Разработка математической модели для тестирования естественной вентиляции: тематическое исследование для жителей Йемена

О. А. Х. Ш. Аль-Думайни, В. А. Величкин

Аннотация: В статье дается представление о традиционных методах пассивного охлаждения, используемых в Средиземноморье и регионах с жарким климатом и демонстрируется эффективность естественной вентиляции и центральных внутренних двориков для повышения теплового комфорта в помещениях и снижения энергопотребления. Интеграция этих традиционных элементов дизайна с современными технологиями имеет решающее значение для создания экологически чистых и культурно значимых архитектурных решений будущего. Далее рассматривается важность энергоэффективности и экологической устойчивости при проектировании современных зданий с особым акцентом на использовании программного обеспечения Ansys Fluent для моделирования естественной вентиляции жилой квартиры в Йемене. В статье подчеркивается необходимость инженерных и архитектурных решений для достижения высоких показателей энергоэффективности и экологической безопасности в современной практике строительства.

Ключевые слова: естественная вентиляция, йеменские дома, модель Спаларта-Аллмараса, Гражданское строительство, Ansys Fluent.

Introduction. Nowadays, scientists from all around the world are paying more attention to urbanization and the quality of urban water runoff as a potential alternative water supply. Sana'a, the capital city of Yemen with an estimated population of 3.52 million, gets large volumes of stormwater overflow from the Sana'a Basin on a seasonal basis. If the runoff is clean, it might be productively utilized [1]. Most tower houses in Ancient City Sana'a (Figure 1) have ventilation gaps multiplied as escape clauses to shoot unwelcomed individuals. Most of the opening frameworks within the tower houses are brightened with pre-Islamic plan themes and components such as half circles and curves. Other components within the opening frameworks are rectangular and cultured-glass windows, likely of outside impact. The sign of early human movement within the region has been dated back 1.6 million a long time to the Paleolithic period. The development of the city began with Shem, the child of Noah [2], in spite of the fact that no chronicled data were recorded in this story [2]. From other sources, Sana'a may be a Sheban city, built by Halk Amr, lord of Sheba and Dhu Raydan, within a long time 140-150 of the Sheban calendar, or 1070-1080 BC [3].

Figure 1. An overview of the old City Sana'a
Source: [2]

The structural character and outside structures of Yemeni houses are unmistakable. Parts of house engineering in Ancient Sana'a city are tall, rising more than six stories. The house has a vertical staircase, and the entry could be better connected with the living zone with the labyrinth of numerous rooms. The passages and entryways can be also quite intricate. Within the Yemeni tower house design, the foremost alluring component is the window composition. The component comprises two parts, specifically: the lower portion is implied for seeing and ventilation, whereas the upper portion is to serve as a fan-light, filled with alabaster or stained-glass layer to hurl light inside the room.

Many researchers, particularly from the hot climate regions, have examined the detached control strategies of conventional houses. A. Michael et al. [4] affirm the commitment to common ventilation for cooling in Cyprus. They examine diverse ventilation techniques, appearing that night ventilation is the foremost successful procedure for passive cooling. F. Soflaei et al. [5] examine the concept of the central patio as a passive cooling strategy. A. Ghaffarianhoseini et al. [6] optimized the plan of yards in hot and sticky climates in Malaysia towards improving their warm execution characteristics for giving thermally comfortable open-air spaces according to diverse plan setups. Domaini A, Halbouni G [7] considered the impact of climatic variables on individuals within the Republic of Yemen and dissected the bioclimatic conditions of a few Yemeni cities. Sooleyon C, Nooshafarin M [8] and Calcerano F, Cecchini C [9] examined the impact of patio and normal ventilation on warm execution of indoor space for dry climate and decreased cooling stack. Micallef D, Buhagiar V, and Borg S. B. [10] explored by a numerical approach the impact of cross ventilation on a yard.

