sustainability

Article

Determination of Optimum Window to External Wall Ratio for Offices in a Hot and Humid Climate

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Abstract: Heat loss and gain through windows has a very high impact on the thermal comfort of offices. This paper analyzes a standard low energy consumption university office that has a standard envelope. Dynamic thermal simulations with EDSL Tas software, a predicted mean vote (PMV), and a predicted percentage of dissatisfied (PPD) with all local discomfort as stated in ASHRAE, ISO 7730: 2005, EN 15251: 2007 were used for thermal sensation, in order to optimize the best window to external wall proportion in a hot and humid climate that exists in the Famagusta case study. A simulated office building is oriented east to west in order to take advantage of the wind direction. In May 45% (PPD < 6%–0.7% open window), 93% (PPD < 10–0.2 open window), and 97% (PPD < 15%–0.1% open window) thermal comfort scores are obtained when the window to external wall ratio (WWR) is 10%. In October 43% (PPD < 6%–0.7% open window), 86% (PPD < 10–0.2 open window), and 92% (PPD < 15%–0.1% open window) thermal comfort scores are obtained when the WWR is 10%. In September 49% (PPD < 10% full open window) and 51% (PPD < 15%–0.1% open window) thermal comfort scores are obtained when the WWR is 10%.

Keywords: PMV-PPD; ISO; ASHRAE; EDSL Tas; low energy design; sustainable buildings; thermal comfort; hot-humid climate

1. Introduction

Dynamic thermal simulation methods are used by academics for assessing building performance. For office windows in hot climates, thermal comfort can be achieved through simulations for losing or gaining heat. EDSL Tas software [1] is one of the options for dynamic thermal simulation generation with ASHRAE [2], ISO 7730: 2005 [3] and EN 15251: 2007 [4] standards.

Pino *et al.* [5] found that by using EDSL Tas software for a fully-glazed façade in Santiago, the cooling and heating energy demand may reach 115 kWh/m^2 in one year. Moreover, if the WWR is 20% with external solar protection and selected glazing, the cooling and heating demand will be 25 kWh/m^2. If night ventilation is applied during cooling periods, a further 37% reduction will be achieved.

In cold climates, artificial energy is needed to provide thermally-comfortable spaces. Additionally, the indoor climate is affected by the building form and envelope [6]. In warm parts of Europe, from an energy saving point of view, windows are weak points of the building envelope, especially for cooling. The performance of clear glass for maintaining cooling loads is very good if its thermal transmittance is between 2.00 W/m^{2}K and 3.00 W/m^{2}K [7]. Operating the windows has great importance on the physical connection with the outside and the use of natural ventilation for controlling thermal comfort conditions to reduce cooling loads. Moreover, natural ventilation will improve indoor air quality [8,9]. The opening proportion of the window should be based upon the outdoor air temperature, season, time, and occupancy pattern [10–13]. HVAC energy can be reduced by up to 17%–47% by using mixed-mode ventilation for summer time in various climates [14]. In moderate climate conditions such as in Germany, Italy, and Turkey, the indoor air quality can be controlled by opening typologies and summer cooling depending upon the natural ventilation strategy [15]. In all climates of the USA, annual cooling energy use can be reduced by using thermal resistance envelope materials (RSI-0.5/RSI-2.5) from 15% to 39%. Annual heating energy can also be saved by up to 10% depending on the window size and internal heat gains [16]. Designing large windows for offices can allow more daylight to enter and creates a balance between the energy consumed for lighting and cooling systems [17]. Although windows are used for visual contact and for the generation of daylight into spaces, they have disadvantages, such as creating weak points in the building skin for heat losses [18]. High levels of solar radiation during the summer period in hot and humid environments increase cooling loads [19]. The correct proportion of window to external wall and the correct opening proportion of the window will reduce cooling loads and increase thermal comfort. In order to design sustainable offices, architects should be offered guidance as to the correct size of windows on external walls and the correct window opening proportion in relation to the whole year's performance. The area of a window is a decision taken by the designers at the early stages of architectural design; therefore, it is difficult or impossible to change it later. It is obvious that windows have a very important effect on the energy use of the building [20].

The construction of passive building requires small windows on the north façade due to potential heat losses. However having large windows on the south façade leads to solar heat gain. A dynamic simulation tool called DEROB-LH showed that the size of windows is not important for winter heating but is very important to meet the cooling demand during summer [21]. In Amman city, using a larger area of glass on the south, east, and west elevations saves energy and decreases the heating load for the winter season if insulating glass of 6 mm clear glass on the outer pane, 12 mm air space and 6 mm clear glass on the inner pane is used. However, energy is saved if the glazing area is decreased with insulating glass of 6 mm clear glass on the outer pane, 12 mm air space, and 6 mm clear low-E (Pilkington) is used on the north elevation [22].

