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Effect of the Built Environment on Natural Ventilation in a Historical Environment: Case of the Walled City of Famagusta

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Abstract: Passive building is among the most important subjects in architecture today. The key factor in terms of a solution is related to the level of renewable energy in buildings. Natural ventilation is among the effective factors in indoor thermal comfort. Virtual simulations prepare a basis for reliable and fast result outcomes. Computer Fluid Dynamics (CFD) software is available thanks to advances in technology and mathematical calculation to simulate projects with any conditions. This paper presents thermal comfort reduction where, in the simulation, the closed environment is considered rather than the individual building with no surroundings. In order to reach the conclusion, a comparison between a single building simulation and two locations in the walled city of Famagusta in the Turkish Republic of Northern Cyprus, a historical settlement, is provided to illustrate the changes according to the closed environment conditions. According to the results, if energy consultants aim to present realistic energy data in order to upgrade the level of sustainability of buildings, it is important to consider the effect of the closed environment on natural ventilation in their calculation.

Keywords: passive building; indoor thermal comfort; closed environment; computing fluid dynamics simulation; natural ventilation

1. Introduction

Architecture, urban planning, and building construction are considered to consume the most energy in terms of energy efficiency, which is involved with daily indoor life in order to protect humans from outside conditions and the outdoor environment. Technological advances influence human lifestyles both positively and negatively [1,2]. Technology and technicians are trying to minimize energy usage and find better approaches to reduce the amount of energy consumed [3]. Currently, the best solution is to use renewable energy, which is accessible all around the world. Among the types of natural energy, wind is among the most important resources that have a direct effect on the feeling of temperature [4–8]. It is possible to track the evolution of natural ventilation in architecture and use elements such as wind catchers in old cities. Buildings are designed based on maximizing the benefits of natural ventilation [9,10]. We can consider natural ventilation as a solution for energy efficiency, mainly in hot climates, by harnessing the wind and bringing down indoor temperatures to acceptable levels [11]. After modernism, people who moved to cities with the dream of a better life caused the cities to grow without following any rules, and it brought chaos between cities, wind, and building design. Commonly, city planners design cities with large-scale factors such as vehicle circulation, energy resources, connection networks, etc. Thus, there is no room for neighborhood microclimates and building-scale natural ventilation [12–14]. There are several factors in between that reduce the possibility of designing buildings according to natural ventilation in order to increase the level of indoor thermal comfort to the maximum that need to be considered in urban planning and city development [15]. It is obvious that, in different climates, there are various factors that affect indoor thermal comfort in buildings; thus, regulations are changing according to the climate [16]. It is clear that, to understand the level of thermal comfort taking natural ventilation and building surroundings into consideration, climate conditions should be analyzed as a first step. Throughout history, one of the main factors in building construction was having the buildings take maximum benefit of natural energy resources, and cities were shaped according to the building designs [17,18]. A city as a systematic process of connection among different factors that come together to shape the living area for people at a larger scale has an important role to play in human health and creating comfortable situations for citizens [19].

Increments in warmth in urban areas expand the length of developing seasons and diminish strong wind events. Natural ventilation diminishes the air quality by expanding contaminants [20,21]. Researchers are concerned about the response of urban air circulation to unnatural weather changes. Different researchers have reasoned that ventilation can effectively impact atmospheric changes at a microclimate scale [22]. The main element acting as guidance for wind in cities is the density of the city pattern, which needs to be considered for natural ventilation in every part of the city [23]. The diminutive size of streets and pedestrian access compared to the sizes of city blocks and building proportions dictates all these effects. It is recognized that the focus must be on the street/pedestrian level regarding the air quality in urban open spaces [24,25]. On a normal street, the base part is the spot for air contamination, while on restricted and long avenues, contamination relies on numerous elements such as breaks and the level of greenery on the road [26].

Passages, proximity, gathering areas, and so on were designed according to the climatic conditions in order to create pleasant and comfortable areas and meet people's needs in historical settlements. One city that was directly designed according to prevailing winds is Bushehr city in southwest Iran [27,28]. A great deal of intersections with open spaces provide a setting for wind circulation and the most extreme exchange of wind and structures [29]. We can say that the stickiness of interior spaces is directed out via air currents in roads. These spaces, notwithstanding social capacity, have conveyed wind in lanes [30].

Natural ventilation relies on differences between air pressure between spaces, which can be caused by wind or buoyancy, and the effects are different temperature or humidity [31]. An empirical model represents the experience and examination of ventilation situations in different cases in order to understand the wind behavior, which can be categorized into two topics: simplified empirical methods for prediction of air flow, and simplified methods for prediction of air velocity inside a building [32]. This category is applicable to low-rise buildings with different functions, in which there will be direct connections to outdoor spaces from building openings. Standards have proposed formulas for calculating natural ventilation in single-side and cross-ventilation configurations [33]. A standards body that gives guidance for calculating the natural ventilation in buildings and general energy topics is the American Society of Heating, Refrigerating, and Air Conditioning (ASHRAE), which requires information of overall effective leakage areas in determining usage pressurization or depressurization methods, which researchers have followed [34]. It is clear in simplified empirical methods for the prediction of air flow that there are many detailed usable approaches to help designers understand and analyze the small scale of a building before construction in order to have the maximum benefit of natural ventilation to improve the indoor air quality and thermal comfort. On the other hand, for simplified methods of estimating the air velocity inside naturally ventilated buildings, it is possible to classify the techniques into five categories: full-scale investigation, computerized numerical simulation (the selected method for this research), tabulated data obtained from parametric wind tunnels, wind discharge coefficients, and direct measurements of the indoor air quality [35].

Zoning and multizoning systems are formulated in order to describe the meaning of airflow through opening sizes and places, wind pressure, buoyancy pressure, and wind variation in order to have the information required for calculating the natural ventilation in building sections and have a representation of real-scale building ventilation systems [36]. The yardstick for assessing wind development is given by a bioclimatic examination in the area, which partitions the year into overheated and cold periods and characterizes areas in need of remediation. Before researching potential plans that will give wind security or use air developments effectively, it is important to think about the direction of the wind [37,38]. Adjusting for wind direction is critical in buildings, where the use of windbreaks, the course of action of openings in high- and low-weight territories, and the directional impact of window channels can improve wind currents [39].

