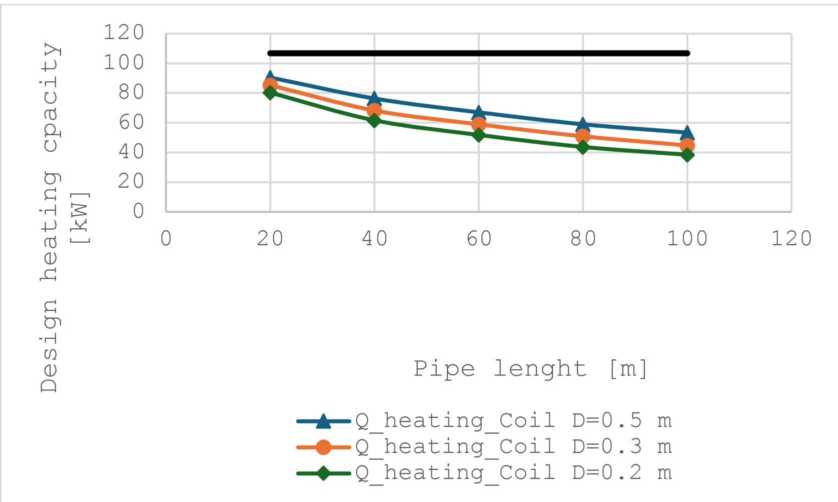


Figure 3. Temperature of the air at the exit of EAHE for different pipe lengths

When the EAHE was included, calculated AHU heating and cooling coil capacities were significantly lower than in the reference system without EAHE.



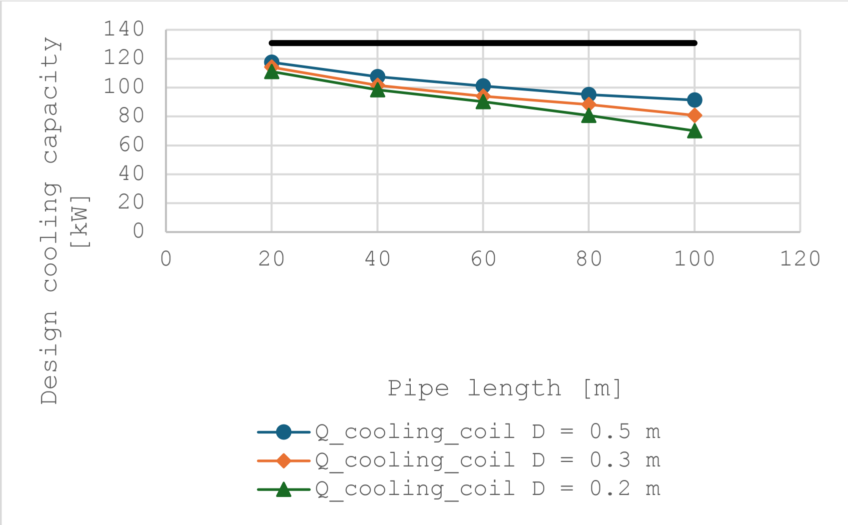


Figure 4. Design heating/cooling coil capacity variation when using EAHE

3.4. Reduction of AHU design power demand

The quantification of ventilation loads revealed substantial sensible load reductions, particularly in extreme outdoor temperature conditions. EAHE performance was found to be climate-dependent, with the highest benefits achieved in regions with large seasonal temperature variations as observed in Budapest.

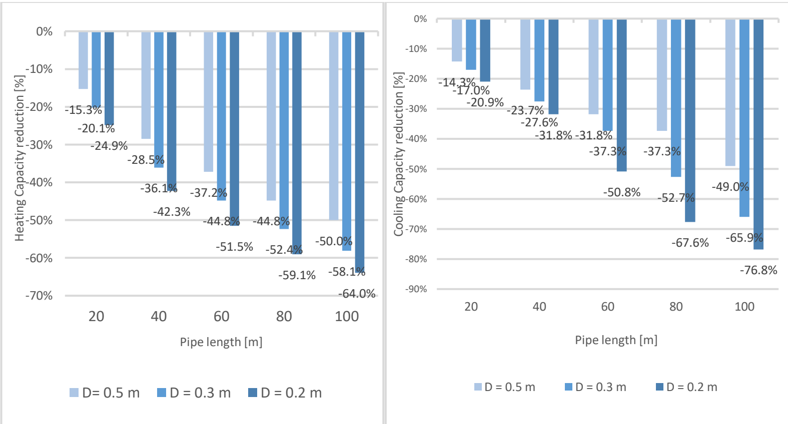


Figure 5. Reduction of heating/cooling design coil capacity with EAHE for Budapest.

