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CFD Investigation of Enhancing Natural Ventilation in Attached Family House Buildings in Hungary

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Abstract. Energy consumption of the residential sector in Hungary is 12% higher than the EU average. Most of existing house buildings in Hungary are inefficient in term of their indoor comfort and energy consumption. This is where the refurbishment process takes a vital role bringing these houses back on the track of achieving the UN sustainable development goals. When a responsible refurbishment is conducted, it leaves room for integrating passive methods to enhance the building behaviour. One of the most important passive methods is utilizing natural ventilation in order to reduce the cooling energy and to improve the Indoor Air Quality (IAQ). This research is investigating the integration of a passive ventilation solar chimney into an attached family house in Hungary as a part of its refurbishment process. This paper is a part of an extended research by the main author. The investigation utilizes Computational Fluid Dynamics (CFD) simulations. Different operation scenarios are tested, compared, and analysed. The simulation results demonstrate the functionality of the integrated solar chimney and the skylight as a ventilation outlet. In transitional seasons, it can provide accepted indoor comfort as the results of air change rate, indoor airflow velocity and indoor temperature indicate.

1 Introduction

Since the building sector is responsible for 30% of the global energy consumption [1] and 40% of it in the EU [2], it is absolutely important to enhance the energy performance of the buildings. Integrating passive design techniques, especially natural ventilation, in the building is one of the most influential methods to reduce energy consumption and to maintain acceptable indoor comfort level [3].

Buildings' retrofitting has been highlighted as a key driver of achieving sustainability and energy efficiency in buildings [4,5], since existing buildings are the main contributor to energy consumption in the building sector. Thus, many governments and international bodies generously invested in improving the energy efficiency of existing buildings by introducing policies and roadmap strategies [5]. The energy-retrofit process considers optimizing the energy efficiency and comfort level, and it is usually supported by simulation tools to help adopting the proper solutions [6]. The architecture practice, therefore, has a significant importance in the buildings' retrofit as it combines the design approach with the technical inputs [7].

Majority of the European residential building stock does not meet the required level of energy efficiency due to the lack of awareness and relative regulations when the dwellings were originally built. Therefore, retrofitting the residential sector is a vital process to make it aligned with the recent energy criteria [8]. It was estimated that by 2020, 90% of the building stock in Hungary should be renovated and that 25% of the population live in dwellings with poor conditions, even though 36% of the residential buildings were refurbished [9].

The indoor environment is the microenvironment where people spend a large share of their time. Therefore, the indoor air pollutants directly affect the occupants' health. The indoor air content of pollutants and particulate matter is mainly affected by the air exchange rate between the indoors and the outdoors environments [10]. Air change rate per hour (ACH) is the measurable indicator to evaluate the Indoor Air Quality (IAQ) and to design the building's ventilation system [11]. ACH refers to the number of times in an hour that the volume of air, equal to the volume of the ventilated space (room or building), is replaced by fresh outdoor air. Thus, it is strongly linked to the infiltration and ventilation rate [12].

Natural ventilation is mainly induced by the generated pressure difference around the building which is influenced by three factors: wind velocity, wind direction, and the difference in temperature. Therefore, any implemented natural ventilation mechanism is more effective when it takes advantage of the pressure difference. The wind tower operation is also induced by

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the pressure difference between the positive pressure on the windward side of the building and the negative pressure on the leeward side of the building. The pressure difference is created by the external wind around the building. Wind driven ventilation usually operates parallelly with the buoyancy or stack effect which is induced by air temperature difference and becomes more effective in the absence of the wind [13].

Ray et al. investigated the buoyancy-driven natural ventilation for 3-storey office building through a shared ventilation shaft. They applied both a physical measuring experiment and Computational Fluid Dynamic (CFD) simulations. They found that a shaft with a smaller size caused higher flow rates in the upper floors due to the higher vertical momentum [14].