Human interference is involved, in which mainly constructed buildings act as windbreaks, as indicated by Bates's description, occupying the airflow upward, keeping in mind that, before long, it turns back and evaporates from the ground level. The most secured piece of this zone is near the windbreak on the leeward side; it turns out to be increasingly uncovered as the good ways from the windbreak increments until arriving at a point where the air flow is again at full speed. There is a smaller quiet territory on the windward side. On the leeward side, such receptiveness will bring about a smaller shielded region more remote from the windbreak [40,41]. Indoor thermal comfort has been studied by two methods, experimental and simulation by software. The problem of most results is that they consider buildings in the best situation according to the wind behavior, about which there are many doubts. The gap in energy efficiency calculation in terms of natural ventilation is that the mentioned factors are not counted in the formula. In general calculations, only weather data will apply without factors that affect the path of the wind to specific building sites, so the results will not be accurate and the outcome will be different from reality. In order to understand complete ventilation in buildings, most parts are covered in [42].

Computing Fluid Dynamics (CFD) software gives the opportunity to examine the regulated standards for indoor air parameters such as the temperature of the room, the level of humidity, and the speed of airflow [43]. The CFD system works with detailed parameters such as airflow, which is responsible for contaminant dispersion and temperature distribution [44]. The building configuration will be affected by such information, and in order for architects to have naturally ventilated designs, they need to have the simulation parallel with other design steps [45]. The advantage of using CFD over experimental or laboratory approaches is clearer and allows for easier assessment of the possibility of natural ventilation. Open-source software is needed in order to illuminate, or at least work with, the minimum boundaries during the process [46]. Based on research and experience with different computing calculations for research simulation, the Rhino Grasshopper plugin was selected. With the use of technology, it is advanced software designed specifically for analyzing and measuring energy use and the effect of every factor on the simulation in order to have the most accurate results compared with the real building model. Most regulations and formulated codes have been entered into the software in order to make the job easy and fast, and reduce mistakes [47].

Rhinoceros 3D is computer-aided design software. Grasshopper is a visual programming language and environment that runs within the Rhinoceros 3D computer-aided design application. Grasshopper is primarily used to build generative algorithms, such as for generative art. Programs may also contain other types of algorithms including numeric, textual, audiovisual, and haptic applications. Advanced uses of Grasshopper include parametric modeling for structural engineering, architecture, and fabrication; lighting performance analysis for eco-friendly architecture; and building energy consumption [48]. Ladybug Tools is a collection of free computer applications that support environmental design and education. Ladybug Tools is among the most comprehensive, connecting 3D computer-aided design interfaces to a host of validated simulation engines [49]. Honeybee supports detailed daylighting and thermodynamic modeling. Specifically, it creates, runs, and visualizes the results of simulations using Radiance and EnergyPlus. It accomplishes this by linking simulation engines to CAD and visual scripting interfaces. For this reason, Honeybee is one of the most comprehensive plugins presently available for environmental design. Figure 1 graphically explains the linkages among Grasshopper plugins and supportive software used in this research.

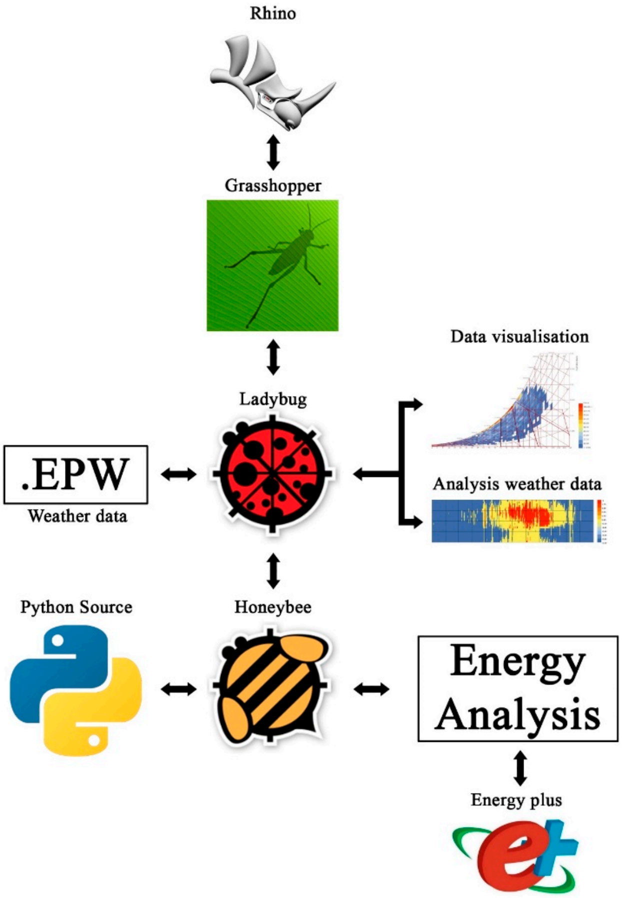

Figure 1. Linkage hierarchy of Rhino software plugins.

2. Materials and Methods

The authors used available information in order to find energy-efficiency calculation methods around the world to compare and analyze the existing requirements in energy-efficiency standards calculations. The findings are limited to building simulations with general weather data input from EPW files according to natural ventilation calculations. Thus, in order to understand the importance of the closed environment and its absence during the mathematical simulation process, the research problem was designed. Examining the existing situation of saving energy within the case study to explore the needed basis and create primary information for illustrating the importance of considering the surroundings in energy calculation formulas is the method in this study. Finding the differences and clarifying the basis for improving natural ventilation calculations to increase the percentage of thermal comfort as the research aims guide the discussion, focusing on climate during the process, and related factors are taken into consideration in order to illustrate the importance of this topic and find the link between the closed environment and indoor human comfort. Data for this research were collected from books, journals, and online resources. Studying the effect of reducing the level of energy consumption and increasing indoor thermal comfort is needed, and the results will have a direct impact on the future of our planet. The objective is to consider the current situation in terms of the climate and find the most accurate outcome of energy consumption calculation based on microclimate and wind effect. The framework of this research methodology illustrates the result of comparing and analyzing different CFD software and understanding the processes in wind behavior and natural ventilation in buildings.

There are two methods of natural ventilation that benefit thermal comfort. The first method is wind-driven ventilation, which normally happens as a breeze blows over a building; the breeze hits the windward divider, causing an immediate positive pressure. The breeze moves around the building and leaves the leeward divider with negative pressure, which is called sucking impact. By locating openings on the windward and leeward dividers in the building, natural air will surge in the windward openings and leave the leeward openings to adjust and relieve the pressure on the windward and leeward faces, which is beneficial in hot climates, as in the selected case. The second method is based on ventilation induced by temperature or humidity, which is commonly used as stack-driven ventilation. For stack ventilation to work appropriately, there must be a temperature contrast. Warm air, which is less dense, rises in the indoor spaces, while the cooler air is sucked from openings from lower levels. This method does not depend on the breeze. On overheated summer days with no wind, a stack impact can occur with moderately stable wind. Besides, since it does not depend on pressure and the course of the breeze, there is better control in finding air admission. Wind-driven ventilation is considered as a basis for simulations and analysis according to climate conditions and the need for fresh air for indoor spaces. Required factors for wind-driven ventilation are building orientation, location, and proportion, and the types and operation of windows [50,51].