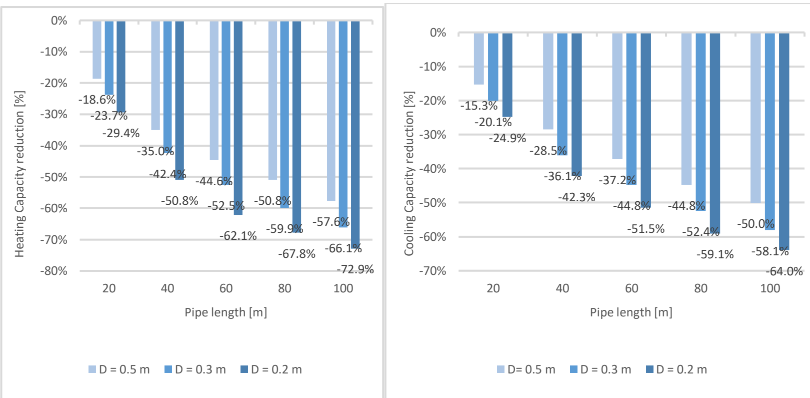


Figure 6. Reduction of heating/cooling design coil capacity with EAHE for Naples.

In accordance with Hungarian regulations, the operational timeframe for a heating system is set from 15 September until the end of March, limited to a duration of 10 hours per day. In contrast, Naples has its heating period from mid-November to March, also with a restriction of 10 hours per day. The results evident that while the decrease in design heating coil capacity is more pronounced in

Naples (72.9%) than in Budapest (64%), the small reduction in a Continental climate is considered highly significant due to the long operational duration of the heating system, suggesting a subsequent increase in energy consumption. Further, considering the climatic characteristics, the operative period for the cooling system for Naples is established from early June to late July, lasting 6 hours each day. In contrast, for Budapest, the same period is designated for only 4 hours daily. The outcomes indicated that the impact of the cooling coil design capacity reduction is more significant in Budapest (76.8%); however, when taking into account the longer operational period of the system during the cooling season in Naples, the capacity reduction in the cooling coil (46.6%) becomes more critical.

4. CONCLUSIONS AND RECOMMENDATIONS

4.1 Conclusions

- This study proposes a fresh air technic comprising an earth-air heat exchanger (EAHE) and Air Handling Unit (AHU), to solve the problem of insufficient fresh air and save primary power use in severe cold or warm to hot regions.
- The analysis confirms that the performance of the EAHE is strongly dependent on the geometric characteristics of the buried pipe.
- Among all configurations analysed, the combination of a 0.2 m diameter and a 100 m length demonstrated the highest thermal efficiency, reaching approximately 88%, and produced the most significant temperature variation between the inlet and outlet of EAHE. This temperature fluctuations account 18.6°C in winter and 17°C in summer

for Budapest while, for Naples it is around 12.9 °C in winter 13°C in summer.

- Additionally, under design day condition, the D=0.2 m and L=100 m configuration led to an important reduction in the peak power of the AHU, equivalent to 64% and 72.9% in the heating season while it reached 76.8% and 46.4% in the cooling season for Budapest and Naples respectively. This signification reduction relative to the baseline AHU, confirm the best performance of the suggested configuration.

4.2. Recommendations and future development

Among the recommendations to develop this study is to:

- Complement coil-load reduction with annual performance to calculate the annual energy savings.
- Conduct techno-economic analyses.
- Promote mechanical ventilation (AHU) adoption in Hungarian schools aligned with EU policy.

