# Impact assessment of natural ventilation on thermal comfort levels in sustainable residential buildings

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## ABSTRACT

In the present paper the impact of natural cross-ventilation on thermal comfort levels in sustainable residential buildings is evaluated. A sustainable dwelling is designed in Crete and various scenarios of different combinations of open windows and doors in the ground floor, the first floor and between the floors are tested to determine the final scenarios with the best possible airflow movement. Three scenarios with open windows and doors in the ground floor and six (6) between the floors (9 total scenarios) are chosen to be the final scenarios where the impact assessment of natural ventilation on thermal comfort levels is performed. Computational Fluid Dynamics (CFD) simulations with the 3D steady Reynolds-averaged Navier-Stokes (RANS) approach and the Shear Stress Transport (SST) k-ω turbulence model are used for the study of thermal comfort levels, along with the Predicted Mean Vote (PMV) index. The Scenarios are tested for a typical summer day for four different hours and environmental conditions. The designed building is treated as a stand alone in all the simulations and it is not an existing construction. From the analysis of the results we observe that natural ventilation, in many cases, is an effective way to achieve indoor thermal comfort. In many Scenarios the high values of PMV from the Base Scenario (no windows or doors open) are decreased and in a few cases the values fall into the cold zone of comfort. The layout of the floors also affects the airflow movement in addition with the openings and the environmental conditions and can be used accordingly. According to the author's knowledge in the field of investigating natural ventilation via numerical approach simulation the present study is an original attempt to examine a more elaborate building architectural design and analyse performance in a dynamic way according to variable weather conditions.

## KEYWORDS

Natural ventilation, Thermal comfort, Computational Fluid Dynamics (CFD), Building simulation, Complex building geometry

## 1 INTRODUCTION

Natural ventilation is an alternative way to achieve indoor thermal comfort and healthy environmental conditions. It is linked to Indoor Air Quality (IAQ) and the comfort of the occupants as well as to the potential of reducing building energy consumption. Natural ventilation can be effectively used during the day for the improvement of thermal comfort levels and during the night for cooling the thermal mass of the building **[1]–[5]**.

Over the years a lot of works study the impact of natural ventilation inside the buildings. For their study, some works **[4]–[12]** used field/experimental measurements or examined the natural ventilation in an existing building. In other works they preferred to use various software packages to model the study case and simulate the airflow pattern inside a space. Some used Flow Networks for their simulations **[2], [13]–[15]** while others used CFD analysis **[1], [4], [5], [8], [11], [16]–[27]**.

According to the author's knowledge in the field of investigating natural ventilation via numerical approach simulation the present study is an original attempt to examine a more elaborate building architectural design. In most of the research works, the examined space, where the simulations were performed, had a simple geometry, except from three works **[21],**

**[24], [27]** where the effects of natural ventilation were examined in simple low-rise house geometry. In the work of **Nikas et al [11]** a simple cell is used but the impact of indoor layout on the indoor flow patterns from natural ventilation is examined.

The most common method for the evaluation of thermal comfort is the Predicted Mean Vote (PMV) with the Predicted Percentage Dissatisfied (PPD). PMV (Predicted Mean Vote) is a thermal comfort index. It was developed for the prediction of the human mean vote of thermal sensation from a large sample of people that was exposed to a given indoor environment. PMV has a 7 scale range from -3 to +3 (-3=cold, -2=cool, -1=slightly cool, 0=neutral, 1=slightly warm, 2=warm, 3=hot). The ideal value of PMV is 0, with a comfortable range from -0.5 to +0.5, but even in the comfortable zone some people will not be satisfied with the indoor temperature **[28], [29]**.

Few works **[2], [18], [30]** address the results of their research to the architects and the necessity of taking into account natural ventilation systems from the early stage of architectural design. **Bastile et al [18]** studied the reduction of the energy consumption by natural ventilation and better bioclimatic design of the building and noted that the followed method is useful for an architect. **Schulze et al [2]** concluded that the method used, for their work, for the study of indoor airflow by natural ventilation can be used in the architectural design phase. **Papamanolis [30]** highlighted the importance of natural ventilation strategies, especially in Greece, as a design factor which is often ignored by the designers.

From literature we find that natural ventilation in buildings is still a concern and is studied with various software packages and field measurements. A numerical approach, mostly CFD, is used but there is no specific method in which provides best results, more accuracy and meets the computational demands. So far, the majority of the simulations are performed in a simple geometry and only one factor is investigated each time.