Ali et al. performed a CFD investigation on natural ventilation in a detached family house in Hungary. The house was equipped with under-floor ventilation inlets, an inner shaft, and a Venturi disc topping the shaft outlet to stimulate natural ventilation through the house. Indoor air velocity, ACH, and temperature were tested and it was proofed that the studied ventilation mechanism is effective in enhancing natural ventilation [15]. Wagner et al. investigated and monitored natural ventilation and passive cooling of a low-rise office building in Germany. They found out that natural night ventilation could provide sufficient indoor thermal comfort even during the hot season by operating the opening of windows and skylights. The simulation results also revealed that different opening angles of the skylights affected the air change rates and their distribution over the different floors [16]. Kazemi Esfeh et al. conducted an experimental and numerical study on a typical room model to evaluate the wind-driven natural ventilation of a semi-cylindrical curved roof with a skylight. It was concluded that the curved roof behaviour regarding natural ventilation was largely influenced by the wind direction and that the skylight operated as a suction element due to its lower pressure. They stated that the height of the curved roof has a considerable importance in enhancing the airflow circulation and that the effect of the curved roof was almost equal to that of the wind tower regarding natural ventilation [17].

Laurini et al. tested a ventilation chimney in a palace building in Italy. They concluded that maintaining a temperature difference between the top and the bottom guaranteed effective natural ventilation through the chimney [18].

Du et al. conducted a skylight ventilation design optimization of a low-rise office building through CFD simulations. They revealed the significant role of skylights on natural ventilation through an atrium. However, to prevent extra heat gain and energy consumption, skylights should be carefully designed to by considering their positioning, arrangement, and height [19]. He et al. presented an experimental and CFD study natural ventilation of a low-rise office building, whereas the natural ventilation was induced by a combination of mechanical equipment and roof window. The roof window proofed to be significantly more influential than the mechanical equipment, and to be more effective when considering other wall openings [20]. Horan et al. investigated a naturally ventilated atrium space of a tow-story office building. The atrium was equipped with roof vents and tested via CFD simulations. Their research revealed that ACH was considerably influenced by the wind direction in connection with the building's form [21]. Wu et al. tested the natural ventilation through an integrated wind tower on the top of a low-rise house. They explored the influence of switching from single-sided natural ventilation to cross ventilation by changing the windows' arrangement which led to enhancing ACH. They also found that the exhaust wind tower had a better performance when indoor temperature was higher than outdoor temperature due to the stack effect [22].

The case presented in this research is an attached family house. The house was originally built in the 70s as a typical family house. It was refurbished in 2015 based on the Active House Standards. The house refurbishment won the Active House Award and the Energy Globe Hungary prize in 2017. In a previous study, the house was tested via dynamic thermal simulations. The refurbishment process considered rearranging the spaces and upgrading the building envelope. After refurbishing the house, the energy demand was considerably reduced and the final energy production was approximately two times larger than the final energy consumption [23]. This research is specifically testing the effectiveness of the skylight and the integrated solar chimney regarding natural ventilation.

2 Methodology

The methodology of this paper could be divided into several steps. The first step is collecting the needed data for the tested building including plans, weather data, building operation data etc., in order to model the building. The second step is modelling and simulating the reference case study in 3D CFD environment using ANSYS Fluent R.17.2 software [24]. The third step is gathering and analysing the results for the following parameters: air velocity, ACH, and air temperature. The final step is simulating the second scenario, comparing the results, and analysing the natural ventilation performance of the house and its integrated solar chimney in connection to the indoor thermal comfort.

3 Case study

3.1. General description

The case study is located in Pécs, Hungary, which has a latitude of 46.0833°N and a longitude of 18.2333°E. The location is demonstrated in Fig. 1. Since the location is next to Mecsek hills, the terrain is sloped in North-South direction.

The case study represents a family house building that was first built in 1974 as a typical attached house with 30 cm thick brick walls and concrete beams and slabs. After refurbishing the house in 2015, the design was modified. The house is directed East-West with a tilted axis. The concrete staircase in the middle is dividing the layout into two parts: the kitchen to the west and the living room to the east in the ground floor level, and the office room to the west and the bedroom-bath to the east in the first-floor level. The solar chimney gallery is facing the staircase and located to the south side of the house. The attic space is not divided from the solar chimney. On top of the solar chimney is an operable skylight. The roof was formed by a specific East-West axis, so it has south-facing pitched half where the Photovoltaic panels are placed. The house is equipped with a Building Management System that monitors and controls the building's functioning and operation to insure acceptable indoor comfort conditions. The system controls the operation of the windows and the solar chimney (natural ventilation), especially that the house was designed that it could be naturally ventilated and night cooled in seven months of the year [23].