This step requires reviewing different types of ventilation in the wind-driven method. Generally, it is possible to group ventilation into three categories: natural, mechanical, and mixed-mode ventilation. As far as mechanical ventilation is not part of the research focus, it is going to be illuminated. The research method and preparation for the comparison was to find the level of indoor thermal comfort difference, so first a simple building model was designed. This building follows the construction regulations of the selected case. Then, thermal comfort percentage is simulated according to energy efficiency standards, which means without surroundings, and later the same building conditions are applied in the unique historical environment with dens and semi-dens in order to illustrate the change in comfort level if building surroundings are considered in the simulation. Realistic weather conditions are considered, which are presented in climate data in Section 3, which means that the yearly simulation setup is done by current weather data and the result is applicable for the selected neighborhood. Results are simplified and shown in an understandable chart for all professionals for better realization of the situation and case condition. Also, the simulation process with all limitations and boundaries is shown for a detailed explanation for researchers if following the same method will be helpful for their design and research process.

3. Case Study Analysis

The Turkish Republic of Northern Cyprus is an accepted state that contains the northeastern section of Cyprus island. A buffer zone under the influence of the United Nations extends between Northern Cyprus and the remainder of the island and cuts Nicosia, the largest city on the island and the capital of both sides, in half. Many powerful countries have occupied Cyprus throughout history because of its strategic location [52,53]. The research case, located in the Mediterranean Sea, has hot-humid and semi-arid zones with a subtropical climate. Climate changes are seen in different cities caused by the mountain located in the middle of the island. Girne is in a hot-humid climate with higher humidity toward the high mountain. A shift between hot-humid and mixed climate is seen in Famagusta and Guzelyurt, caused by the distance from the sea. Lefkosa, which is located at the center of the island, has a hot-dry climate [54]. At the eastern shore of the island is Famagusta, a port city with a rich history. During the medieval period, Famagusta was the island's most significant port city and an entryway to exchange with ports of Western European countries, from where the Silk Road dealers conveyed their merchandise. This city, with a population of about 54,000 [55], is the third-biggest city of Northern Cyprus. Famagusta is located at 35°7′ N and 33°55′ E, and is 25 m above sea level. According to the Köppen–Geiger climate classification, it has a hot Mediterranean/dry summer subtropical climate that is mild with moderate seasonality. In other words, due to the subtropical high pressure system, it is hot and dry in summer, and due to the polar front, it has rainy and moderate weather. The average maximum temperature in the hot season is approximately 33 °C in the city, and the average minimum temperature for the cold season is about 17 °C [56]. Dividing walls were constructed by the Lusignan Kingdom of Cyprus in the 14th century and completed by the Republic of Venice during the 15th and

16th centuries before the attack of the Ottoman Empire in 1571 [57–60]. The Famagusta walled city is a unique closed historical environment with gates, surrounded by a ditch on three sides (Figure 2).

Figure 2. Walled city of Famagusta.

The Famagusta walled city is an interesting, unique protected historical settlement. Since this study focuses on the closed environment, it is interesting to find the effect of surrounding walls next to buildings on indoor thermal comfort. In order to define the reason behind the selection of a two-story residential building for this study, applicable rules in this settlement are followed, which restrict any building from surpassing the wall height, and the majority of the neighborhood is residential, and this function has the highest time count function for daily activities. In Figure 3, selected sites for simulations are highlighted according to surrounding density and street access that act as guidance for wind direction. The first location is within the extension of the walled city main path, which illustrates the effect of the wall on natural ventilation combined with low-density surroundings, and the second selected building site is deeper in the historical urban pattern. Results of mathematical simulations of both buildings are compared with the single building with the same requirements without closed environment conditions.

Figure 3. Selected building locations in the Famagusta walled city.

Wind effect factors have been studied in terms of how they change the thermal conditions in buildings. The factors that affect users' thermal comfort characteristics can be categorized into six subheadings, according to the effect the wind will have on them and change the adaptive comfort parameters:

- Pressure: Atmospheric pressure or air pressure is the power applied to a surface by the air above it as gravity pulls it to Earth. Pressure is normally estimated with a biometer, which uses mercury in a glass cylinder that rises or falls to indicate the heaviness of air pressure [61].
- Temperature: Temperature is a feeling of how hot or cold the weather is. It is the most commonly estimated climate parameter. More explicitly, temperature explains the dynamic energy of the gases that create the air. As gas particles move more and increase speed, the air temperature will be higher. Generally, air temperature influences the rate of evaporation, relative humidity, and wind speed and direction [62].
- Wind direction: It is generally detailed in cardinal ways or in azimuth degrees. Wind course is estimated in degrees clockwise from the North. Wind headings are estimated in units from 0° to 360°, which means 90° between north, east, south, and west [63].
- Relative humidity: Relative humidity is the proportion of the fractional weight of water vapor to the balance vapor weight at a given temperature. It relies on temperature and the weight of the arrangement of schemes. A similar measure of water vapor brings about higher relative humidity in cold climates than warm climates. Relative humidity is ordinarily communicated as a percentage; a higher rate implies that the air–water ratio is increasing [64].
- Wind speed: Wind speed, or wind flow velocity, is a central barometric amount related to air moving from high to low pressure, generally because of temperature change. Most of the time breezes are parallel to isobars because of the Earth's rotation. Wind speed is presently estimated with an anemometer, but it can also be characterized with the Beaufort scale. Wind speed is influenced by various variables and circumstances, including the pressure gradient, Rossby waves and jet streams, and nearby climate conditions. There are additional connections to be found between wind speed and wind direction with pressure and territory conditions [65].
- Wind circulation: Wind circulation is the large-scale development of air. The Earth's wind circulation differs from year to year; however, the enormous scale structure of its flow remains consistent. Mid-latitude or tropical convective cells happen as random events, and climate forecasts of those cannot be made more than 10 days before. The Earth's climate is a result of its brightening by the sun and the laws of thermodynamics. The work delivered by the sun causes the movement of the majority of air, and in that process, it redistributes and is consumed by the Earth's surface close to the tropics. Large-scale wind cells move poleward in hotter periods, yet remain to a great extent consistent, as they may be, in a general sense, a property of the Earth's size, pivot rate, warming, and barometric depth, all of which change nearly nothing [66].

