Enhancing Natural Ventilation in Family House Buildings in Hungary by Integrating Passive Air Conduction Systems

A Thesis Brochure

by

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1. Introduction

1.1. Abstract

In the time of climate change, it is fairly argued that humankind is perhaps facing the most serious existential threat throughout its entire history on planet Earth. At the same time, there is an overwhelming body of evidence that proves the responsibility of humankind for triggering global warming and climate change, specifically after the industrial revolution that started in the middle of the 18th century. Since then, greenhouse gases (GHGs) have been rapidly emitted and have accumulated in the atmosphere causing the global greenhouse effect. Climate change has been threatening our way of living by the increasing extreme weather events and the degradation of ecosystems. The rapidly growing global population, on the other hand, is putting more pressure on our resources and involving more aspects in the climate challenge like the social, economic, and political aspects. Therefore, it is absolutely necessary to organize a global collective collaboration of governments, agencies, professional bodies, decision-makers, and experts to take actions that are based on scientific ground, in order to mitigate climate change and adapt to it. Since the topic of climate change is not exclusive to a certain field of science, researchers from multiple research areas are getting increasingly involved in sustainability-related research in their own fields to investigate and suggest considerable improvements that could be applied in daily life.

Architects and researchers in the field of architecture and building physics are not an exception from being involved in climate-related and sustainability-oriented studies and research activities. On the contrary, it is essential to further improve the built environment especially when we find that the building sector is affiliated with roughly a third of the global energy consumption and greenhouse gas emissions.

This research is specifically dealing with the family house buildings within the building sector. The residential sector is responsible for a considerable share of energy consumption within the building sector, but it is mostly not in the research focus as other building types like industrial, commercial, and office buildings. Enhancing the energy performance of buildings

incorporates many approaches that include and are not limited to refurbishment and utilizing passive design principles. The refurbishment process provides an excellent opportunity for rethinking the building design and structure in a way that improves the building's energy performance and allows the incorporation of new passive approaches. The case studies of this research were either partially or totally subject to a refurbishment approach in their own context. As will be explained in later chapters, the refurbishment process made room for adjusting the building design and integrating architectural elements that utilize passive energy and passively use the forces of nature to reduce reliance on mechanical equipment. The passive approach in this case is natural ventilation that was enhanced by integrating passive air conduction elements. Utilizing natural ventilation efficiently saves energy from mechanical cooling and mechanical ventilation. The research investigates the efficiency of different geometry and operation scenarios of such solutions in order to reveal their effectiveness and provide recommendations for future research and implementations. It investigates integrating passive air conduction systems (PACS) and their influence on airflow patterns, air change rate (ACH), and indoor temperature. The Venturi effect is tested as an important factor in magnifying the passive conduction and stimulating natural ventilation.

1.2. Research Questions

The findings of this research aim to answer the following questions:

1. How much is the residential sector highlighted in the literature regarding the topic of passive ventilation?
2. What is the current status of updraft passive ventilation in residential buildings in the literature?
3. What are the potential benefits of refurbishing typical Hungarian detached family houses, and how to optimize the process in terms of energy consumption and comfort in the indoor environment?
4. What is the influence of integrating a PACS that has a Venturi-shaped roof in the detached family house?

5. What is the influence of different wind directions on the aerodynamic performance of the detached family house, and how to optimize it?
6. What is the influence of integrating a PACS in an attached family house building within a surrounding built environment?

1.3. Research Aim and Objectives

The research focuses on utilizing natural ventilation in the residential sector and more specifically, in family house buildings. Therefore, it aims to reveal efficient practices in this regard and to provide further recommendations for either practical implementation or future research and development. Through this process, the research objectives could be broken down into the following:

1. Scanning the literature regarding the investigated topic by conducting a literature review. The literature review provides the needed background and understanding of the topic in the context of energy and comfort, main physical principles, utilizing natural ventilation in vernacular architecture, evaluation of natural ventilation, and modeling airflow.
2. Conducting a bibliometric analysis to reveal and analyze the current status of literature regarding the topic of updraft passive ventilation. The analysis aims to provide metrics regarding publication trends, affiliated research areas, geographical distribution, and trends of keywords.
3. Developing a simulation-based refurbishment approach of typical Hungarian detached family houses.
4. Analyzing the impact of the proposed refurbishment in terms of energy demand, thermal comfort, visual comfort, and indoor air quality (IAQ).
5. Identifying the aerodynamic impact of Venturi-shaped roof and PCAS when integrating into a detached family house.
6. Analyzing the impact of all wind directions on the performance of an integrated PACS in a detached family house and developing optimized operation scenarios.