The quality of the indoor environment requires thermal comfort because of its effects on well-being, the performance of people, and energy requirements [23]. For the thermal sensation of people, mean radiant temperature is one of the important variables. [24]. In order to investigate the energy behavior of buildings, a thermal infrared imaging tool is useful. This tool is used for the thermal insulation of the envelope, ventilation, air leaks, and mechanical devices performance [25]. The choice of window systems is very important for building energy saving due to the U value and solar heat gain coefficient of windows [26]. When venetian blinds are installed on windows in tropical climates, the satisfaction of people who are sitting next to glass depends on the level of solar radiation striking the body [27]. A virtual window was designed with an array of 32 LED tiles and a line of LED linear fixtures with adjustable color temperatures to provide direct light into the test room. As a result a 100% view from the window is achieved; moreover, the average work plane luminance reached 239 lx and 11% of total area became 500 lx [28]. This study used daylight metrics and lighting energy that are influenced by window to wall ratio, wall reflectance, and window orientation in a tropical climate. As a result 30% of the window to wall ratio with 0.8 wall reflectance on the south orientation led to the optimum solution [29]. In order to calculate the PMV and PPD ISO 7730: 200 and EN 15251 [3,4] with air temperature, mean radiant temperature, air velocity, and relative humidity are required [30].

2. Objective

This research reports on the outcomes of dynamic thermal simulations via EDSL Tas software [1] for finding the thermal comfort of naturally ventilated office environments via an optimal proportion of window to external wall with an optimal window opening percentage. Moreover, it underlines the fact that average acceptable PMV and PPD for yearly-based thermal comfort of the office environment should be achieved for sustainability. According to ISO 7730 [3] and EN 15251 [4] standards for overall thermal comfort and local discomfort, there are a number of categories. First, category A is PPD < 6% (PMV −0.20 to 0.20), the second category, B, is PPD < 10 (−0.50 to 0.50) and the third category, C, is PPD < 15% (PMV −0.70 to 0.70). There is also a fourth category, D, that begins from the minimum of category C. Natural ventilation is a sustainable solution for decreasing cooling load in the summer season and the heating load for the winter season. This paper examines the influence of different window to external wall proportions with different window opening percentages for averaged yearly and monthly thermal performances of naturally-ventilated sustainable office environment in Famagusta, Cyprus. The goal is to offer advice to designers on the thermal comfort of office environments.

3. An Overview of Previous Studies

Ochoa *et al.* [20] developed a computer model for optimizing low energy and visual comfort in the temperate climate of Amsterdam, the Netherlands with window to external wall ratios from 10% to 100% at 10% intervals of four main orientations. The window used in this work was located in the middle of the external wall and was double glazed without any shading device. As a result of this work, it was concluded that large windows should not be used because they provide heat transfer during winter and summer periods. The cooling demand is large in a southerly orientation with large windows and conversely the heating demand is also large in a northerly orientation, again with a large window size. Moreover, with large sized windows the least electric consumption was observed with 30% WWR at the north direction and 20% WWR at the south, east, and west façades. The window to external wall ratio between 50% and 70% in the North, 60% in the South and 50%–60% in the east and west orientations were observed for the intersection of optimum visual comfort and luminance criteria.

Gasparella *et al.* [31] used TRNYS software for evaluating the effect of two different double glazing and two different triple glazing windows with sizes of 16%, 25%, 34%, and 41% of window to floor area for the parameters of orientation of the window, internal gains for winter and summer energy need with peak loads, of a well-insulated residential building in the climate of Paris, Milan, Nice, and Rome. The results of the simulations found that a large glazing area increases the winter performance of the building but having a peak load is a disadvantage. Moreover, this disadvantage can be addressed by using shutters during the night. A southerly orientation performs best in winter, as wintertime windows with low thermal transmittance are good with high solar transmittance. It should not be forgotten that high solar transmittance creates a disadvantage in summertime, and the use of shading devices during this time is advantageous.

Poirazis *et al.* [32] used IDA ICE 3.0 for dynamic energy simulations of a single skin office building in Sweden. Studies have been done when the building was occupied with 30%, 60%, and 100% window to external wall area. Moreover, building orientation and plan type with shading devices were analyzed for low energy use and good thermal comfort. The study concludes that single skin buildings consume more energy than conventional façades during occupation. In addition to this, the impact of using shading elements and appropriate window types can save 15% of energy for fully glazed façade buildings.

Thalfeldt *et al.* [33] studied costly optimal and energy efficient window to external wall ratio and external shading device simulations in the cold climate of Estonia. The optimal window to external wall ratio was 40% and 60%. In addition to this, the costly optimal façade solution was high transparent triple, low-emissivity glazing with window to external wall ratio of 25% and the external wall insulation of 200 mm (U = 0.16). Limited simulations studied in Central Europe concluded that a window to external wall ratio of 40% with triple glazing and double low-emissivity coating leads to optimal cost.

Susorova *et al.* [34] created typical office models in design builder software and concluded that the geometry of fenestration affects energy consumption like 3% and 6%, maximum 10% and 14% in hot climates but only 1% in temperate and cold climates.

Lee *et al.* [35] conducted research via building thermal simulation models in order to identify optimum annual heating, cooling and lighting by means of energy consumption for different window systems on a building skin with different window to external wall ratios and orientations in Manila, Taipei, Shanghai, Seoul and Sapporo which all have an Asian climate. The study concluded that in Manila, Shanghai, Seoul, and Sapporo, only 25% of the window to external wall proportion on the south façade was effective. In Sapporo and Seoul, solar heat gain had a positive effect on increasing the indoor temperature during the heating season. The north façade is less affected from the variations of window to external wall ratio with the solar heat gain coefficient and the visible transmittance. However, the east and west façades are affected, and care is needed. From a U-value perspective, window systems with 1.5 W/m^2K to 0.8 W/m^2K have a greater effect on reducing the heating load than the cooling load. For cold areas lower U-values can be used for window systems.