Theoretical framework. Engineering manages a building plan of frame, space, and work, which adresses particular socio-economic conditions. Design is the capacity to set out the specific components in particular relations. This was seen clearly in the aesthetic environment in Hadhramout Valley which accomplished utilitarian and creative flawlessness in organizing the buildings to suit human benchmarks.

Estimation was known in the past in numerous civilizations, utilizing parts of the human body, such as the arm, as an estimation unit. Beat is considered one of the most that lead and interface the engineering structure of the buildings. This reflects on rehashing aesthetic engineering components such as structure, vents, and vertical sequent stories.

The Yemeni engineering is unique in utilizing the characteristic components from the environment and the legacy. The Hadhrami engineering embodies a commonplace fashion for people living inventively and viably with the environment. The Hadhramies succeeded in making constructions and structures in accordance with the environment. The conventional design and development go exceptionally well with the environment and meet the utilitarian perspectives, as well as reflect the religious beliefs of the tenants.

Yemen stands within the southern portion of the Middle easterner Landmass. To the southwest and the south, it faces the Indian Ocean, Gulf of Aden, and Indian Yemen's geological area, allowing differentiating with encompassing nations.

Since geological, normal, and climatic differing qualities in Yemen, building materials are too different, and these differing qualities have a bearing on urban and provincial design. Muslims are among their conventions related to protecting the environment and nature through the creation of social orders and social and financial exercises, and the environment is comparable to the three columns of sustainability (Figure 2). Islam empowers social relations and sets up rules to manage them, social and financial development through the lessons of Islam zakat, where Islamic financial rules which connected through the Qur'an. It appears the Islamic setting includes sustainability.

Figure 2. Three primary columns of supportability
Source: [13]

Figure 3 demonstrates the conventional house components in chosen Middle easterner cities, Jeddah (a), Cairo (b); Mashrabiyah, which gives protection and cool discussion for the house; and (c) the wind catcher (Malkaf) which in one of the conventional houses in Dubai that gives cross ventilation [12].

a b c

Figure 3. Various parts of Yemeni structures
Source: [11]

Climate adaptation. The city of Sana'a has a special climate. Although it is located in a tropical climate zone at latitude (31◌15˚N) and longitude (11˚44W), it is located in a mountainous high region at an altitude of approximately (2300m) above sea level.

It surrounds the hill so that the rainwater descends towards the flat area where the city is located. The climate here is temperate throughout the year, with intense solar radiation, relative coolness in winter, and frequent rainfall. In summer, cold north and northeast winds predominate. [5]. In winter the city suffers from dry air due to low relative humidity levels. The ancient Yemeni architects tried to find architectural styles that would be compatible with the environment and specific climate. In Table 1 hourly temperature values by month of the year are demonstrated. Hourly humidity values by month of the year are shown in Table 2.

Table 1

Hourly temperature values by month of the year

Temperature											
Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**

23.7	26.0	25.7	26.9	28.9	29.7	29.1	28.4	27.3	24.9	23.6	23.2
5.6	8.0	10.5	12.2	14.1	15.3	16.6	16.1	13.5	9.6	6.8	6.1

Table 2

Hourly humidity values by month of the year

Humidity											
Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
66	62	53	49	64	74	57	54	63	65	67	67,5
23	23	21	21	23	21	15	17	22	24	19	21

Methodology. Overall dimensions of the room axbxh: 3.5×4.0×2.8 m. The air flow rate was determined according to the standard flow rate for bedrooms and common rooms with a total apartment area per person of less than 20 m2 in the amount of 3 m3/h per 1 m2 of room area. The problem being solved is considered in a stationary formulation. Characteristics of the alignment grid (Figures 4-5): the minimum model spacing is 0.002 m; maximum model spacing is 0.13 m; number of nodes – 1560878 pcs; number of elements – 1439833 pcs.