5. New scientific findings

a) Contribution to knowledge: EAHE-AHU integration to school ventilation in the Budapest climate:

In this research, a bibliographic coupling network of countries is done to better understand which of them are active in the investigation on Earth–Air Heat Exchangers integrated with Air Handling Units and the results are presented in Figure 7. Where the dominant contributor and central intellectual hub according to the analysis is Italy, showing a high bibliographic connection to China and in a limited way to Portugal, and Hungary, meaning that these countries shared theoretical and methodological foundation. The findings of the literature review shows that the evaluation of an EAHE implemented upstream an AHU specifically for Budapest design day coil load reduction in a school building ventilation context remains barely reported in the open literature, as earlier studies related to Hungary and Central European climates, including comparative studies that feature Budapest focus on EAHE performance in different building typologies. Therefore, based on our research findings, there is a huge opportunity to conduct this research on hybrid system in Hungary.

Figure 7. Network of bibliographic coupling among nations engaged in the study of EAHE combined with AHU.

Further, In the present study we combine several research key words related to the topic of EAHE-AHU hybrid system including indoor air quality, air conditioning, EAHE, AHU, energy efficiency and shallow geothermal energy, highlighting the temporal evolution of the field based on average publication year, as Figure 8 illustrated. Based on this bibliometric analysis, there is a clear thematic shift in recent years (2020-2025) toward the integration of EAHE within mechanical air conditioning systems. In general, the researchers focused on isolated heat transfer mechanisms, meanwhile in the last recent five (05) years, a transition from the earliest studies aim toward applied research addressing whole system performance and environmental impact is suggested. We concluded this research shift by emerging keywords such as energy efficiency, air handling unit and capacity reduction. In contrast, older keywords related to fundamental cooling systems and numerical modelling appear predominantly in earlier periods, reflecting their role as the conceptual foundation of the field. Overall, the overlay visualization confirms that recent EAHE–AHU research is increasingly application-driven, performance-oriented, and aligned with low-carbon building objectives, underscoring the timeliness and relevance of further investigation in this area.

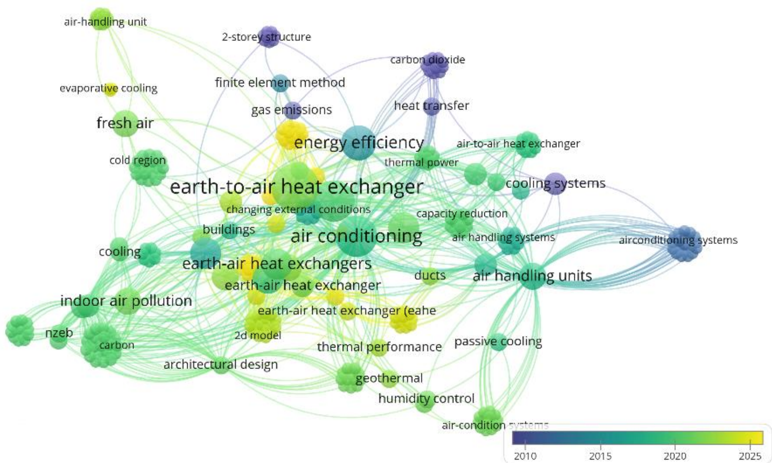


Figure 8. Visualization of keywords co-occurrence in EAHE–AHU research in the last recent 5 years (data retrieved from Scopus database on 27 January 2025)

b) Reduction of load at AHU level based on climate-dependent:

The reduction in coil capacity of the existing AHU mechanical ventilation system that we calculated in research are comparable to and in some cases exceed, those that were documented in earlier research on the integration of EAHE and HVAC systems. According to the literature, D'Agostino et al. [8] conducted an analysis of a similar EAHE pre-treating unit that was integrated with an air-conditioning system, examining its performance across different global climates. The results showed that, with a duct length of 100 m, the reductions in coil capacity ranged from about 24% to 65%, influenced by the climatic zone. Ben Ali et al. [9] examined the performance and cost benefits of an EAHE integrated with an AHU, noting a significant decrease in mechanical cooling needs. Under favourable design conditions, the analysis quantifies the compressor power savings as 38.2%, leading to annual operational cost reductions of about 1470 $, with a feasible 3.8-year payback period. A similar trend is observed when these findings are examined alongside with yearly simulations and monitoring studies. Zhang et al. [10] performed an assessment of an EAHE-assisted ventilation system in the framework of a hot-summer and cold-winter climate in China. The results demonstrated seasonal decreases of approximately 16% in cooling energy requirements and 50% in heating needs for ventilation air. Whitin this framework, the current analysis indicates that integrating an EAHE pre-conditioning before AHU yields a greater heating coil demand reduction (64%) in the continental climate of Budapest, while the reduction in cooling coil capacity is more significant in the Mediterranean climate of Naples (46.4%), reflecting the dominant heating or cooling characteristics of each climate. The results of our research are justifiable as the current research focus on design day peak loads in two selected climates, in contrast with the previous investigations.

c) Translation of EAHE performance into HAVC design metrics:

This work assesses EAHE advantages through mechanical ventilation system loads. Among all the configurations analysed (D=0.5 m, D=0.3 m, D=0.2 m) and (L=20, 40, 60, 80, 100 m), the 0.2 m diameter and 100 m length pipe achieved the highest thermal efficiency (≈88%) and the greatest inlet–outlet air temperature difference equal to 18.6°C in winter and 17°C in summer for Budapest while, for Naples it is around 12.9 °C in winter 13°C in summer. Our research findings are consistent with Zhang et al. [10]. This improved thermal conditioning of the supply air through the integration of the EAHE translated directly into significant reductions in HVAC design loads. In winter, our optimal EAHE configuration reduced the design heating coil capacity by up to 64% in Budapest and 72.9% in Naples. In summer, the design cooling coil capacity was reduced by 76.8% in Budapest and 46.4% in Naples. These reductions confirm the effectiveness of EAHE, which directly support HVAC system size reduction and peak power demand evaluation.

d) Interpretation of psychrometric-based approach:

By analysing the fluctuations in humidity ratio and specific enthalpy, we confirm through the present study that latent load mitigation acts as key role in the hybrid system summer performance. Specifically, in the continental climate, the humidity ratio decreased from 14g/kg at the EAHE inlet to 11 g/kg at the outlet, corresponding to a latent moisture removal of $\Delta\omega$=3 g/kg. This dehumidification process resulted in a latent enthalpy reduction of approximately 7.5 kJ/kg (the calculations in our research are done using latent heat of vaporization equal to 2501 kJ/kg). While in the Mediterranean climate, the humidity ratio decreased from 14.8 g/kg at the EAHE inlet to 13 g/kg at the outlet, corresponding to reduction in latent enthalpy of 2.5 kJ/kg. According to the calculations related to the air properties at the inlet and outlet of EAHE (provided in Annex 2 for Budapest case) and (provided in Annex 3 for Naples case), the sensible cooling reflected as temperature reduction remains the dominant component; however, the latent contribution represents around one-third (almost 29%) of the EAHE summer cooling effect which is associated with moister removal in the case of Budapest and around 15% in the case of Naples.

e) Cross-climate comparison with consistency:

In our research we modelled an identical school building geometry (total floor area of 1534 m^2) and envelope thermal performance (floor U=0.27 W/m^2K, windows U=1.70 W/m^2K, roof U=0.26 W/m^2K and wall U=0.19 W/m^2K) with a fixed ventilation demand of 10692 m^3/h calculated based on EN 16798-1 standard, identical EAHE-AHU system configuration and occupancy schedules from 8:30 a.m. to 2:30 p.m. for 347 person under two different European climates (Budapest and Naples) on a design day condition. Our aim is aligned with the European Union's decarbonisation goals by conducting a robust and transferable framework for assessing and comparing the effectiveness of the proposed hybrid ventilation technology across different climatic regions according to Koppen classification (Budapest: Cfa and Naples: Csa). The research primarily focuses on providing the adequate thermal indoor comfort condition which is established according to EN16798-1:2019 in schools (classroom) to be within the range of 20-24°C in winter and 23-26°C in summer both at equal relative humidity of 50% and ensuring indoor air quality while minimizing the energy consumption. Thereby in the adopted approach we maintain all the parameters related to the building and they EAHE-AHU system constant and varying only climate dependent inputs such as outdoor air temperatures (-9.1°C and 32°C in Budapest) (2.3°C and 31.8°C in Naples) based on 99% occurrence of ASHRAE handbook [11] and ground temperature (12.3°C in Budapest and 17°C in Naples) according to Kusuda-Achenbach equation.