In cool climates, such as Lithuania, without any shading, a north direction is the most energy efficient orientation for air conditioned buildings. The most energy efficient window to external wall ratios for south, east, and west orientations are 20%, but for north orientation is 20%–40% [36].

When all existing researches are considered, it became clear that there is an absence of research relating to optimum averaged yearly and monthly effects of window to external wall ratios with various window opening ratios for offices in hot and humid climates on thermal comfort issues. The necessity of filling this gap motivated the author to carry out this research. The consequences of the study will guide architects during the determination process of window to external wall ratios for offices in hot and humid climates.

4. Methodology

4.1. Predicted Mean Vote (PMV) Method

Dynamic thermal simulations of EDSL Tas [1] were carried out for the office environment located in Famagusta, Cyprus. EDSL Tas version 9.3.3 is used which is a building modeling and dynamic simulation tool. The simulations were performed with the Famagusta weather file. Figure 1 illustrates the size and plan of the office model. The dimensions of the office were 3.0 m × 5.0 m and the room height was 3.0 (m). The office chosen as a model consisted of only one zone and two windows (inlet and outlet) which were placed on the east and west walls. The proportions of the window to external east and west walls range from 10% to 100% and the opening percentages of windows on east and west external walls range from 0.1 to 1. By using EDSL Tas simulations [1], results of all PMV and PPD were obtained for the analyzed office.

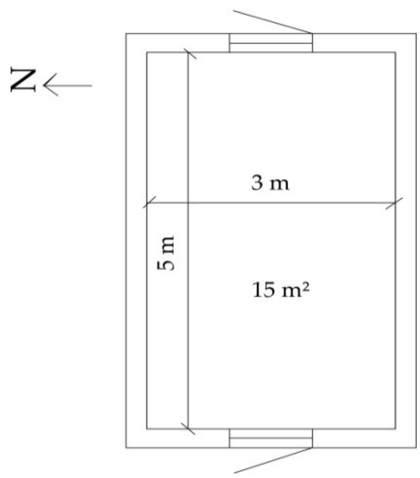

Figure 1. Plan of the naturally-ventilated model office with dimensions (3.0 m × 5.0 m × 3.0 m).

Categories A, B, C, and D, which are stated above, can be seen with all the details in Table 1. The properties of opaque and glass construction layers with U-values are given in Tables 2 and 3 respectively, for simulated office buildings.

Table 1. Classification of thermal environments proposed by ISO 7730 [3] and EN 15251 [4].

Thermal State of The Body as a Whole			Local Discomfort			
Category	Predicted Percentage of Dissatisfied (%)	Predicted Mean Vote Range	Percentage of Dissatisfied (PD) Due to Draught (%)	PD Due to Vertical Air Temperature Difference (%)	PD Due to Cool or Warm Floor (%)	PD Due to Radiant Temperature Asymmetry (%)
1 (A)	<6	−0.20 to 0.20	<10	<3	<10	<5
2 (B)	<10	−0.50 to 0.50	<20	<5	<10	<5
3 (C)	<15	−0.70 to 0.70	<30	<10	<15	<10
4 (D) (EN 15251)	>15	<−0.70 or >0.70				

Table 2. Shows used properties of opaque construction layers with U-values for the simulated office.

Category	U-Value (W/m^2K)	Solar Absorptance		Emissivity		Conductance (W/m^2K)	Time Constant
		Ext. Surface	Int. Surface	External	Internal		
Ground floor	0.283	0.760	0.500	0.910	0.900	0.297	127.999
Walls	1.135	0.400	0.400	0.900	0.900	1.407	4.920
Ceiling	1.01	0.700	0.500	0.900	0.900	1.251	13.749

Table 3. Shows used properties of glass construction layers with U-values for the simulated office.

	U-Value (W/m^2K)	Solar Transmittance	External Solar Absorptance		Internal Solar Absorptance		Light Transmittance	Time Constant
			Ext. Surf.	Int. Surf.	Ext. Surf.	Int. Surf.		
Windows (clear 6-12-6 double glazing low E)	1.803	0.498	0.173	0.135	0.227	0.097	0.760	0

The Percentage of Dissatisfied People (PPD) and Predicted Mean Vote (PMV) calculations are produced via EDSL Tas [1] software by using its macros section for thermal comfort prediction. The simulated office building has one zone and the PMV parameters are as follows; metabolic rate is 1.2 met, air speed was between 0.15 m/s as the lower limit and 0.3 m/s as the upper limit. Clothing value was 0.6 clo as the lower value and 0.95 clo as the upper value. The schedule for the office environment is created for the whole year (365 days, 7 days, and 24 h).

The ASHRAE Thermal sensation scale [2,3,37] can be summarized as; −3 cold, −2 cool, −1 slightly cool, 0 neutral, 1 slightly warm, 2 warm, and 3 hot. Providing thermal comfort conditions should include metabolic rate (met), clothing insulation (clo), air temperature (°C), radiant temperature (°C), air speed (m/s), and humidity (%) [3,37].