3.1. Famagusta Weather Analysis

During the year, Cyprus faces prevailing winds from south to northwest. It is important to see how the winds affect the city in different months of the year. Figure 4 shows Famagusta wind roses during winter and summer in order to understand the general wind directions and wind speeds to check the yearly average and seasonal wind portfolio at the same time. The graph in Figure 4b shows the wind direction and temperature during summer at the same time, so we can estimate the wind effect. During the summer from the south, and in winter from the west, we have the prevailing wind direction. In the same figure, the left side clarifies when, in which direction, and for how long we will have discomfort, which is a challenge for designers to increase the hours of thermal comfort during those times.

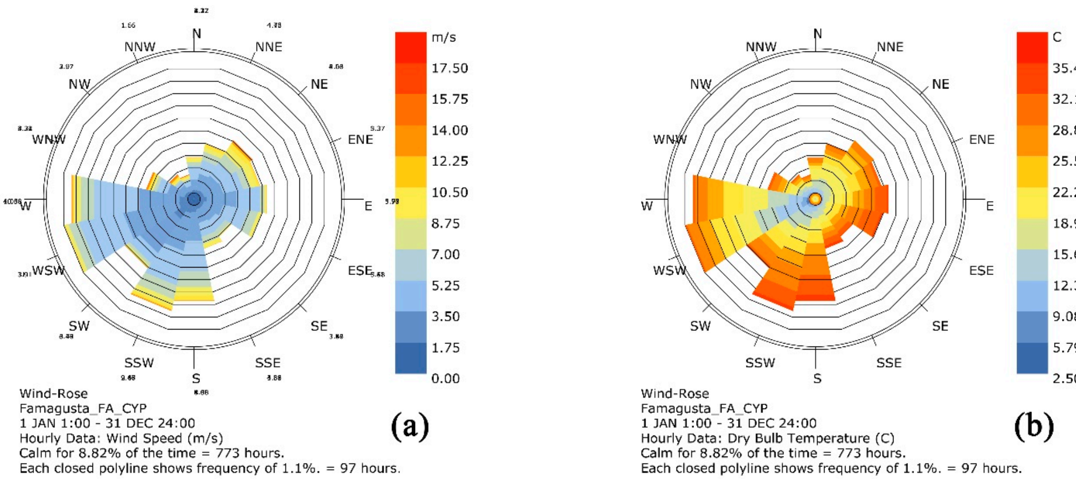

Figure 4. Wind roses in Famagusta in (**a**) winter and (**b**) summer.

Providing the extracted information from CFD software requires graphical formulas as an interface for the main mathematical calculations that can be used by any Grasshopper user in order to find any climatic condition wind rose based on the Ladybug plugin. The Ladybug EPW file download section is a platform that provides users with access to updated weather data all around the world. General information is necessary in simulations to extract daily data from wind direction and wind speed to be imported to the simulation based on daily conditions in order to have realistic results. Figure 5a illustrates daily temperature information for the selected case. Daily temperature is required, as it is a basic measurement of users' thermal comfort, so the same data were used as the base in the software simulation. According to temperature, Figure 5b shows the universal thermal climate index for Famagusta in terms of whether it is comfortable or not as a simplified graphic, where red stands for comfortable times and blue shows uncomfortable times. Around five months a year, people feel comfortable in these weather conditions, which shows the importance of a new systematic way to control the microclimate in order to increase the benefits. Microclimate details are presented in Figure 5c, which shows outdoor thermal comfort. Outdoor thermal comfort has a strong role in the process, since the atmosphere surrounding the building dictates the weather input from the openings to the indoor spaces.

Based on yearly weather data, it is possible to find the yearly percentage of comfortable and uncomfortable conditions and how citizens feel the temperature. Research shows that the air temperature is not the exact felt temperature. In order to find out, it is necessary to add velocity and humidity factors. The result is found by following the Grasshopper Ladybug adaptive comfort method, which is strong, useful, and one of the most complete mathematical systems to be imported to the main calculation. Figure 5 shows that about 60% of the year is still not comfortable based on the user feeling criterion.

Wind speed is not a single variable; many factors affect the wind. It is possible to calculate the wind factors at different heights with a single component in the Ladybug plugin. This information is useful in detailed building design, but as a general decision for an international approach in most scientific research and simulations, wind speed at 10 m height is considered as a standard. The most important and effective components for these research simulations are adaptive comfort and psychometric charts. After all analyses, these two components prepare the ground for comparison and understanding of the situation. Also, they provide a chance to export numeric data into usable and easily understandable graphs so everyone can benefit from the prepared results. The adaptive comfort chart below shows three criteria: when people in the selected climate feel cold, hot, or comfortable. This zoning is the basis for the solving strategy (Figure 6).