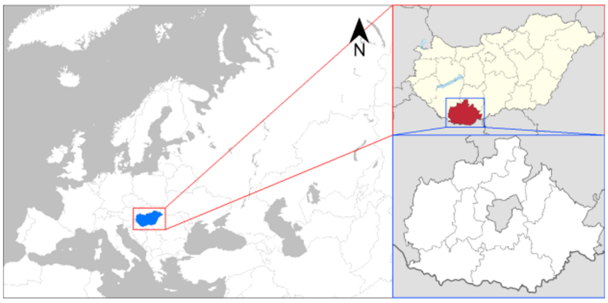

Fig. 1. Location of the case study.

3.2. Geometry and mesh generation

The executive plans and details were collected and cleaned. The building and the terrain were modelled from scratch via SpaceClaim modeller software. The height of the building h=10 m. Therefore, the computational domain was created with size: 20*20*5 h according to the recommended practice guidelines. The computational domain must consider the neighbouring buildings and the sloped terrain since these factors could largely influence the air flow around the building. Fig. 2 Shows the computational domain size.

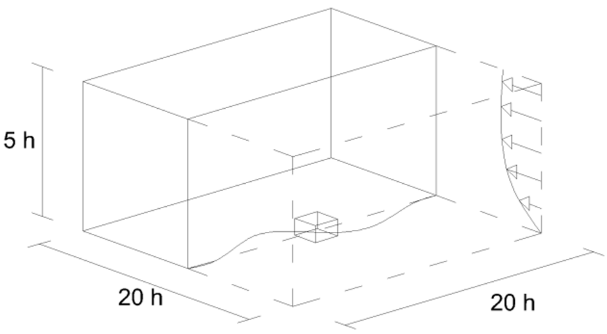

Fig. 2. The size of the computational domain.

The following step is generating the mesh. The generated mesh is an unstructured hybrid mesh that combines hexagonal, tetrahedral, prism, and wedge cells. Fig. 3 shows a section in the generated mesh. The mesh considered dividing up the geometry of the flow volume into zones so that the Navier-Stokes and turbulence equations can be solved. The mesh metrics are listed in Table 1.

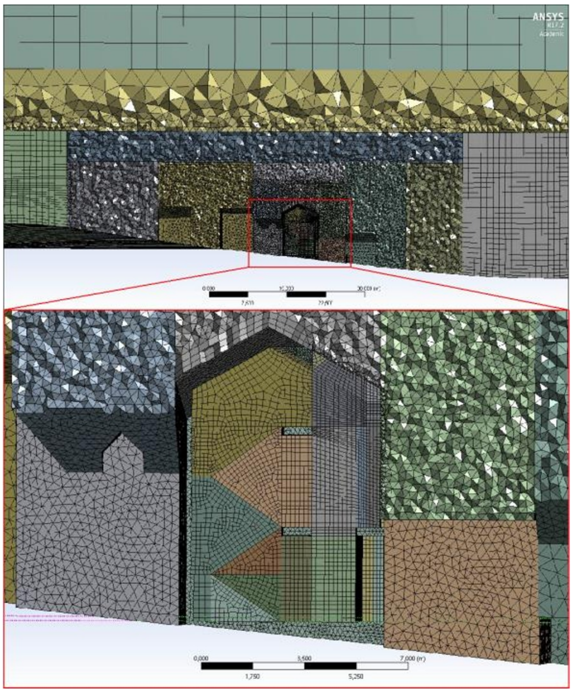

Fig. 3. A section in the generated mesh.

Table 1. Metrics of the generated mesh.

Mesh metrics	Value
Element sizing of the interior	0.2 m
Number of elements	4905236
Number of nodes	1382904
Cell aspect ratio (max)	29.09
Ortho Skewness (max)	0.816
Orthogonal quality (min)	0.1001

3.3. Boundary conditions

The fluid material is set as "Compressed Ideal Gas" and the Reynolds Average Navier Strokes Equation (RANS) and standard k-ε are chosen for the airflow turbulence simulation. Fluent finite volume is used as a solver. The "SIMPLE" coupling algorithm is chosen with the first-order scheme for equation discretization. A fixed temperature of 19.7°C is set for all parts of the fluid domain. The hourly-based Meteonorm database is used to acquire weather data (air temperature and wind speed

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and direction) for the local region [25]. Heat sources are considered for the simulation including persons and electrical appliances as shown in Table 2. The inlet of the computational domain is defined as velocity inlet, and the outlet as pressure outlet, and the side and top boundaries as symmetry boundary condition.