4.2. TAS Simulation Results and Discussions

In order to generate the best window to external wall ratio with different window opening ratios, dynamic simulations of EDSL Tas are carried out. Macros are used for thermal comfort predictions (PMV and PPD) for averaged yearly and monthly performance generation. For the results three categories of ISO 7730 [3] and EN 15251 [4] are used. According to these standards, PPD and PMV hours are found for Famagusta that has hot and humid climatic conditions. As a result of the findings for the simulated office during the whole year (8760 h) categories of ISO 7730 [3] and EN 15251 [4] which provide thermal comfort conditions with WWR and window opening ratio can be found in the following paragraphs and in Figures 2–11 respectively.

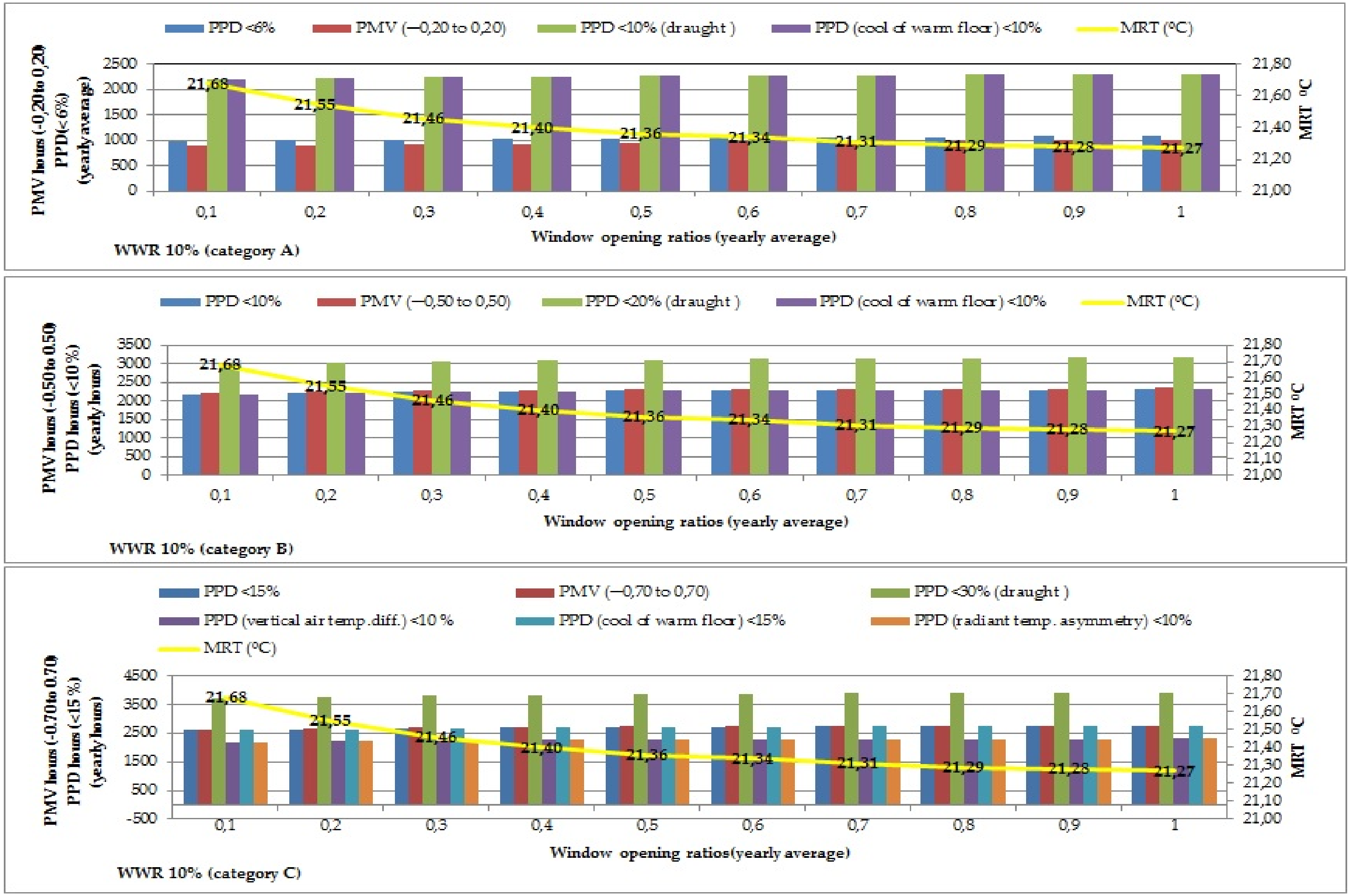

Figure 2. Predicted Mean Vote (PMV) and Predicted Percentage of Dissatisfied People (PPD) for categories A,B, and C by means of hours (out of 8760 h in a whole year) for WWR 10% with all window opening ratios (from 0.1 to 1) with M: 1.2 met, air speed of 0.15–0.3 m/s, clothing value with 0.6–0.95 clo.