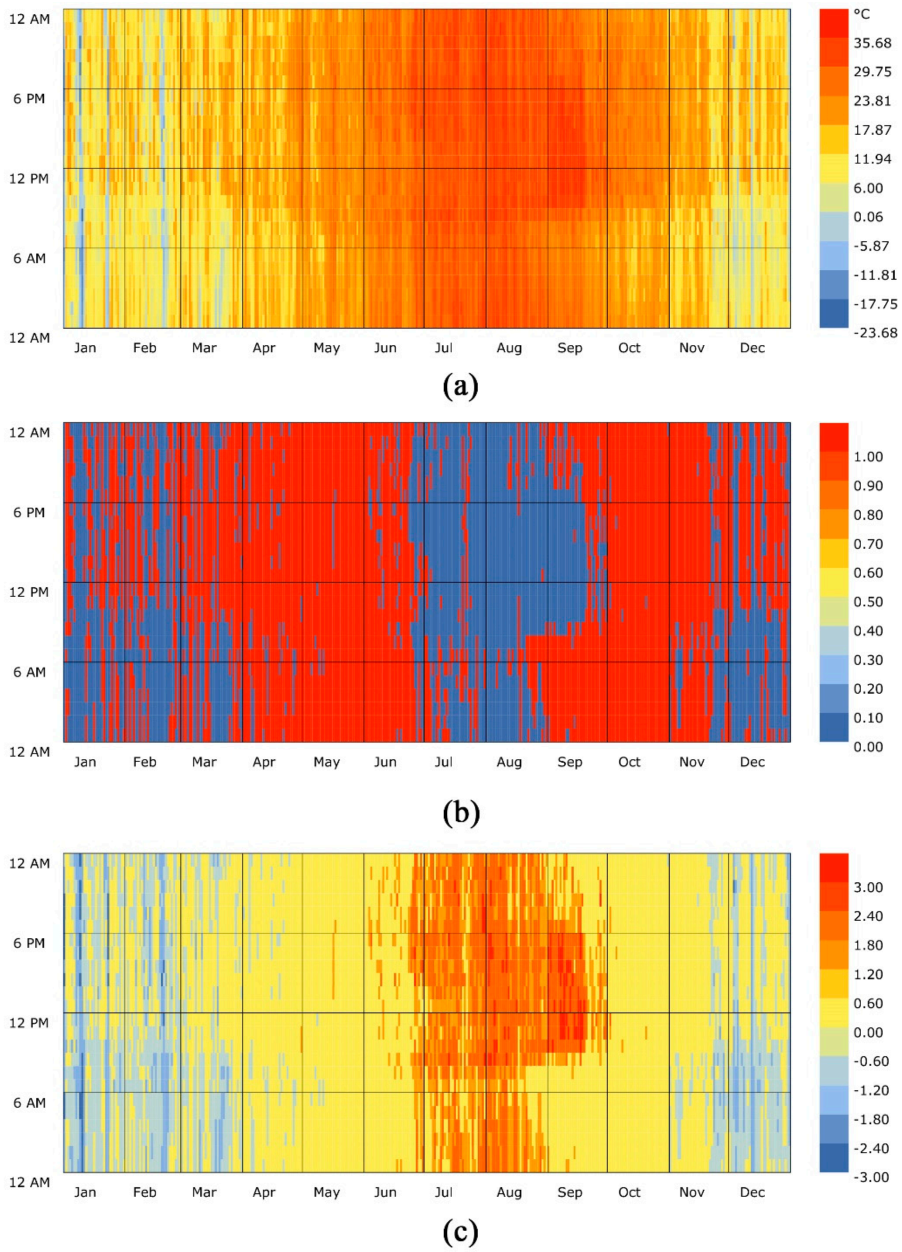

Figure 5. (**a**) Climate index, (**b**) comfort level of temperature, and (**c**) outdoor comfort in Famagusta.

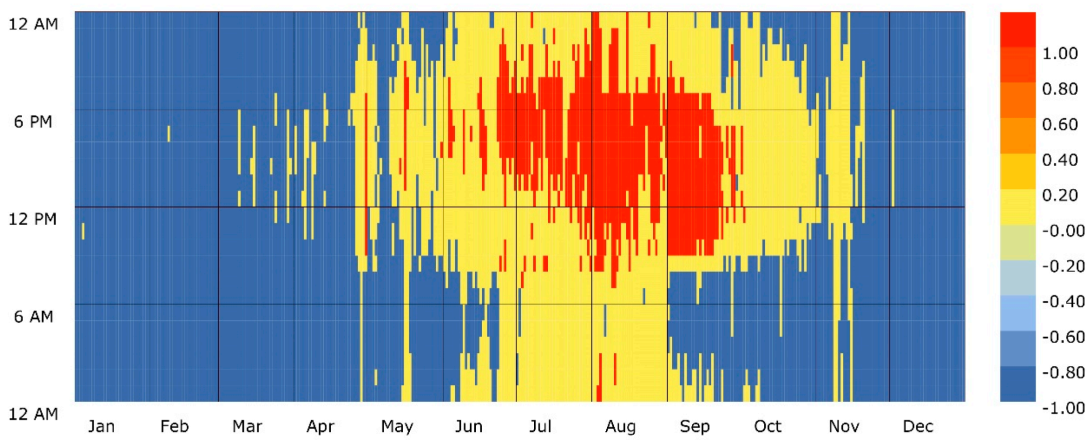

Figure 6. Adaptive comfort.

3.2. Simulation and Model Design

The simulation model was made based on construction rules and regulations as well as typical land divisions and boundaries in the Turkish Republic of Northern Cyprus. The first step of the analysis is to follow the individual building with inputs from weather data in order to have a basis for comparison, and then the same building is simulated in two different neighborhood patterns to find the percentage of thermal comfort reduction. The weather data were downloaded and run for Famagusta by the Ladybug EPW file downloader. The simulation model was created based on allowed square meter construction according to the Northern Cyprus land division average. The building length is 17 m and the width is 16 m. Each floor height is 3.5 m, which means that, in a two-story building, the building height is considered 7 m in total. After designing the model, we can define the windows for cross-ventilation. According to Northern Cyprus regulations, openings should be a minimum of 5% of the construction area in square meters, which means 20% of the surface based on the designed model for this section. During the simulation, it is defined that windows will be 100% open or closed according to the setting in the formula, and the window frame infiltration is counted as 0.015, which does not have an effect on the final outcome. In order to define the windows, first walls that will have the openings are selected by filtering and then transferring to zones. Only cross walls are selected to have openings, as the research focuses only on a cross-ventilation system. Then, the whole opening percentage is designed as three windows in each façade. The opening breaks are based on a typical building design method in the neighborhood according to indoor space organization, and a single opening does not ventilate indoor space corners, which will appear as nonconformable zones as a result. The breakup distance is a 1.5 m offset from the ceiling and 1.2 m from the floor, according to construction regulations (Figure 7).

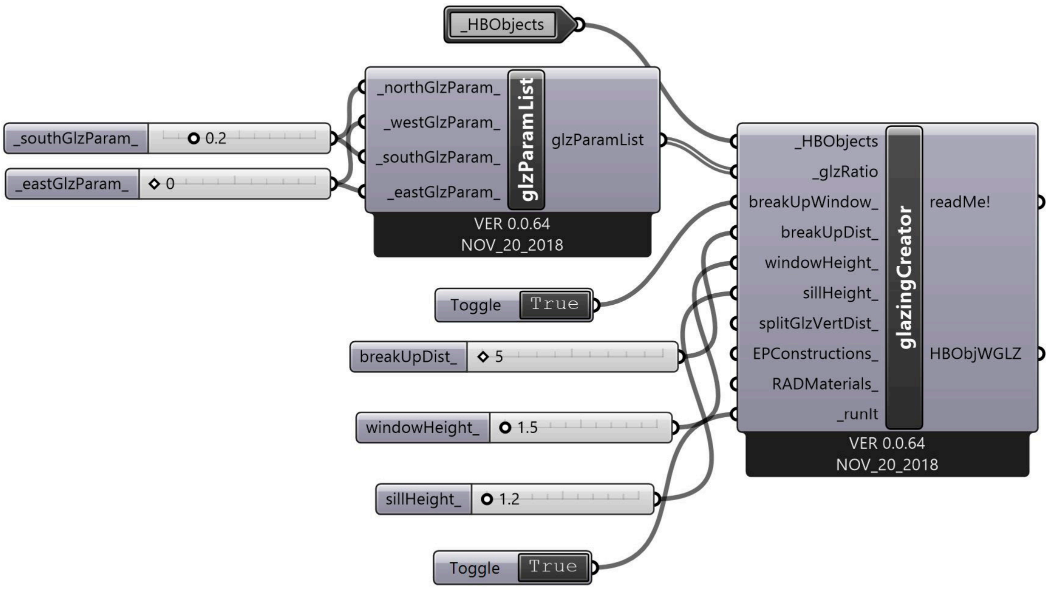

Figure 7. Honeybee formula for defining openings on model surfaces according to cross-ventilation method and opening percentage based on Northern Cyprus regulations.