West wind direction is tested since it is the prevailing local wind direction with an annual wind average wind velocity of 2.73 m/s at a reference height of 10 m [26]. Fig. 4 shows the local wind rose. 21st of September at 1 p.m. is the chosen simulation time for its suitability for utilizing natural ventilation.

Table 2. Indoor heat sources included in the simulation.

Location	Heat source	Value (W)
Kitchen	Cooking person	200
	Coffee machine	250
	Electric oven	800
	Dishwasher	400
	Microwave	400
	Fridge	60
Living room	TV	40

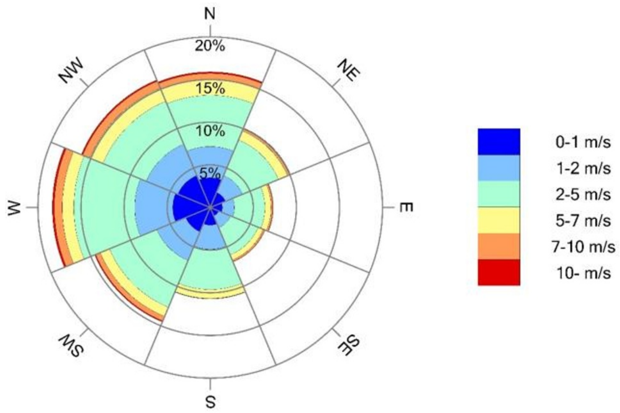

Fig. 4. The local wind rose [26].

4 Results and discussion

The main purpose of this paper is to detect the influence of the integrated solar chimney and the skylight operation regarding natural ventilation in the investigated house building. Therefore, two scenarios were tested. The reference scenario where the skylight is closed and only the western kitchen window and the eastern terrace door are opened to mimic the regular cross ventilation. In the second scenario (Skylight scenario) the only changing parameter is that the skylight is opened. In both scenarios, the western office room and the eastern bedroom-bath on the first floor are cut out from the investigated flow domain by closing their doors. Fig. 5 shows schematic drawings of the two scenarios.

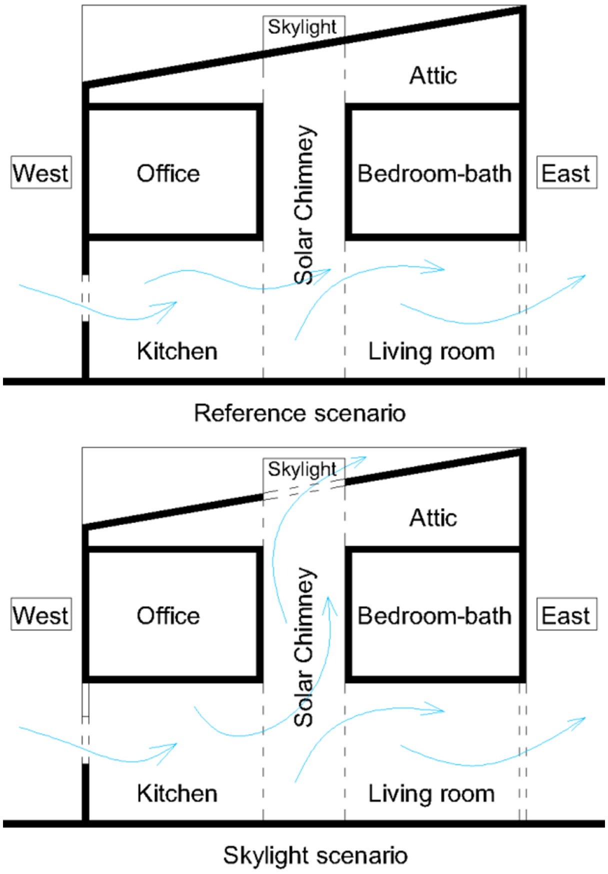

Fig. 5. Schematic drawings of the two investigated scenarios.

The simulation results show the effectivity of the integrated solar chimney when opening the skylight (Skylight scenario). The most relevant indicator is the ACH which is 6.2 times higher in the Skylight scenario than it is in the reference scenario. Fig. 6 shows ACH comparison in both scenarios.