f) the need for multi-objective optimization in EAHE design:

It has been widely documented in the literature related to EAHE system, that longer pipes and smaller diameters enhance the effective heat-transfer surface and extend the residence time of the airflow, which in turn improves thermal performance. However, these design choices also result in increased frictional pressure losses. Consequently, the required fan power increases as the system is sized for greater heat exchange [12], [13]. This trend has been observed in our study as well. Under design day circumstances, according to the calculations we have done by decreasing the pipe diameter from 0.5 m to 0.2 m and increasing pipe length from 20 m to 100 m in the reason of improving soil-air heat transfer, the associated fan power of the hybrid system is simultaneously increasing from 2.15 kW to 2.24 kW (provided in Annex 4), which means more need for electrical energy (more initial cost). In parallel, the literature confirms that extending the pipe length or augmenting the number of pipes leads to elevated installation expenses, since material, excavation, and installation costs are typically calculated on a unit-cost-per-meter basis, resulting in a roughly linear increase in capital costs relative to the total pipe length. According to the economic analysis of Ben Ali et al. [9], the installation expenses grow linearly with pipe length ($370/m). Thus, in this context and in the absence our own economic analyses, we may conclude based on the existing studies that optimal EAHE design cannot be determined solely by thermal efficiency but should be based on a multi-objective optimization approach that balances heat exchange performance with ventilation energy requirements.

6. Dissertation Theses

1. **The integration of an Earth-to-Air Heat Exchanger (EAHE) with an Air Handling Unit (AHU) achieves peak-load performance comparable to international benchmarks under day boundary conditions:** the calculated reductions in heating and cooling coil capacities of the existing AHU system indicate that EAHE pre-conditioning can achieve performance comparable to, and in some cases better than, results reported in previous international studies. Earlier research has shown coil capacity reductions of 24–65%, compressor power savings of around 38%, and seasonal energy demand reductions of up to 50%. In comparison, the present design-day analysis shows a 64% reduction in heating coil demand in the continental climate of Budapest and a 46.4% reduction in cooling coil capacity in the Mediterranean climate of Naples. These findings highlight that the performance of EAHE–AHU integration strongly depends on climatic conditions and becomes particularly significant under peak load scenarios. Therefore, this study provides new insight by focusing specifically on design-day peak performance, rather than on annual or seasonal evaluations as in most previous research.
2. **An optimized EAHE configuration (0.2 m diameter, 100 m length) achieves up to 88% thermal efficiency, enabling an important HVAC peak load reductions under design-day boundary conditions in continental and Mediterranean climates:** the parametric analysis of EAHE configurations demonstrates that a 0.2 m diameter and 100 m length pipe provides the highest thermal

efficiency (≈88%) and the largest supply air temperature modification, reaching 18.6°C in winter and 17°C in summer in Budapest, and approximately 12.9–13°C in Naples. This enhanced pre-conditioning performance directly results in substantial reductions in HVAC design loads. The optimal configuration achieved heating coil capacity reductions of up to 64% in Budapest and 72.9% in Naples, while cooling coil capacity decreased by 76.8% in Budapest and 46.4% in Naples. These findings confirm that EAHE integration significantly contributes to HVAC system downsizing and peak load mitigation under design conditions.