The objective of the present study is to assess the impact of natural cross-ventilation on thermal comfort levels in sustainable residential buildings. Alternative strategies were explored for the study of natural ventilation and the effect of a complex two story building geometry, with its inner layout, on indoor airflow patterns and thermal comfort levels for four different environmental conditions. Moreover, the thermal comfort is studied on seven human figures (Avatars) located in various spaces of the residence, and not just on some points in a specific height or plane of the building volume. In all the simulations the building is isolated modelled and various software packages are included in this research for the required simulations.

## 2 ARCHITECTURAL DESIGN

The building has openings in the North, East and South directions, avoiding completely the West. The floor plan of the house is elongated with the long sides facing the north-south direction. In the ground floor an open space of the Living room-Kitchen-Dining room is created and on the first floor the two bedrooms and the office are placed. The living room has N and S orientation, the kitchen E and N and the dining room S, but the open space layout of the ground floor allows the diffusion of light in the various areas. In the living room there is a two-story open space which allows communication with the hallway on the first floor and a two-story northern opening that creates a sense of unity. The office has N and E openings and the two bedrooms have E and S openings. The laundry and the 3 bathrooms are located in the western area of the residence with N and S windows. The floor plans of the residence are presented in **Figure 2.1** below.

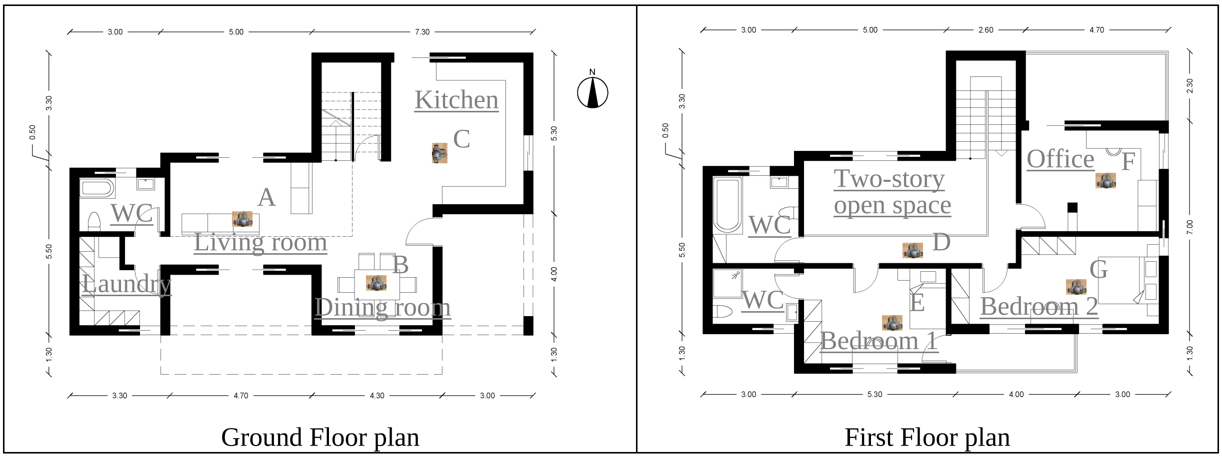



Figure 2.1 **F**loor plans and position of the Avatars inside the building

# 3 NATURAL VENTILATION MODELLING

For the study of natural ventilation and thermal comfort levels, the climate data of four hours of a typical summer day are chosen. The examined environmental conditions, as they were recorded from the meteorological station, are presented in the **Table 3.1** below.

Table 3.1 The examined outdoor conditions for the selected hours

| **Time** | **Temperature (°C)** | **Relative Humidity (%)** | **Wind speed (m/s)** |
|---|---|---|---|
| **2:00** | 25 | 65 | 2 |
| **8:00** | 25 | 65 | 1 |
| **14:00** | 30 | 40 | 7 |
| **20:00** | 27 | 50 | 5.5 |