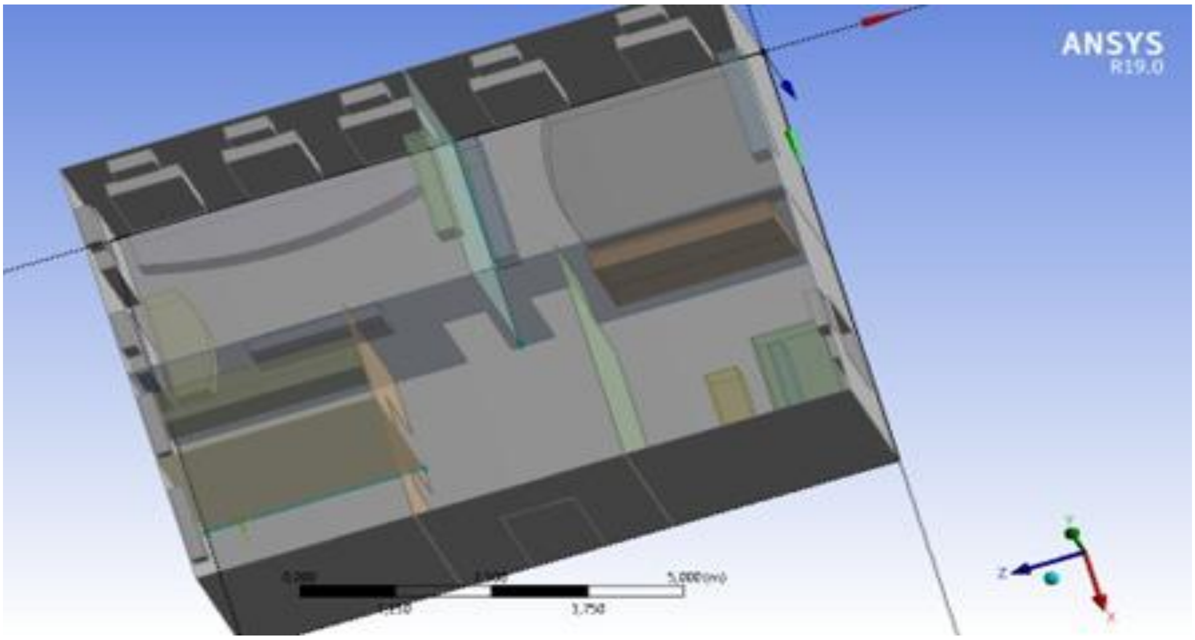

Figure 4. General view of the 3D model of the room

Source: compiled by the author

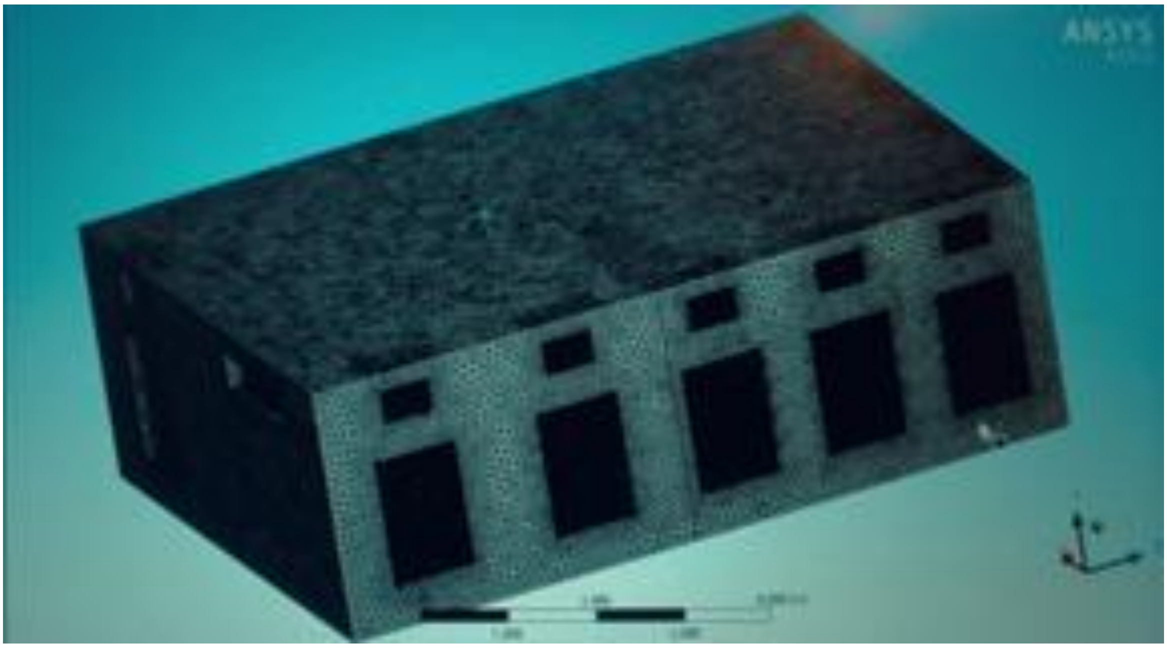

Figure 5. Density of geometry partitioning step

Source: compiled by the author

To test the selected system of ventilation is possible through a mathematical model. For this purpose, Navier–Stokes equations can be used to describe the air movement, and Boussinesq approximation – for the description of the convection. The Spalart-Allmaras model is applied in Ansys Fluent to solve the system of equations [14]. Air parameters under various specific conditions can be identified through computer modeling. Applying this method allows to find problematic places of the given design solution. The study was aimed at analyzing the findings of modeling air conditions in constructions with natural ventilation through the use of Ansys Fluent software program. The simulation results were expected to identify the parameters of the openings necessary for the natural ventilation and to reveal whether it would work under the given conditions of the building.

The floors are 0.3 m thick, the glazing is 0.1 m. The building is designed with natural ventilation, operating due to the difference in pressure between internal and external air. The size of window openings in the outer wall is 0.5 m.