3. **Thermodynamic analysis confirms that EAHE integration significantly mitigates latent loads under summer design-day boundary conditions in Central of Hungary and South of Italy:** the thermodynamic analysis of humidity ratio and specific enthalpy confirms that latent load mitigation plays a significant role in the summer performance of the hybrid EAHE–AHU system. In the continental climate of Budapest, the humidity ratio decreased from 14 g/kg to 11 g/kg ($\Delta\omega$ = 3 g/kg), corresponding to a latent enthalpy reduction of approximately 7.5 kJ/kg, while in the Mediterranean climate of Naples the latent enthalpy reduction was 2.5 kJ/kg. Although sensible cooling remains the dominant component of the EAHE summer effect, the latent contribution accounts for nearly 29% of the total cooling impact in Budapest and approximately 15% in Naples. These findings demonstrate that moisture removal constitutes a substantial performance factor in continental

climates and must be considered in hybrid system peak load evaluation.

4. **The study is transferable optimization framework that isolates climatic influence on hybrid EAHE–AHU systems by maintaining identical building geometry and ventilation demands while varying design-day boundary conditions for Budapest and Naples:** This research develops a robust and transferable comparative optimization framework for evaluating hybrid EAHE–AHU ventilation systems under different European climatic conditions by maintaining identical building geometry (1534 m^2), envelope thermal properties, ventilation demand (10692 m^3/h in accordance with EN 16798-1), system configuration, and occupancy schedules, while varying only climate-dependent boundary conditions. The analysis, conducted for design-day scenarios in Budapest (Cfa) and Naples (Csa), isolates the climatic influence by applying standardized outdoor air temperatures (99% ASHRAE occurrence) and ground temperatures derived from the Kusuda–Achenbach equation. Within this framework, system performance is evaluated through the optimization of thermal comfort (20–24°C in winter, 23–26°C in summer, 50% RH), indoor air quality requirements in school classrooms while minimizing energy consumption, enabling a climate-sensitive assessment of optimal operating conditions in line with European Union decarbonisation objectives.

5. **Multi-objective parametric analysis reveals that optimal EAHE design requires balancing thermal**

efficiency against increased fan power and linear installation costs when varying pipe geometry under design-day load conditions: The parametric analysis highlights the need for multi-objective optimization of EAHE design parameters, particularly pipe length and diameter. While increasing pipe length and reducing diameter improve thermal performance by enhancing heat-transfer surface area and airflow residence time, these changes simultaneously increase frictional losses, fan power demand, and installation costs. Under design-day conditions, reducing the pipe diameter from 0.5 m to 0.2 m and extending the length from 20 m to 100 m increased the required fan power from 2.15 kW to 2.24 kW, while installation costs scaled approximately linearly with pipe length (≈370 USD/m). These results demonstrate that optimal system design requires balancing competing objectives, including heat exchange effectiveness, ventilation energy demand, and economic investment, rather than maximizing thermal performance solely.

7. Author's scientific publications

- Vityi Andrea; Diana D'Agostino; Nadjat Kouki; Federico Minelli; Francesco Minichiello. Reduction of the HVAC system size in school buildings through Earth-to-Air Heat Exchangers (EAHE). Case Studies in Thermal Engineering. Volume 81 (2026) 108025. DOI: 10.1016/j.csite.2026.108025. Q1.

- Kouki Nadjat; D'Agostino Diana; Vityi Andrea. Properties of Earth-to-Air Heat Exchangers (EAHE): Insights and Perspectives Based on System Performance. ENERGIES 18: 7 Paper: 1759, 16 p. (2025). DOI: 10.3390/en18071759. Q1

- Kouki Nadjat; Vityi Andrea; Belatrache, Djamel. Exploring Earth Air Heat Exchanger as an Innovative and Sustainable Application for Cooling and Heating. WASTE FORUM 2025: 3 pp. 205-223., 19 p. (2025). Q4

- Diana D'Agostino, Nadjat Kouki, Federico Minelli, Francesco Minichiello. Application of Earth-to-Air Heat Exchangers (EAHE) for Sustainable Energy Management in School Buildings. Journal of Physics: Conference Series 3143 (2025) 012050. ATI Annual Congress (ATI 2025), IOP Publishing. DOI:10.1088/1742-6596/3143/1/012050. Q4

- Kouki Nadjat; Vityi Andrea. The Use of Geothermal Energy for Sustainable Development and Economic Prosperity. Sopron, Magyarország : Soproni Egyetem Kiadó (2024) 821 p. pp. 365-379., 15 p. DOI: 10.35511/978-963-334-499-6.