## 3.1 CFD simulation: computational settings and parameters

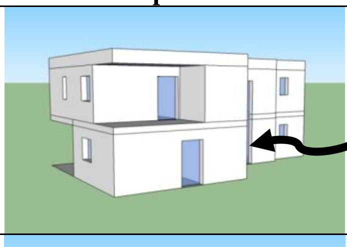
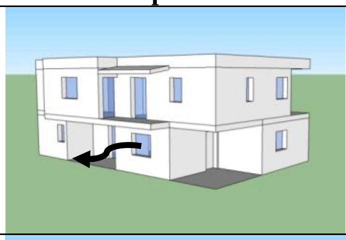
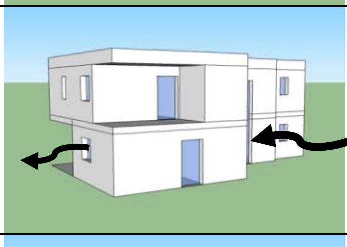
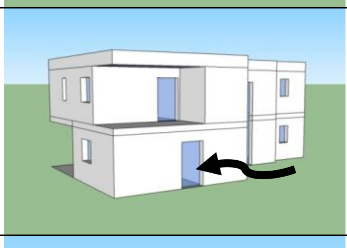
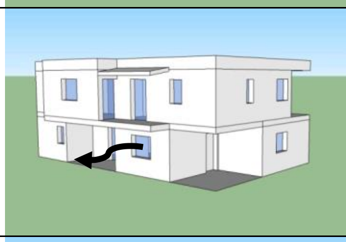
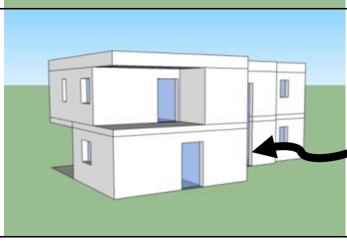
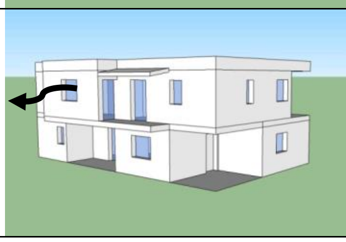
Regarding the creation of the model in Autodesk CFD **[31]** for the simulation of natural ventilation inside a building and its impact on thermal comfort levels, there are no specific instructions. From research, tutorials and documentation of the Autodesk Knowledge Network the following methodology is created. In this work, the building is treated as stand alone case for the CFD analysis. The steps for the model creation are:

- Creation of the building geometry in Revit
- Set of the orientation of the building, so that the domain in Autodesk CFD is on the x&y axes and the wind direction (NW) is on the y axis (it was observed that the software responded a little better if the domain was aligned to the axis)
- Hide, in the 3D view, the selected windows/doors that will be open in the simulation
- Launch in Autodesk CFD
- Use the Geometry Tools to:
  - Merge edges
  - Fill Void, to create the air volume inside the building since there are some windows/doors open
  - Create the Domain, the air volume of the environment around the building (150 × 150 × 30m)
- Assign the Materials in the imported geometry

- Assign the Boundary Conditions, velocity and temperature for inlet and pressure=0 for outlet for the domain and 70W heat generation for the human figures
- Set initial conditions, 26°C for the inside air volumes
- Create the Mesh of the model
- From the Solve dialog:
    - Set the Thermal Comfort Factors, Metabolic rate 60W/m², Clothing 0.36clo and Relative Humidity (different values)
    - The location of the building, the study time and day and the orientation
    - For the turbulence the SST k-ω model is chosen
    - The PMV index is used for the thermal comfort assessment
- Run the Scenario

## 3.2 Presentation of the examined Scenarios

For the airflow movement inside the dwelling various scenarios were simulated in Blender software with the basic CFD plug-in and in Autodesk CFD. The examined Scenarios are presented in the **Figure 3.1** below.

| Scenario | NE Perspective view | SE Perspective view | Openings |
|---|---|---|---|
| **1** |  |  | Inlet: N glass door of the living room<br>Outlet: S window of the dining room |
| **2** |  |  | Inlet: N glass door of the living room<br>Outlet: E kitchen window |
| **3** |  |  | Inlet: N glass door of the kitchen<br>Outlet: S glass door of the living room |
| **4** |  |  | Inlet: N glass door of the living room<br>Outlet: S window of the bedroom 1 |