In this section, limitation data for the window situation are added to the program formula. Natural ventilation is set as an active means, and a heating, ventilating, and air conditioning (HVAC) system is not involved in the simulation in order to get only the wind effect on thermal comfort. Then, the software is set to keep windows open completely (100%) when the indoor temperature is between 21 and 30 °C. Out of that range, we will need a heating or cooling system, which means that windows will be considered closed, as the ventilation will not have a positive impact on indoor thermal comfort. Also, windows will be closed if the outdoor temperature is less than 15 °C or above 30 °C. Figure 8 shows the formula section that defines the limitations for window conditions.

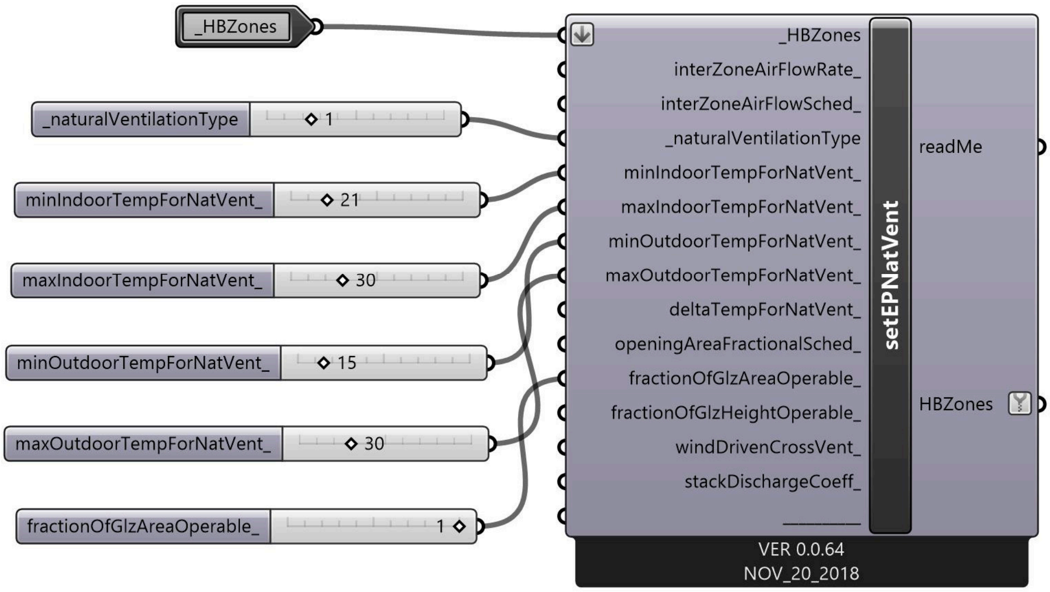

Figure 8. Temperature limits for windows to be open or closed.

As a next step, needed data are fixed for the EnergyPlus simulation engine. During this part, the complete set is calculated by EnergyPlus as a supportive software link to Grasshopper Honeybee. The formula is explained step-by-step in the following section. The general information imported from the weather data file is attached to the formula as a basis for calculation. It is important to define the analysis period in this part as the result will be exported based on summer and winter. The reason behind this division in the adaptive comfort calculation section is that it is needed to define the clothing level, which will be different based on the season. The energy simulation parameter is set to 1 in the terrain section, which defines the neighborhood pattern. That means that the preset definition for this area is suburbs with distance between buildings and low density. In the Honeybee context section, surface parameters that represent the other buildings located in the neighborhood are attached to the main formula. This selection will give definitions to the software to count them as surrounding environment that will have a windbreak effect. An hourly time step is selected for the simulation output to generate detailed information as a result. That means that, for each month, the prevailing wind might be from a different direction, but at the end, with different angles, the result will be in the same framework; thus, a comparison is possible (Figure 9).

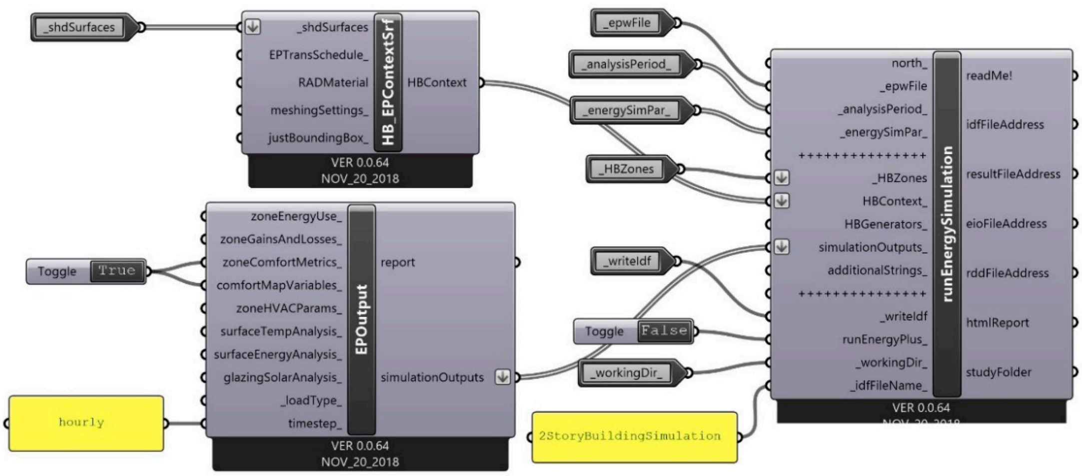

Figure 9. EnergyPlus simulation preparation linkage from Grasshopper Honeybee plugin.