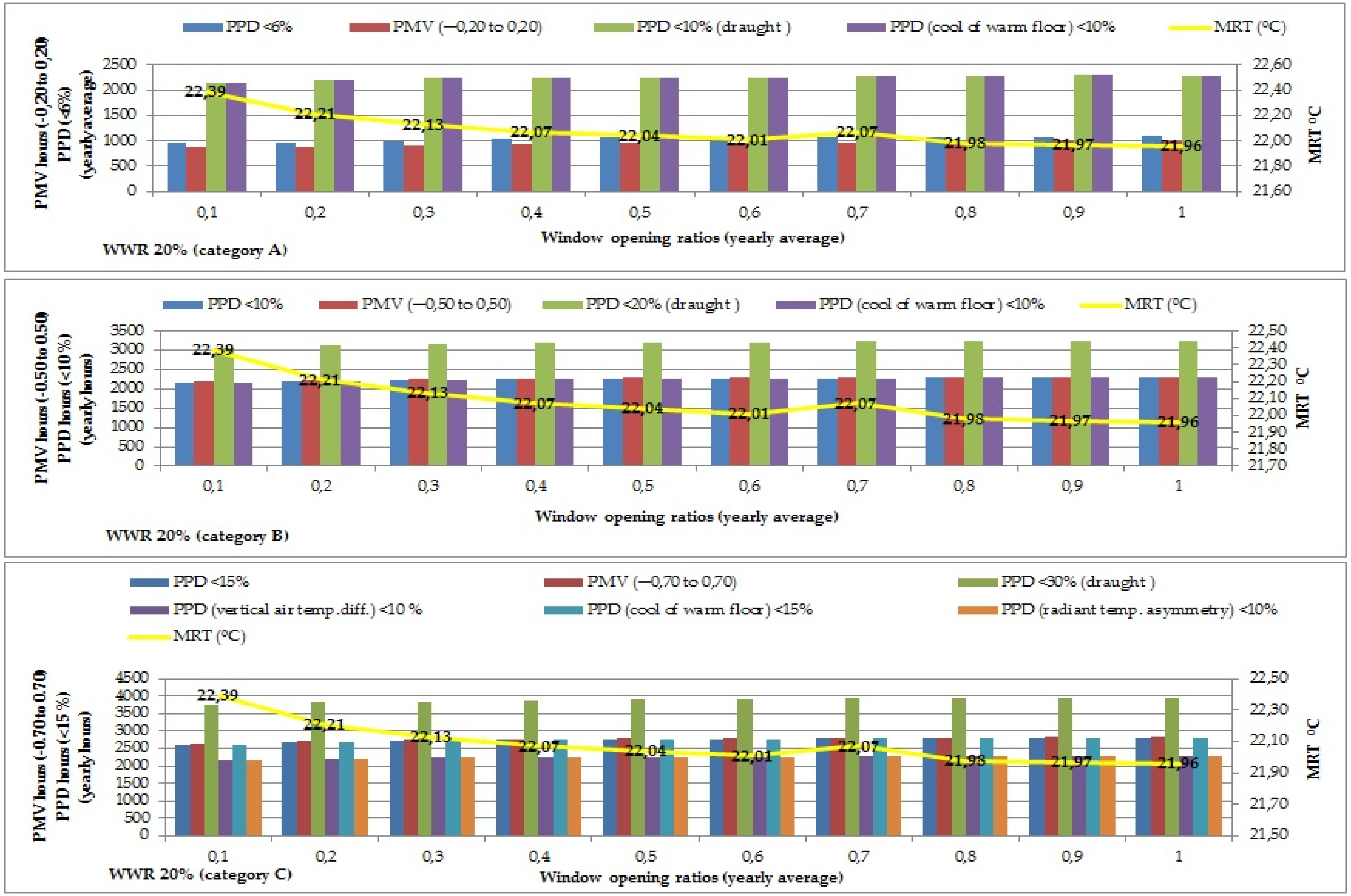

Figure 3. Predicted Mean Vote (PMV) and Predicted Percentage of Dissatisfied People (PPD) for categories A,B, and C by means of hours (out of 8760 h in a whole year) for WWR 20% with all window opening ratios (from 0.1 to 1) with M: 1.2 met, air speed of 0.15–0.3 m/s, clothing value with 0.6–0.95 clo.