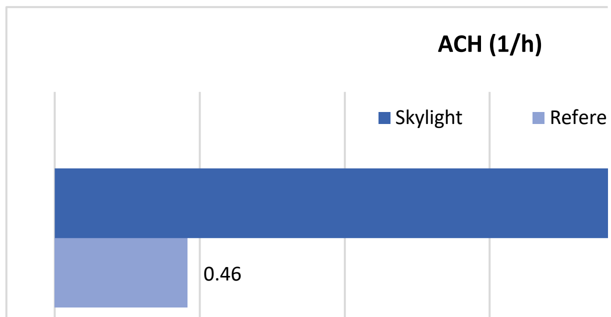

Fig. 6. ACH comparison of the two scenarios

The suction effect of the skylight converted both of the openings in the ground floor into inlets as shown in Fig. 7. Because of the urban context, neighbouring buildings are creating a buffer which causes vortexes next to the house.

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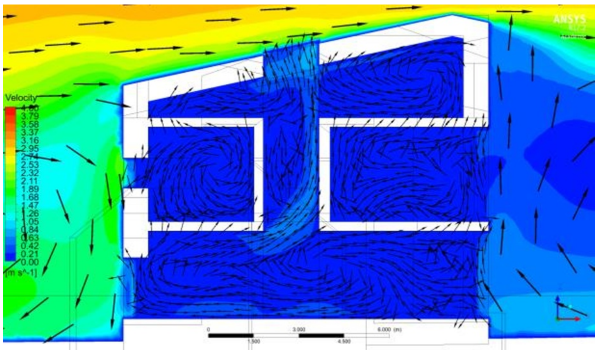

Fig. 7. A section showing airflow velocity.

Regarding other indoor comfort indicators, there is no significant difference in airflow velocity in the interior space and it is generally small in value (around 0.12 m/s). However, when we consider the chimney zone alone, air velocity in the Skylight scenario is 35% bigger than that in the reference scenario. That is understood because of the suction effect implied be the opened skylight.

Indoor temperature comparison perhaps clarifies the role of ACH in removing the interior heat loads. The average temperature in the Skylight scenario is around one degree cooler than that in the reference scenario, even though both cases are within the accepted comfort levels as shown in Fig. 8. Airflow behaviour is always linked to the indoor air temperature and the thermal comfort. Fig. 9 clarifies how the ventilation through the chimney helps in removing the internal heat load together with the buoyancy effect when warmer air with less density floats upward.

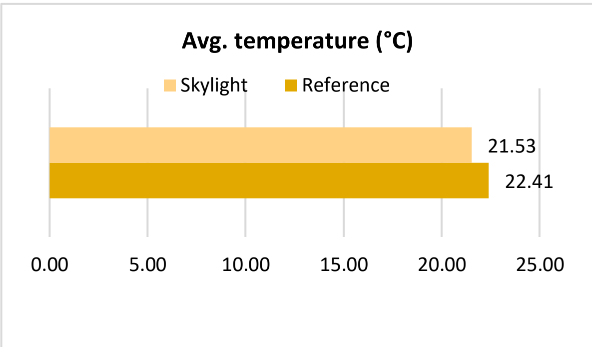

Fig. 8. Avg. temperature comparison of the two scenarios.

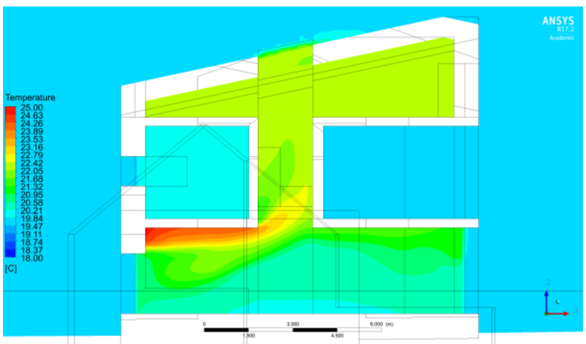

Fig. 9. A section showing the temperature distribution.

5 Conclusion

This paper conducted a CFD investigation of the role of an integrated solar chimney in enhancing natural ventilation in an attached family house building in Hungary. Two scenarios were tested and compared: the reference scenario (skylight closed) and the Skylight scenario (skylight opened). The solar chimney proved to provide 6.2 times more ACH and cooler indoor temperature.

For future research, it is recommended that field measurement are taken and to simulate further scenarios including more wind directions and investigating different geometries of the solar chimney that could enhance natural ventilation in the studied context even further.

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