As the last step, we calculate the thermal comfort percentage for the selected period. The important factor in this section is to properly consider clothing level based on exported data. For the seven months that are counted as hot temperature conditions based on Figure 5a, the simulation was run with a clothing level of 0.6, which means two-piece light clothing, the common outfit for residential indoor living. For the other five months, the clothing level changed to 1, which means three-piece clothing during the cold period. Indoor activity also has an effect on how temperature feels. So, in order to keep all results simple and in the same condition, sitting was selected as an activity. Dry bulb temperature, relative humidity, mean radiant temperature, and wind speed are attached to related trees for final calculation from the EnergyPlus results directory. Biometric pressure is also defined for the formula. In comfort parameters, the humidity ratio upper boundary is defined as 0.012 according to ASHRA E55 standards, which means that higher humidity will create discomfort for people, and the humidity level is high as the case is a coastal city. After the calculation is finished, there are several results to be exported, of which the usefulness of this research and the percentage of indoor thermal comfort are gathered as the main outcomes (Figure 10).

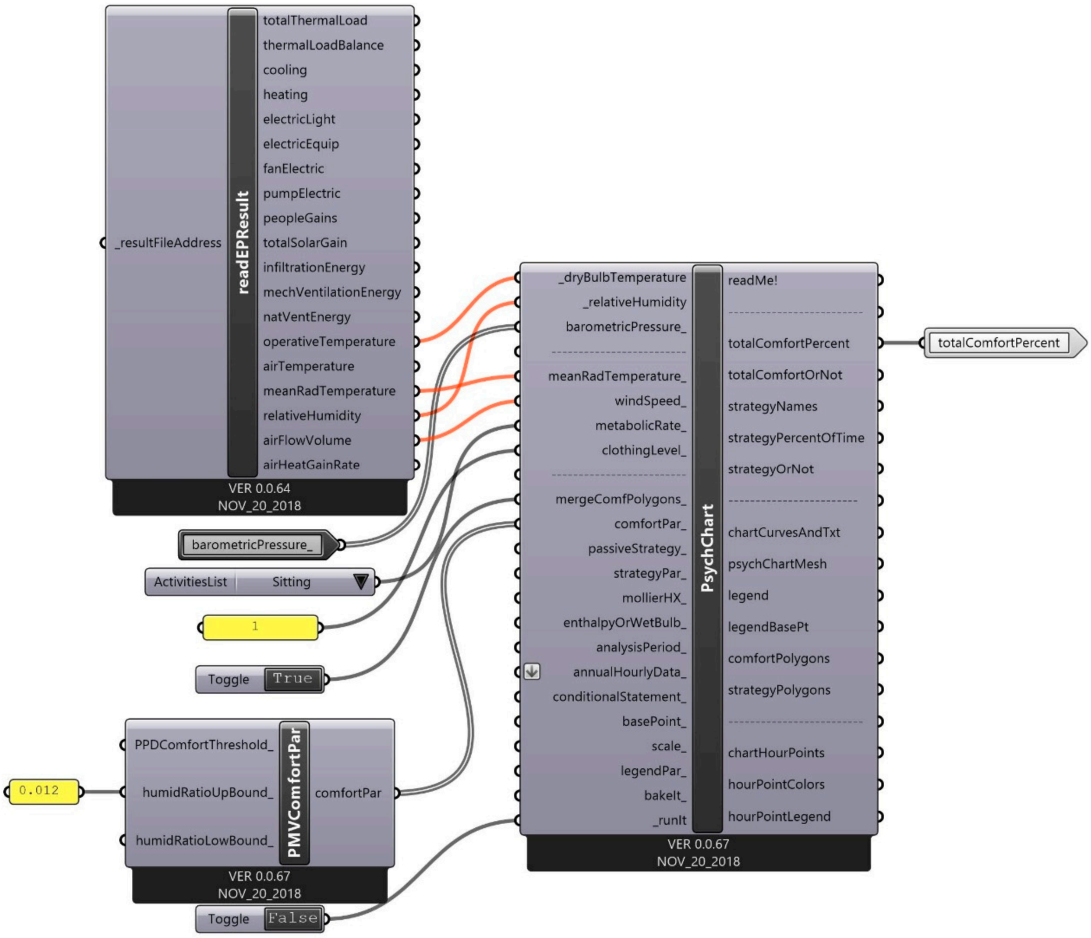

Figure 10. Thermal comfort percentage calculation.

4. Discussion

The main point of thermal comfort calculation is to make an agreeable situation for inhabitants by making changes toward decreased energy consumption. At present, there is a contention that, by utilizing the passive design principles of sustainable energy sources, better thermal comfort can be achieved in buildings. In an inbuilt neighborhood with current closed environment conditions, it was impractical to provide complete thermal comfort, so an attempt was made to lessen dissatisfaction instead. Architects and energy consultants try to use energy calculations to estimate the existing conditions of buildings in order to design thermal comfort improvement strategies. However, by using natural ventilation systems, achieving comfort zones is easier. The problem is how to produce accurate and reliable calculation outcomes by only considering the individual building itself. Based on the results, indoor thermal comfort changes are made according to closed environment conditions. Thus, it is not enough to simulate the level of comfort based only on weather data specifically related to natural ventilation.

The results of the advanced mathematical simulations for all three mentioned cases are gathered in Figure 11. The x-direction shows the monthly division of the year and the y-direction shows the thermal comfort percentage during each month. The blue line represents the single building simulation based on energy codes, which means that the basic weather data information was entered into the simulation without a closed environment effect on natural wind. It is obvious in this stage that the general indoor temperature covering the comfort zone is higher than the other cases located in the neighborhood pattern with surrounding buildings. The orange line represents the outcome for the first building located in the main path of the Famagusta walled city with a more open surrounding built environment, which has lower thermal percentage than the individual building simulation. At the end, the gray line represents the second building located deep in the neighborhood with higher density.