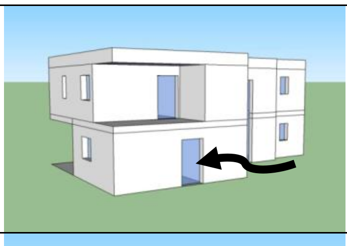
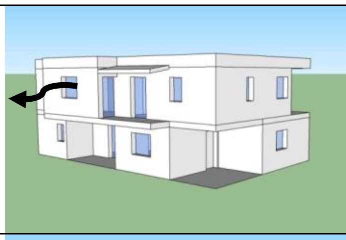
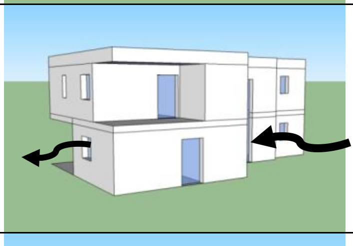
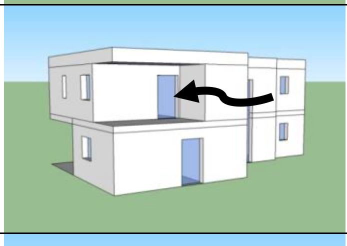
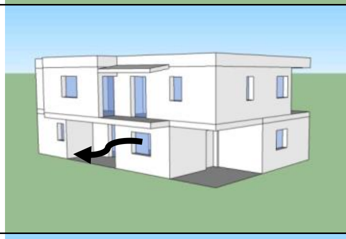
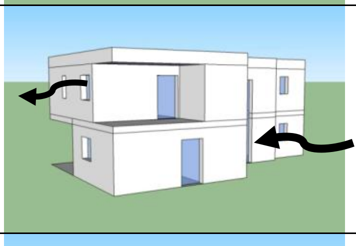
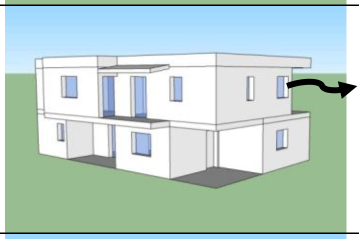
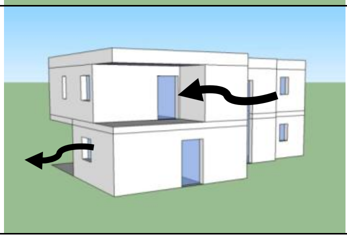
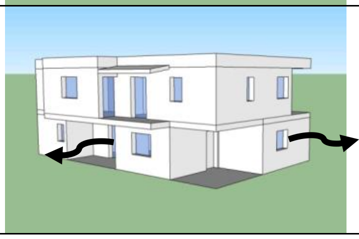
| | | | |
|---|---|---|---|
| **5** |  |  | Inlet: N glass door of the kitchen<br>Outlet: S window of the bedroom 1 |
| **6** |  |  | Inlet: N glass door of the living room<br>Outlet: S window of the bedroom 1 and E kitchen window |
| **7** |  |  | Inlet: N glass door of the office<br>Outlet: S glass door of the living room |
| **8** |  |  | Inlet: N glass door of the living room<br>Outlet: E window of the office |
| **9** |  |  | Inlet: N glass door of the office<br>Outlet: S glass door of the living room and E kitchen window |

Figure 3.1 Examined Scenarios

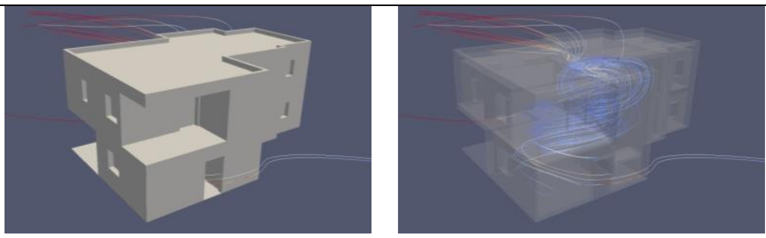
For the evaluation of the thermal comfort levels, seven (7) human figures (Avatars) are placed in the examined spaces of the building as they are depictured in **Figure 2.1**. One Avatar is placed in a room that is not examined to see if the changed conditions in the other spaces will affect it.