- Saadi Zine; Kouki Nadjat; Boukhlef Djedjiga; Allali Malika; Amina Bekraoui; Abdelkrim Rouabhia. Experimental Analysis on Performance of a Solar Photovoltaic/Thermal (PV/T) Air Collector with a Single Pass. Advanced Computational Techniques for Renewable Energy Systems. Springer International Publishing (2023) pp. 770-776. Paper: Chapter 78, 7 p. DOI: 10.1007/978-3-031-21216-1_78.

8. References

[1] 19.6.2018 Official Journal of the European Union, 'Directive (EU) 2018/844 of the European Parliament and of the Council of 30 May 2018 amending Directive 2010/31/EU on the Energy Performance of Buildings and Directive 2012/27/EU on Energy Efficiency', Accessed: Jun. 10, 2025. [Online]. Available: https://eur-lex.europa.eu/eli/dir/2018/844/oj

[2] Hungarian Central Statistics Office, '5.7.1. Final energy consumption', Accessed: Jun. 14, 2025. [Online]. Available:

https://www.ksh.hu/docs/eng/xstadat/xstadat_annual/i_ui009.html

[3] Hungarian Central Statistics Office, 'Household energy consumption, 2008', *CSO Bp.*, 2010.

[4] M. González-Torres, L. Pérez-Lombard, J. F. Coronel, I. R. Maestre, and D. Yan, 'A review on buildings energy information: Trends, end-uses, fuels and drivers', *Energy Rep.*, vol. 8, pp. 626–637, Nov. 2022, doi: 10.1016/j.egyr.2021.11.280.

[5] European Committee for Standardization (CEN), *EN 16798-1: Energy Performance of Buildings – Ventilation for Buildings – Part 1: Indoor Environmental Input Parameters*, Brussels, Belgium., 2019.

[6] American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE), *ANSI/ASHRAE Standard 62.1: Ventilation for Acceptable Indoor Air Quality*, Atlanta, GA, USA,., 2019.

[7] Interreg, Central Europe, InAirQ, *National Indoor Air Quality (IAQ) Action-Plan-Hungary*, Version 1. Hungary, 2018.

[8] D. D'Agostino, A. Greco, C. Masselli, and F. Minichiello, 'The employment of an earth-to-air heat exchanger as pre-treating unit of an air conditioning system for energy saving: A comparison among different worldwide climatic zones', *Energy Build.*, vol. 229, p. 110517, Dec. 2020, doi: 10.1016/j.enbuild.2020.110517.

[9] N. B. Ali *et al.*, 'Performance and cost-benefit analysis of an integrated earth-air heat exchanger and air handling unit system', *Sci. Rep.*, vol. 16, no. 1, p. 2478, Dec. 2025, doi: 10.1038/s41598-025-32275-5.

[10] C. Zhang, J. Wang, L. Li, F. Wang, and W. Gang, 'Utilization of Earth-to-Air Heat Exchanger to Pre-Cool/Heat Ventilation Air and Its Annual Energy Performance Evaluation: A Case Study', *Sustainability*, vol. 12, no. 20, p. 8330, Oct. 2020, doi: 10.3390/su12208330.

[11] American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE), 'Handbook - Fundamentals, (SI) ed.; ASHRAE: Atlanta, GA, USA'. 2017.
[12] T. S. Bisoniya, 'Design of earth–air heat exchanger system', *Geotherm. Energy*, vol. 3, no. 1, p. 18, Dec. 2015, doi: 10.1186/s40517-015-0036-2.
[13] Abdessamia Hadjadj, Boubaker Benhaoua, Abdelmalek Atia, Abderrahmane Khechekhouche, and Nacer Lebbihiat, 'Influence of parameters on performance of earth air heat exchanger in arid and hot climate', presented at the International Pluridisciplinary PhD Meeting (IPPM'20), ECHAHID HAMMA LAKHDAR UNIVERSITY - EL-OUED, 26/02 2020.