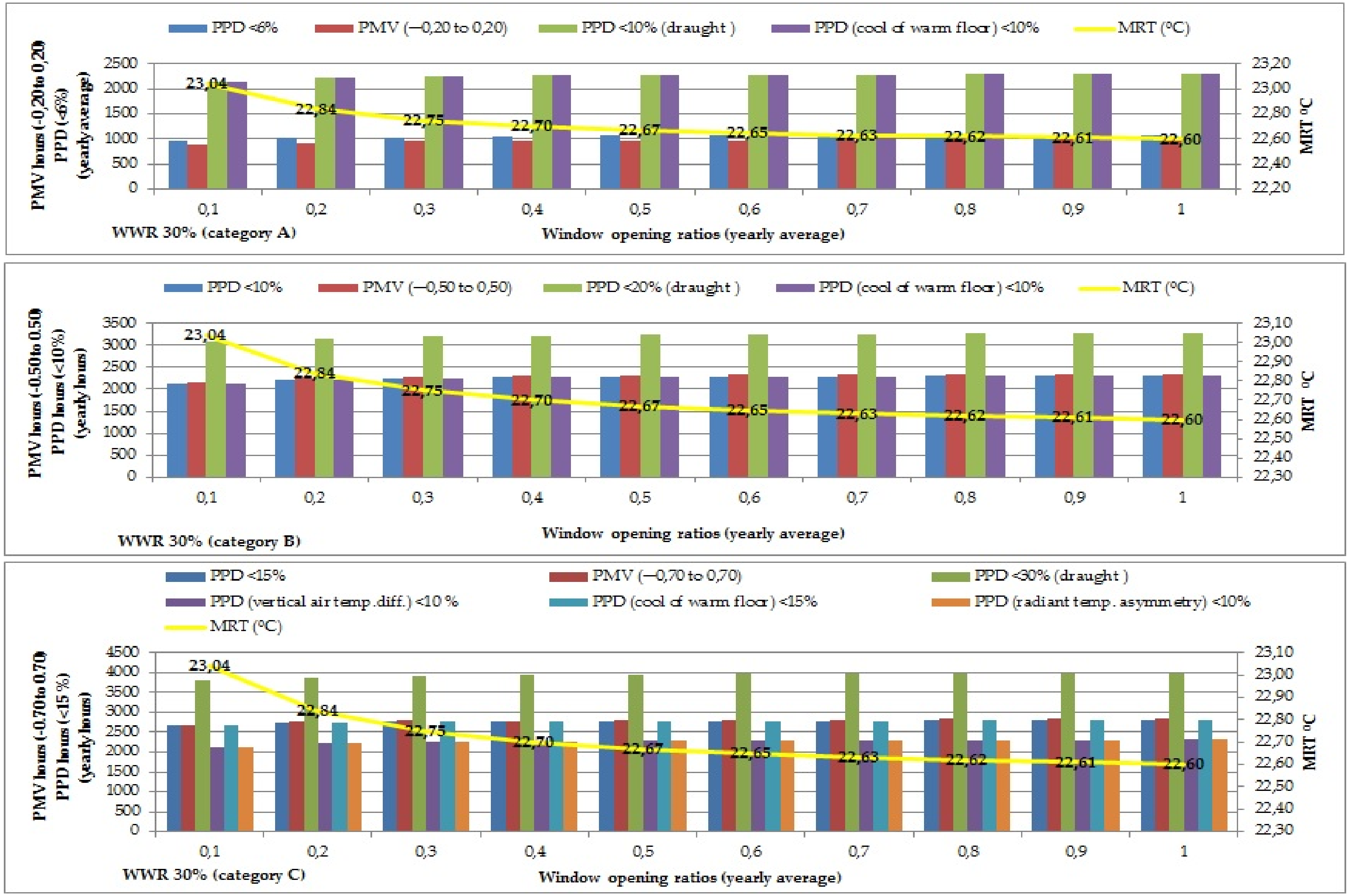

Figure 4. Predicted Mean Vote (PMV) and Predicted Percentage of Dissatisfied People (PPD) for categories A,B, and C by means of hours (out of 8760 h in a whole year) for WWR 30% with all window opening ratios (from 0.1 to 1) with M: 1.2 met, air speed of 0.15–0.3 m/s, clothing value with 0.6–0.95 clo.