## 4 RESULTS ANALYSIS AND DISCUSSION

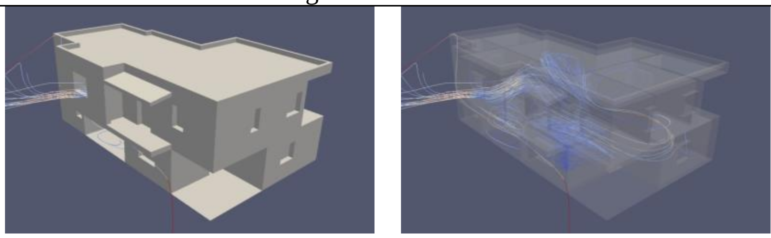
In this section the results and analysis of Scenario 5 are presented. The airflow pattern inside the building, in 3D view, from the first set of simulations in Blender, and the airflow movement and PMV values of the Avatars, from the second set of simulations in Autodesk CFD, are depictured and discussed. From the thermal comfort results, PMV values appear on the body of the Avatars. In this study the PMV value on the heads of the Avatars is measured but not without leaving uncommented the thermal comfort levels on the rest of the body.

## 4.1 Scenario 5: openings in the kitchen and bedroom

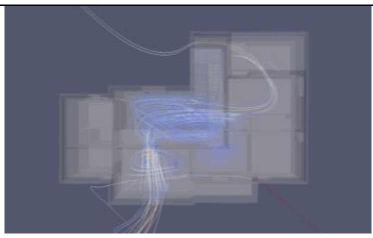
In Scenario 5 the northern glass door of the kitchen (inlet) and the northern window of bedroom 1 (outlet) are open (**Figure 4.1**). The air is moving fast through the kitchen and the bedroom but stays in the dining and living room exploiting the height of the open space.

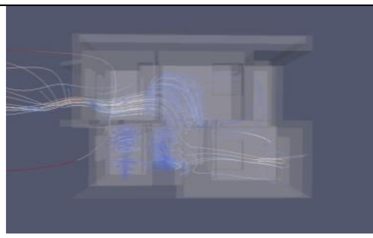
**(a)** NW view of the building. Air with NW direction is going through the northern glass door of the kitchen



**(b)** SE view of the building. Air is coming out of the building from the southern window of the bedroom

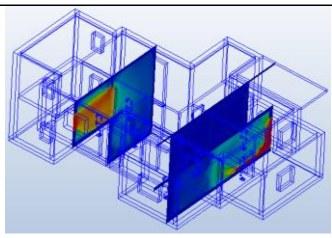


**(c)** Top view

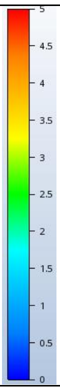
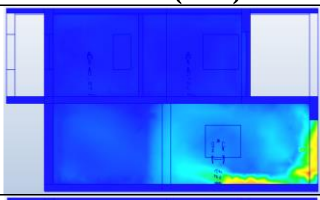
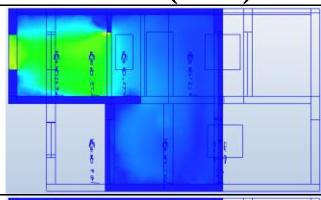
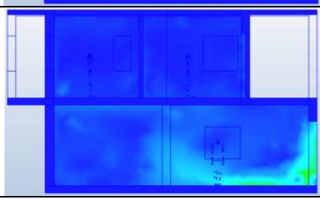
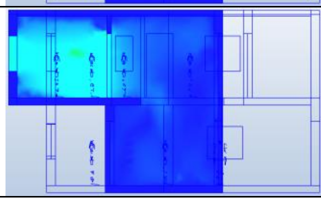


**(d)** East view

Figure 4.1 Airflow movement inside the building



Position of the measurement planes, SE view

| Time | PMV | Plane a (inlet) | Plane b (outlet) |
|---|---|---|---|
| 2:00 |  |  |  |
| 8:00 | |  |  |