7. Identifying the impact of integrating a PACS in an attached family house on the behavior of natural ventilation and thermal comfort.

1.4. Research Methodology

The research objectives were realized in several published studies [1]–[3] which are presented in the chapters (3, 4, 5, and 6) where the methods of each study are explained and detailed. Figure 1.1 represents a conceptual framework for the research methodology in a simplified manner.

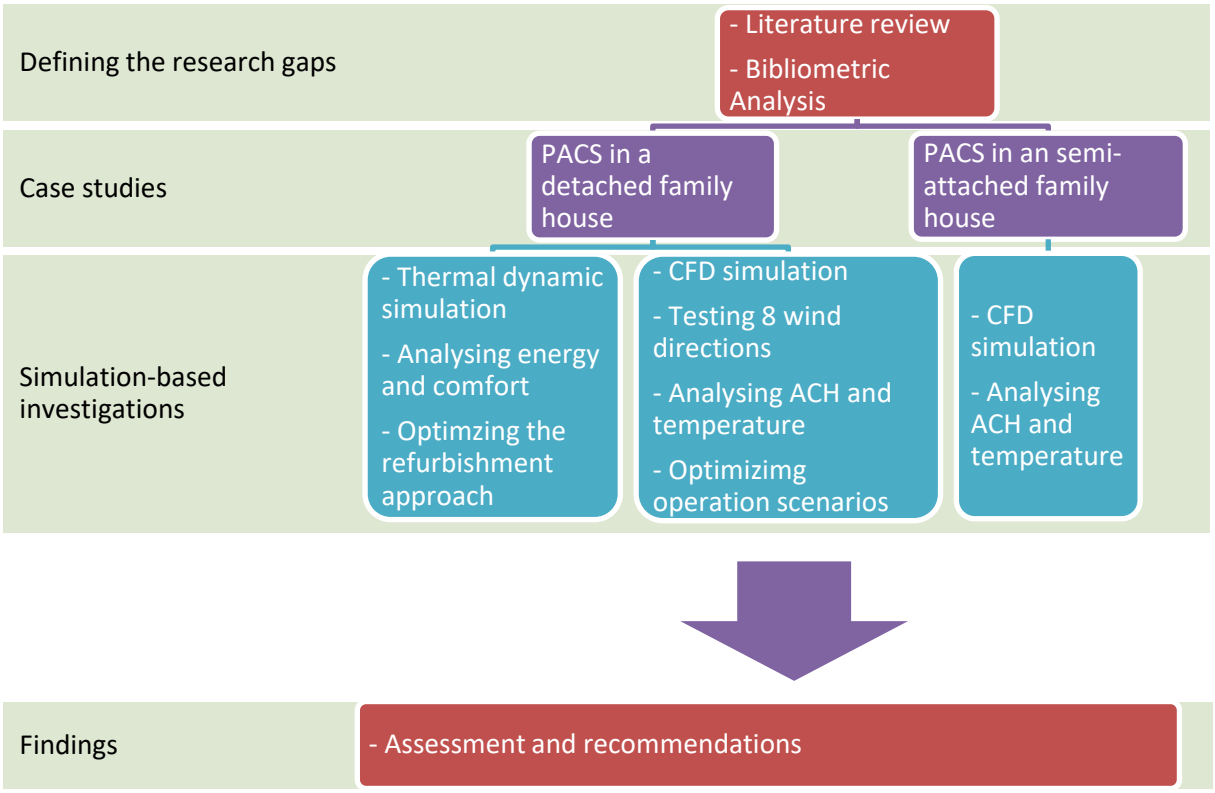

Figure 1.1. Conceptual framework of the research methodology

1.5. Research Structure

In addition to the introductory chapter, this research includes the following chapters:

Chapter 2 includes an extensive literature review that provides a general overview of the topic of natural ventilation in family house buildings while reviewing related topics like energy and comfort, climate change and the building sector, the residential sector, principles of natural ventilation, and a brief background of its physics, natural ventilation implementations in vernacular architecture, and computational fluid dynamics (CFD).

Chapter 3 is a bibliometric analysis with the purpose of mapping the current research trends on the topic of updraft natural ventilation in residential buildings. The search covers the two main databases: Scopus and Web of Science. A selected combination of keywords is adopted for the search. This chapter analyses the growth of the research interest in the topic, the affiliated research areas, the geographical distribution, and the keyword clusters.

Chapter 4 investigates the refurbishment approach of a detached family house building in Hungary. It utilizes the thermal dynamic simulation tool to compare the old state of the house with the refurbished one. The comparison basically includes energy demands, energy consumption, and thermal comfort.