The outside air temperature during the day for modeling is arbitrarily taken as 29.4 oC. The equivalent internal thermal loads per floor area are 43 W/m2. Heat gains from solar radiation on the surface of the outer wall of the atrium and its covering are 44 and 40 W/m2, respectively. The indicated heat inputs represent heat fluxes from convective heat transfer only. Heat transfer due to thermal conductivity and radiation can be neglected during modeling.

Results and discussion. When modeling hydrogasodynamic processes, it is reasonable to reduce the finite element mesh spacing near the walls.

The key parameters of microclimate of the building premises were estimated during modeling: velocity and temperature distribution fields. They affect significantly the natural ventilation and comfort in general.

At the end of the simulation of the operation of the ventilation system, the temperature and air speed distribution in the given room was identified (Figure 6-7). Velocity distributions in the longitudinal section (Figure 6): the highest air velocity is observed along the outer wall ~0.8–0.9 m/s; along the ceiling plane at a height of 1.5 to 2.5 m ~0.1 m/s; along the floor plane at a height of up to 0.2 m ~ 0.1 – 0.2 m/s; in the serviced area of the room, the speed of air movement below 1.5 m from the floor is ≥0.08. In corners and areas near walls, the speed is minimal. At the border of the service area (0.5 m from the wall) near the outer wall, the air speed is ~0.08–0.15 m/s. The areas of low temperatures in the service area are absent. The distribution of speed in the volume of the room indicates low ventilation efficiency; the serviced area of the room is stagnant.