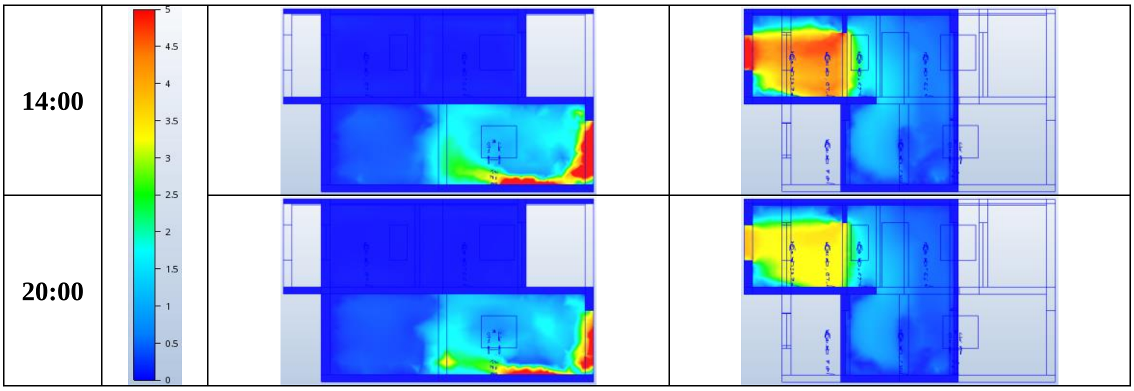



Figure 4.2 Velocity results for the four examined hours of the day

In the **Figure 4.2** below the measurement planes a (inlet) and b (outlet) are presented. The highest velocity is recorded close to the inlet kitchen opening and in the bedroom space. The air that is moving in the two story open space reaches 2m/s velocity at 14:00 and 20:00 o'clock. For the cases of 2:00 and 8:00 o'clock the maximum air speed is around 2m/s and for the 14:00 and 20:00 o'clock around 5m/s.

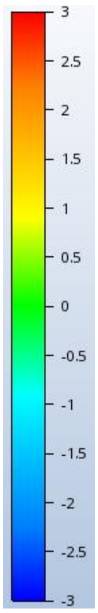
| Time | PMV | Human position | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | A | B | C | D | E | F | G |
| 2:00 |  | S | S | E | S | S | S | S |
| | | 0 | 0 | -0.5 | 0 | 0 | 0 | 0 |
| | | N | N | W | N | N | N | N |
| | | 0 | 0 | 0 | -0.5 | -0.5 | 0 | 0 |
| 8:00 | | S | S | E | S | S | S | S |
| | | 0.5 | 0.5 | 1 | 1 | 1 | 3 | 3 |
| | | N | N | W | N | N | N | N |
| | | 0.5 | 0.5 | 1 | 0.5 | 0.5 | 3 | 3 |

Figure 4.3 Detailed PMV results of the Avatars inside the building (A-G: position, S-E-N-W: orientation)

In the **Figure 4.3** above at 2:00 o'clock, Avatars C, D and E present a decrease of their PMV values but they remain in the comfort zone. Avatar C records high negative values on the legs, where the air is moving with high speed, and Avatar E on the northern side of the body where the air is coming from. In the case of 8:00 o'clock (**Figure 4.3**) the PMV of the Avatars A and

B is in the comfort zone, while the values of the Avatars C, D and E are moving around the high end of the comfort zone.