Chapter 5 deals with the same previous case study, but it analyses the role of the integrated PACS and the Venturi-shaped roof in enhancing natural ventilation. 8 wind directions and 3 operation scenarios are investigated through the CFD simulation tool. The performance is assessed by two main factors: ACH and indoor temperature. Based on the results, further operation scenarios are developed and assessed.

Chapter 6 tests the integrated PACS in the second case study which is an attached family house building. It utilizes the CFD tool to analyze the effectiveness of the ventilation method.

Chapter 7 contains the final conclusions of the research and recommendations for future research.

2. Key Findings

2.1. Thesis 1

I investigated the potential benefits of refurbishing 'Cube houses' in a novel approach that combines the typical architectural characteristics of these houses. The proposed refurbishment is characterized by re-arranging orientation, Window-to-Wall Ratio (WWR), shading elements, improved building materials, energy-saving mechanical systems, and integrating a passive ventilation mechanism (PACS).

Under the specific climatic conditions of the continental region, the refurbished version of the typical family house demonstrates notable advantages in terms of Predicted Mean Vote (PMV), daylight performance, Indoor Air Quality (IAQ), and energy balance. The key conclusions drawn from the calculated results are as follows:

- The designed refurbishment offers substantial energy savings, with up to a 52.3% reduction in energy consumption, primarily attributable to enhanced thermal properties of the building envelope.
- Cooling plays a minor role in the energy performance of the family house in this context.
- The PMV significantly improves (by 44.75%) due to superior thermal qualities, higher wall surface temperatures, and operative temperature.
- IAQ experiences a substantial enhancement, with up to a 91.4% decrease in CO_2 concentration resulting from increased airflow rates due to passive and AHU ventilation.
- Daylight condition is significantly improved, with 36.1% higher illuminance intensity under mixed sky conditions and an average of 20% improvement under clear sky conditions, primarily due to a four times increase in Window-to-Wall Ratio (WWR).

Corresponding publications: [1].

2.2. Thesis 2

I conducted an extensive exploration to assess the passive ventilation performance and indoor thermal comfort of a PACS in a lightweight detached family house located in Hungary. The investigation revolved around passive design strategies, with a specific focus on a central ventilation chimney featuring a Venturi-shaped roof and its connection to an underfloor airflow inlet structure. I considered various operational scenarios and opening characteristics. To analyze airflow patterns and their impact on indoor thermal comfort, CFD simulations were employed, with air temperature, velocity, and ACH serving as the main parameters for assessment and comparison. The findings underscore the substantial role played by the PACS in promoting natural ventilation whether used alone or in conjunction with cross ventilation. It was found that:

- When compared to cross ventilation alone, PACS provides a six-times increase in ACH and a reduction of average indoor temperatures by 9.5° degrees.
- Activating air conduction through the chimney alone led to a more than twofold increase in ACH and a 1°C reduction in interior temperatures.
- The Venturi-shaped roof alone increased ACH by 7.4 times compared to cross ventilation alone.

Corresponding publications: [2], and a journal manuscript under review and to be published.

2.3. Thesis 3

Integrating the proposed PACS system into a detached family house has the potential to achieve enormous energy savings in heating, cooling, and mechanical ventilation. With taking into consideration that an acceptable level of indoor comfort is provided in 90% of the occupation hours throughout the year when applying only PACS and without operating any mechanical HVAC. The energy performance of the tested case achieved around 50% savings compared to a regular AHU-operated scenario. The in-depth investigation shows that operating the proposed PACS has the potential to achieve energy savings that round up to 97% in summer (hot period)

and 40% in autumn (transitional period) while maintaining a relatively acceptable level of comfort.

Corresponding publications: a journal manuscript is under review and to be published.

2.4. Thesis 4

I undertook a CFD investigation to examine the effectiveness of an integrated solar chimney with a skylight in enhancing natural ventilation within a semi-attached family house in a fairly dense urban fabric. The findings unveiled the substantial benefits of the solar chimney, which generated a remarkable 6.2-fold increase in ACH and a reduction in indoor temperature by 1 degree.

For prospective research endeavors, it is strongly recommended that field measurements be implemented to complement the CFD simulations. Such measurements would provide empirical validation and further insight into the actual performance of the solar chimney.

Corresponding publications: [3].

3. Publications by the Author:

3.1. Published Papers

[1] M. Ali and I. Kistelegdi, "'Cube House' Refurbishment in Hungary – A Simulation-based Approach," *Pollack Period.*, vol. 16, no. 2, pp. 156–162, Apr. 2021, doi: 10.1556/606.2021.00271.