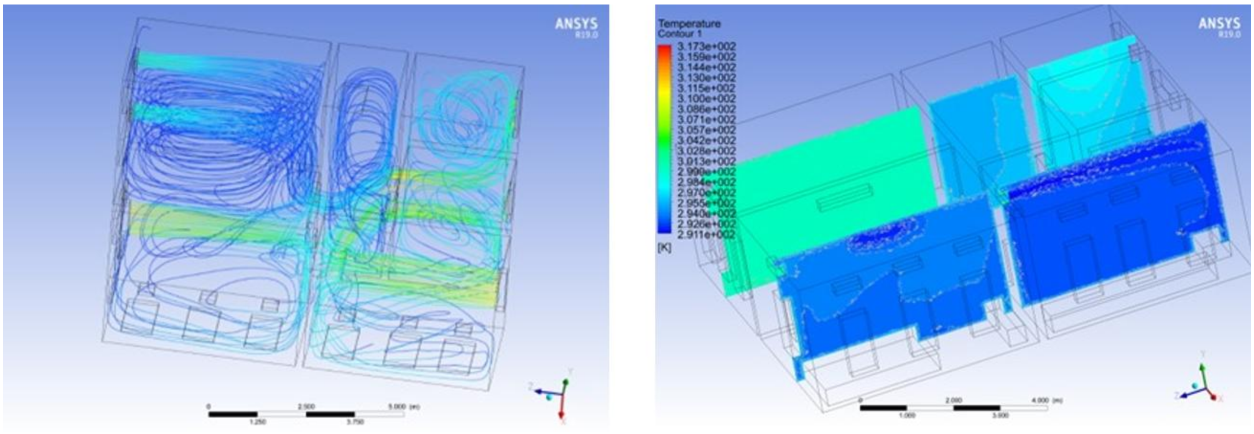

Figure 6. Velocity distribution in the section through the center of the room

Source: compiled by the author

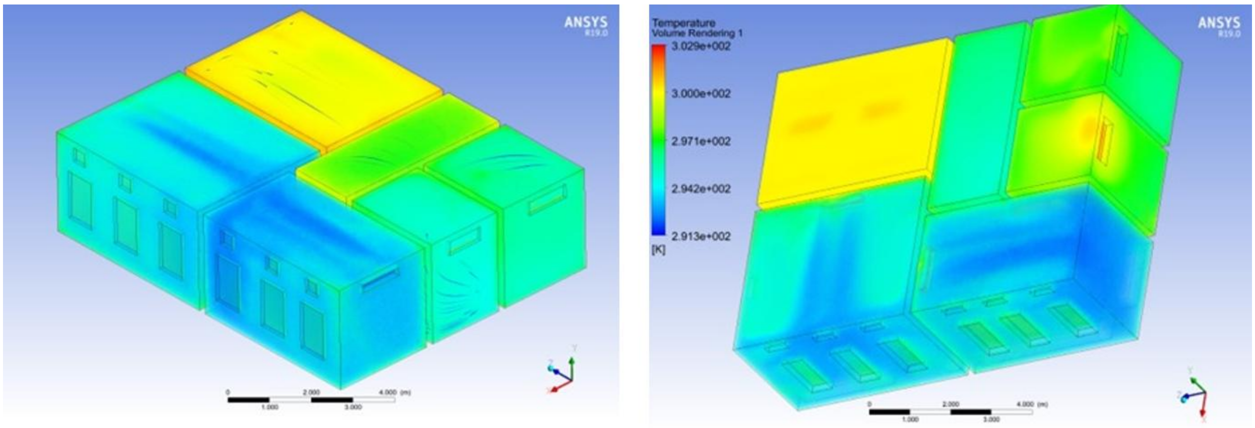

Figure 7. Graphical representation of the temperature field

Source: compiled by the author

It can be said that the accuracy of simulation results depend substantially on changing the grid spacing, which is particularly relevant for the cases of the natural ventilation. It is crucial to create an appropriate air flow for the purposes of comfortable conditions since intake openings are mostly situated near the work area. Ansys Fluent makes it possible to achieve accurate results regarding the microclimate of the designed building.

Conclusion. Mathematical model allowed to make the following conclusions:

- low ventilation efficience is the reason of air stagnation and drying, which leads to the deterioration of living conditions in the building in general;

- air exchange organized in the described way allows to meet the requirements of the normative literature, but the broken tightness of the external envelope leads to overconsumption of thermal energy for heating the infiltrated air for the periods of time when the guests are not in the room and the inflow is not required;
- low ventilation efficiency leads to the formation of stagnant zones in the room, contributes to air drying and, as a consequence, to the appearance of dust, deterioration of health, etc;
- the optimal scheme to achieve the goals of energy efficiency and air exchangeability will be mechanical supply and natural exhaust.

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