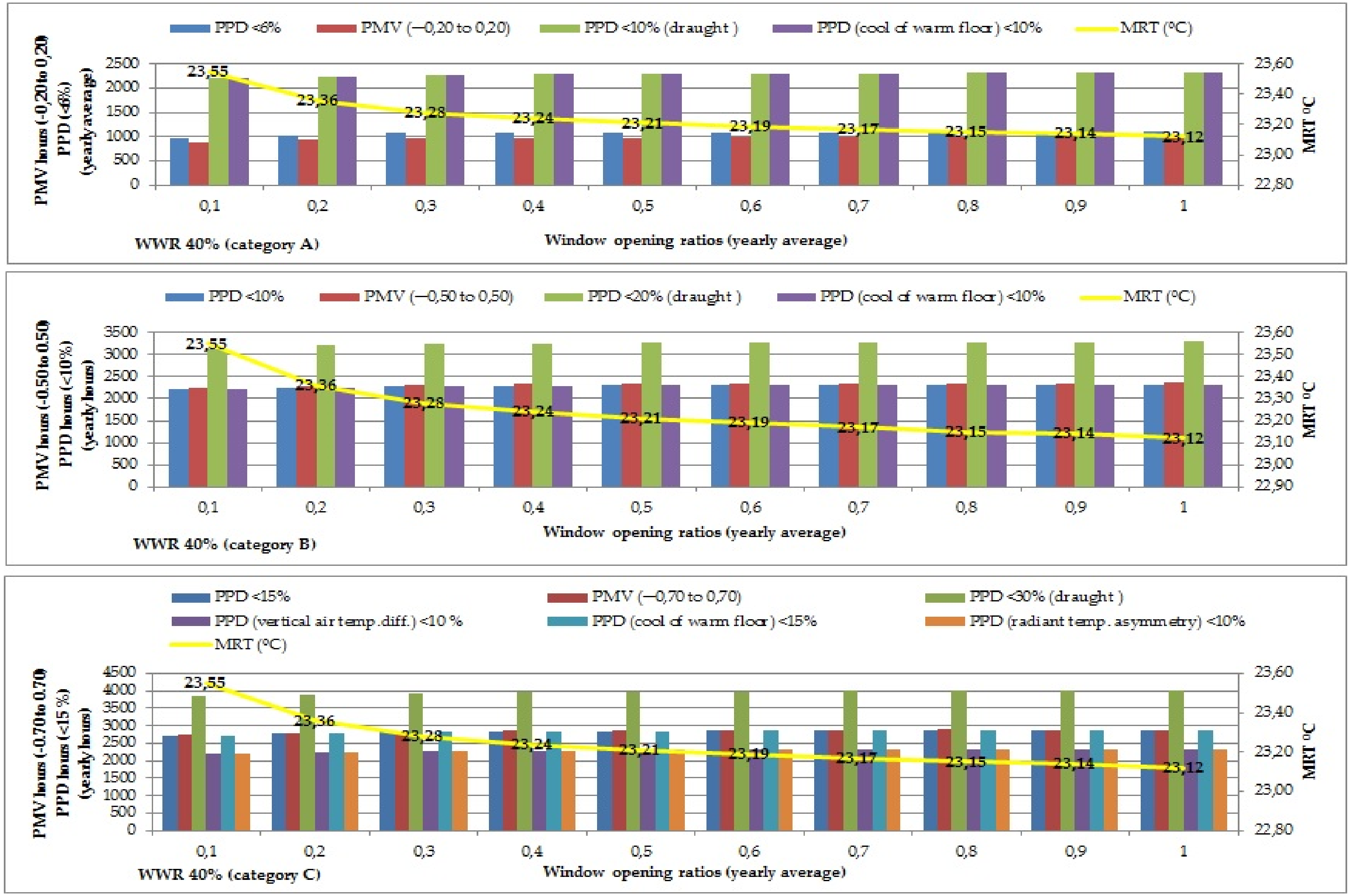

Figure 5. Predicted Mean Vote (PMV) and Predicted Percentage of Dissatisfied People (PPD) for categories A,B, and C by means of hours (out of 8760 h in a whole year) for WWR 40% with all window opening ratios (from 0.1 to 1) with M: 1.2 met, air speed of 0.15–0.3 m/s, clothing value with 0.6–0.95 clo.