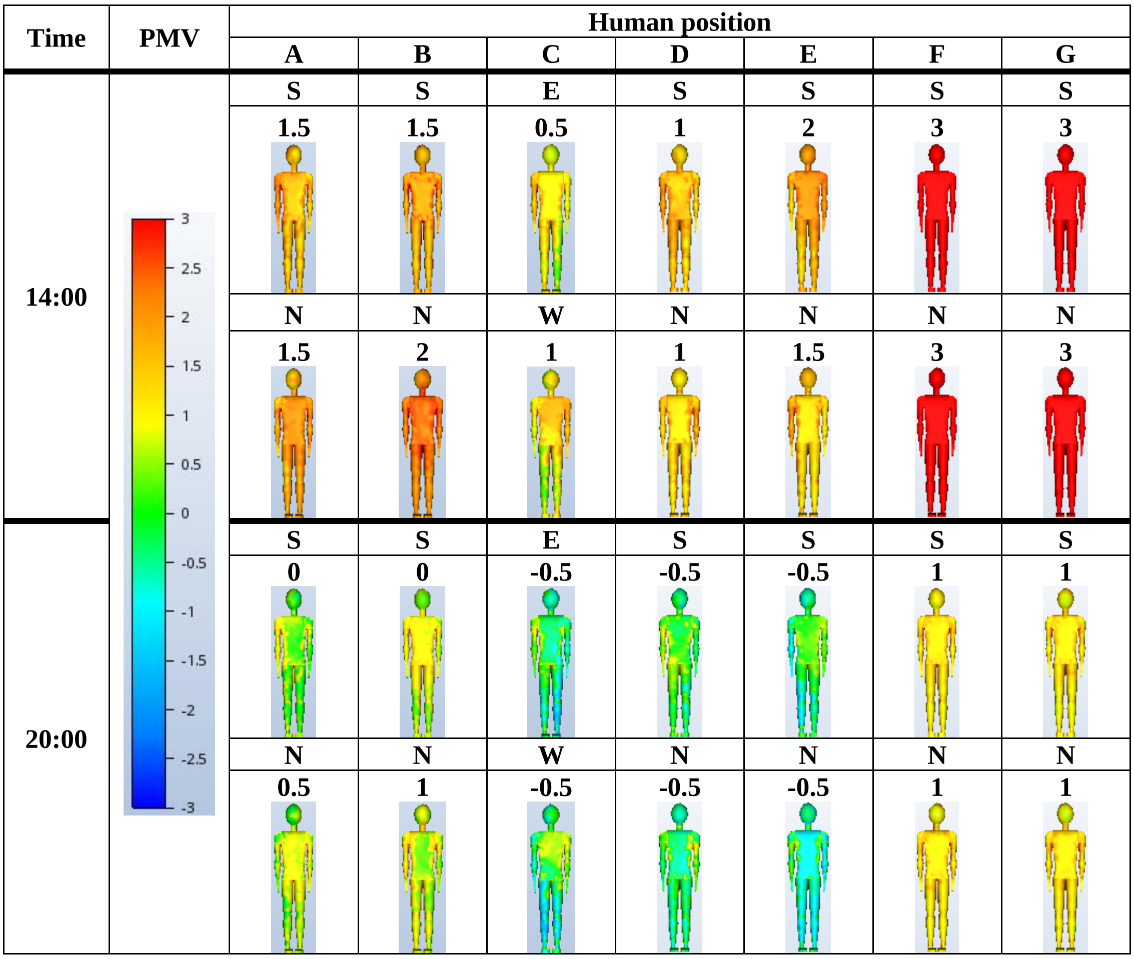



Figure 4.4 Detailed PMV results of the Avatars inside the building (A-G: position, S-E-N-W: orientation)

In the 14:00 o'clock case (**Figure 4.4**) none of the Avatars present PMV values in the comfort zone but Avatar C is close with o value of 0.75. At 20:00 o'clock (**Figure 4.4**) the PMV of the Avatars C, D and E is located in the low end of the comfort zone but higher negative values are observed on their legs.
Avatars F and G are in spaces that the air cannot reach, therefore they do not record any difference in the PMV values in any case of this Scenario.

## 5 CONCLUSIONS

In the presented paper the impact of natural cross-ventilation of sustainable residential buildings on thermal comfort levels is evaluated. A residence with bioclimatic parameters is designed in Chania, Crete, and is modelled for the study of the indoor airflow pattern, created by natural wind-driven cross-ventilation, from the different selection of the openings. Nine Scenarios of the previous study are chosen for the assessment of indoor thermal comfort. In all the simulations the building is isolated modelled.
A two story open space between the floors seems to be significant for the air movement and cooling of all the possible areas of the building, even if there are no open windows on the upper floor. The impact of the floors' layout on the indoor airflow needs to be studied and taken into account from the early stages of the architectural design. The geometry of the building, as well as the position of the selected openings affect the conditions of the incoming air. The position and orientation of the outlet opening regarding the inlet opening must be

cautiously selected so the architectural design and environmental conditions can be best exploited. The asymmetric position of the selected openings is suggested for a better movement of the air inside the building.

Naturally wind-driven ventilation appears to be an effective way of cooling the building in many cases during the day. In the majority of the cases the thermal comfort levels drop 1 thermal zone and in many cases two thermal zones. Night ventilation is able to provide comfortable indoor conditions, but in a few cases it can drop the thermal comfort levels in the cool zone of comfort and thus creating uncomfortable conditions. The selected openings must be chosen regarding the environmental conditions, indoor conditions and the spaces that need cooling.

From this research it is also concluded that for the study of natural indoor ventilation and thermal comfort levels on a complex building geometry, the followed methodology can be applied. Natural ventilation has a significant impact on the quality of living standards and energy consumption and needs to be acknowledged both from the architects and the occupants. CFD simulations can be effectively used for the study of natural ventilation and the provided information can be used in the early stage of architectural design. Software packages prove to be a useful tool for the architects and other professionals and are frequently used for similar studies for the purpose of understanding and designing of appropriate actions.

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