[2] M. Ali, Á. L. Katona, and I. Kistelegdi, "CFD Investigation of Natural Ventilation in a Family House in Hungary," in *Journal of Physics: Conference Series*, 2021, vol. 2069, no. 1, p. 012095, doi: 10.1088/1742-6596/2069/1/012095.

[3] M. Ali and I. Kistelegdi, "CFD Investigation of Enhancing Natural Ventilation in Attached Family House Buildings in Hungary," in *E3S Web of Conferences*, 2023, vol.

436, p. 01004, doi: 10.1051/E3SCONF/202343601004.

[4] S. Ibrahim, M. Ali, B. Baranyai, and I. Kistelegdi, “Simulation-Based Analysis of Earthen Heritage Architecture as Responsive Refugee Shelters (Case Study: Domes of Northern Syria),” *Int. Arch. Photogramm. Remote Sens. Spat. Inf. Sci.*, vol. XLIV–M-1-2, no. M-1, pp. 365–372, Jul. 2020, doi: 10.5194/ISPRS-ARCHIVES-XLIV-M-1-2020-365-2020.

3.2. Accepted Papers or under Review

- M. Ali, “Updraft Natural Ventilation in Residential Buildings: A Bibliometric Analysis" in *Recent Advances in Environmental Science from the Euro-Mediterranean and Surrounding Regions (5th Edition), Springer* (status: accepted for publication).
- M. Ali, Á. L. Katona, and I. Kistelegdi, " Ventilation Performance of an Updraft Passive Air Conduction System with Venturi-shaped Roof Structure in a Detached Family House” *Buildings* (status: under review).

3.3. Other Contributions by the Author:

- Modar, Ali; István, Kistelegdi. CFD Investigation of Enhancing Natural Ventilation in Attached Family House Buildings in Hungary. In: Kajos, Luca Fanni; Bali, Cintia; Puskás, Tamás; Horváth-Polgár, Petra Ibolya; Glázer-Kniesz,Adrienn; Tislér, Ádám; Kovács, Eszter (eds.) XI. 11th Interdisciplinary Doctoral Conference 25-26th of November 2022: Book of Abstracts, Pécs, Hungary: Doctoral Student Association of the University of Pécs (2022)253 p.p. 52 , 1 p.

- Modar, Ali; Ádám, László Katona; István, Kistelegdi. Natural Ventilation Enhancement toward Reducing Energy Consumption in Family House Buildings2. 3. 4. 5. 6. In: Iványi, Péter (eds.) Abstract book for the 17th MIKLÓS IVÁNYI INTERNATIONAL PHD & DLASYMPOSIUM: ARCHITECTURAL, ENGINEERING AND INFORMATION SCIENCES. Pécs, Hungary: Pollack Press (2021)227 p.p. 74 Paper: Paper 32

- Modar, Ali; Sonia, Ibrahim; Bálint, Baranyai**; István, Kistelegdi. Sustainability analysis of vernacular earthen domes in northern Syria as responsive refugee shelters. In: Csiszár, B; Hankó, Cs; Kajos, L F; Kovács, O B; Mező, E; Szabó, R; Szabó-Guth,

K (eds.) 9th Interdisciplinary Doctoral Conference 2020. Book of Abstracts. Pécs, Hungary: Doctoral Student Association of the University of Pécs (2020)384 p.p. 316

- Modar, Ali; István, Kistelegdi. Geometry-based analysis for natural ventilation in high-rise office buildings. In: Iványi, Péter (eds.) Abstract book for the 16th MIKLÓS IVÁNYI INTERNATIONAL PHD & DLASYMPOSIUM. Pécs, Hungary: Pollack Press (2020) p. 56

- Sonia, Ibrahim; Modar, Ali; Bálint, Baranyai; István, Kistelegdi. Earthen heritage architecture as sustainable refugee shelters: A case study of the domes of northern Syria. In: Iványi, Péter (eds.) Abstract book for the 16th MIKLÓS IVÁNYI INTERNATIONAL PHD & DLASYMPOSIUM. Pécs, Hungary: Pollack Press (2020)Paper: P 57

- MODAR, ALI; ISTVÁN, KISTELEGDI. Car race' with buildings… 'cube house' refurbishment in Hungary - A new design approach in the framework of Solar Decathlon 19 Competition. In: Iványi, Péter (eds.) Abstract book for the 15th Miklós Iványi International PhD & DLA Symposium: Architectural, Engineering and Information Sciences. Pécs, Hungary: Pollack Press(2019)197 p.p. 52 Paper: Paper 7