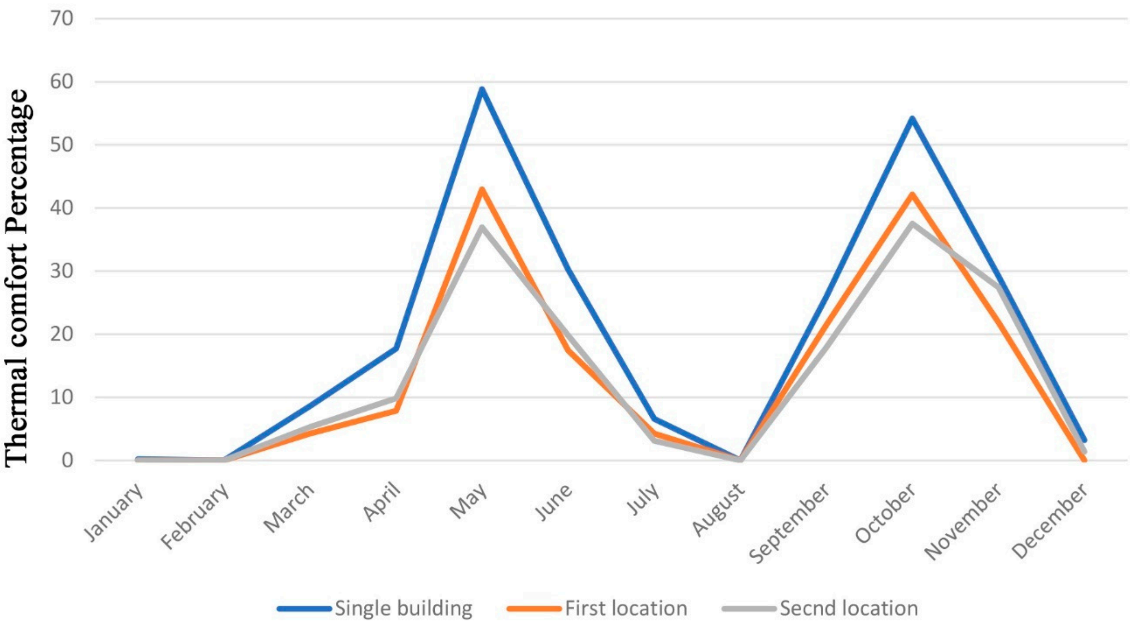

Figure 11. Comparison chart between one building with no surroundings and two buildings in Famagusta walled city considering the closed environment.

During January, February, August, and December the thermal comfort percentage is either 0 or close to nothing. The reason behind this is that, when the outdoor temperature is out of the limit range, the windows will automatically close, which means that there will be no natural ventilation during these periods. It happens mainly during the winter, when the outdoor weather is very cold, and in the middle of the summer due to high temperature. Also, the thermal comfort percentages in March and July are less than 10%, which is very low, and, during these months, the HVAC system will be needed. In April, the individual building performance is above 10%, but the simulated models with surrounding environment are less than 10% according to user satisfaction. The other reason for the low percentage for the summer period is the high level of humidity during that time, which, if it goes above 0.012 based on ASHRAE standards, will not be counted as a comfortable situation even if the temperature is in the acceptable range.

In terms of the general thermal comfort percentage calculated hourly for all three simulated cases, the individual building with no surroundings has the maximum, which is normally considered in energy calculations at 19.56% during the year, considering all limitations in the simulation process. It is followed by the first location with wide open surroundings, at 13.51%. This shows that the wall constructed around the historical settlement in Famagusta itself affects the natural ventilation, and the only path for the wind is from the top of the wall and three main gates designed for passage to the fortress. The third building location shows an even lower indoor thermal comfort percentage, 13.02% for the year. In Figure 12, examples of thermal comfort percentage are presented with a color code as yearly outcome to analyze and compare the numeric differences between them. The same as Figure 11, the individual building simulation is shown in blue, the first building is shown in orange, and the last building is shown in gray in the chart.

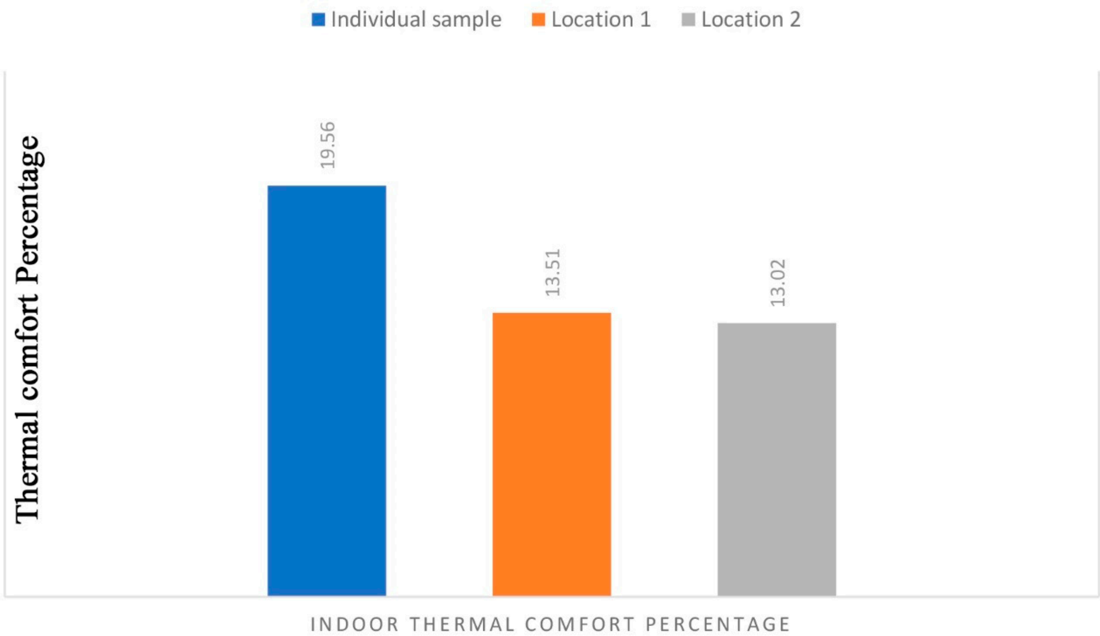

Figure 12. Average thermal comfort percentage for complete year comparison.

5. Conclusions

Taking the results into consideration, it is obvious that the percentage of thermal comfort for the single building with no closed environment is higher than that for the buildings located in the existing pattern that are affected by the surroundings (Figure 11). It is important to mention that, in the thermal comfort mathematical simulations, only the effect of natural ventilation is calculated. Thus, the percentage is determined accordingly, which means that counting other factors such as material, solar gain, insolation, window shading, building form, etc., will change the percentage accordingly. During energy calculation for passive building design, the other factors are designed in the formula. Simulations are done for each month of the year separately and entered on the main chart in order to prepare a basis for comparison in order to analyze and illustrate the differences between models. In the general average calculation, it became clear that there was a reduction in thermal comfort of about 6.05% when comparing the individual building simulation and the first building located in the neighborhood with a closed environment. This gap increases to 6.54% when the first building location is replaced by the second, which is deeper in the neighborhood (Figure 12). These percentage differences should be covered by indoor mechanical HVAC systems, which means that the energy consumption in the passive building design process will be different and might surpass the acceptable limits. Thus, the effect of the closed environment on natural energy ventilation calculations should be considered in calculating energy standards. To summarize, in contrast with the individual building energy consumption formula based on natural ventilation, a mathematical calculation needs to be developed based on closed environment conditions in order to have reliable results.

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