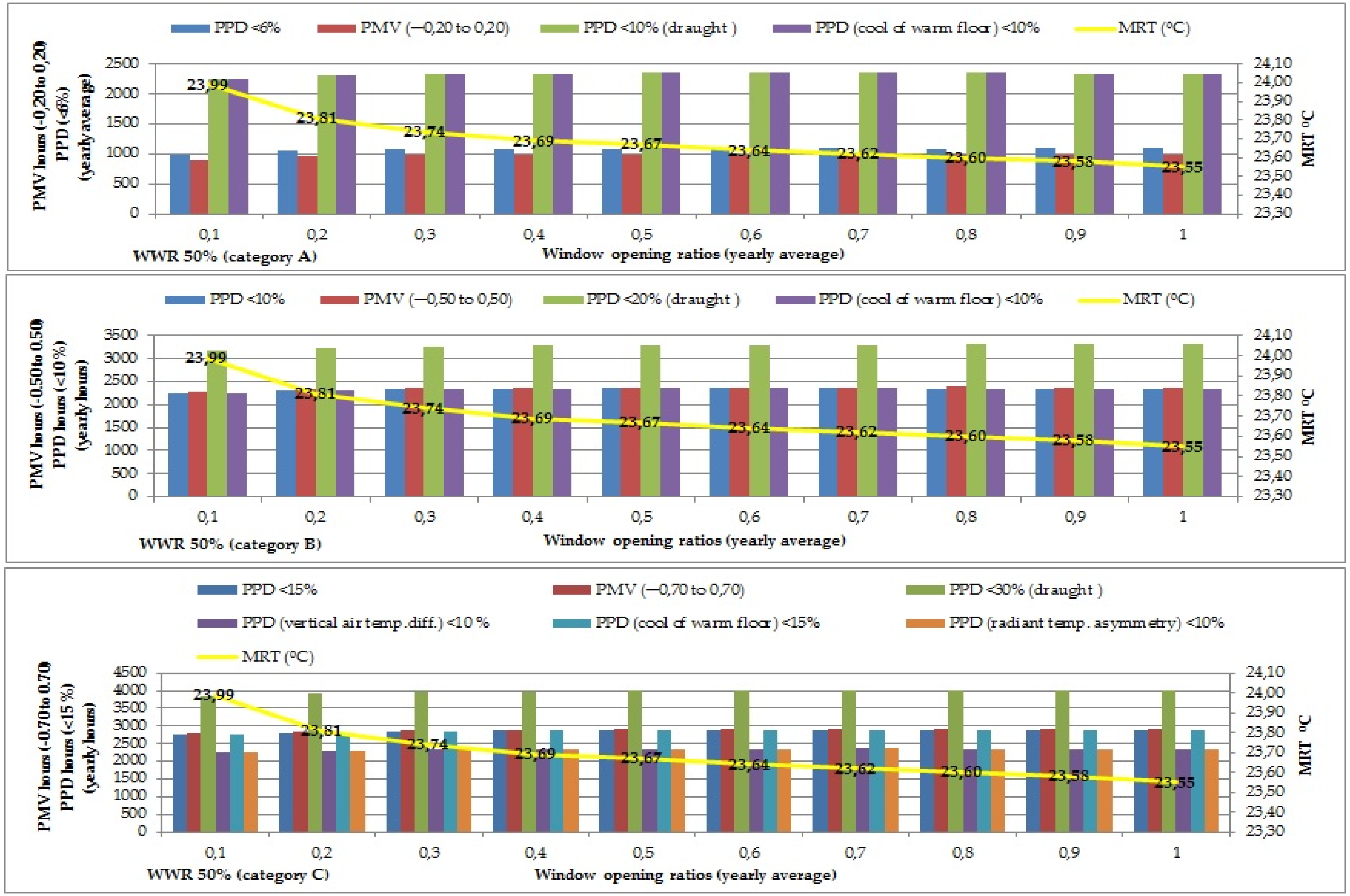

Figure 6. Predicted Mean Vote (PMV) and Predicted Percentage of Dissatisfied People (PPD) for categories A,B, and C by means of hours (out of 8760 h in a whole year) for WWR 50% with all window opening ratios (from 0.1 to 1) with M: 1.2 met, air speed of 0.15–0.3 m/s, clothing value with 0.6–0.95 clo.

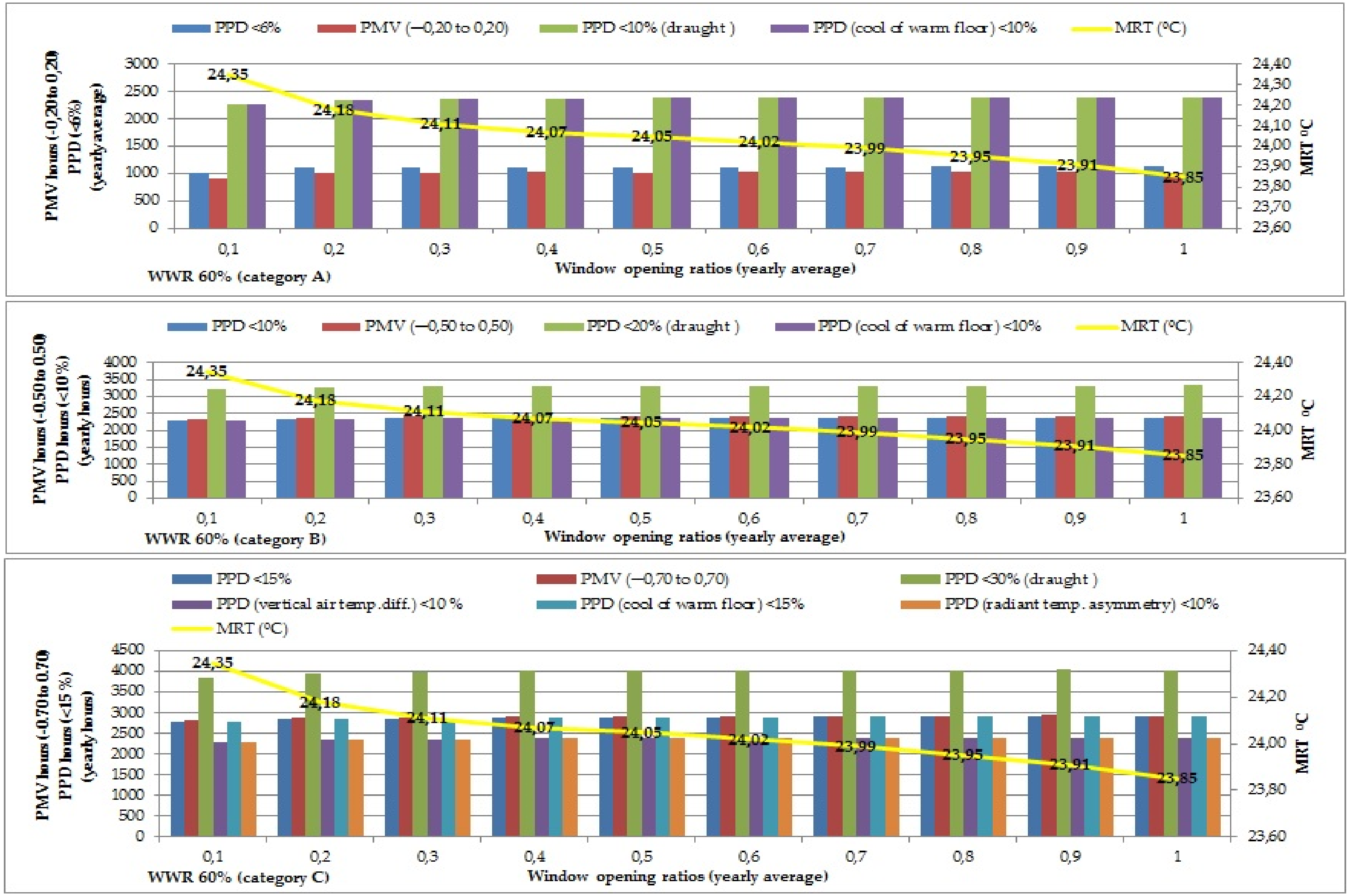

Figure 7. Predicted Mean Vote (PMV) and Predicted Percentage of Dissatisfied People (PPD) for categories A,B, and C by means of hours (out of 8760 h in a whole year) for WWR 60% with all window opening ratios (from 0.1 to 1) with M: 1.2 met, air speed of 0.15–0.3 m/s, clothing value with 0.6–0.95 clo.

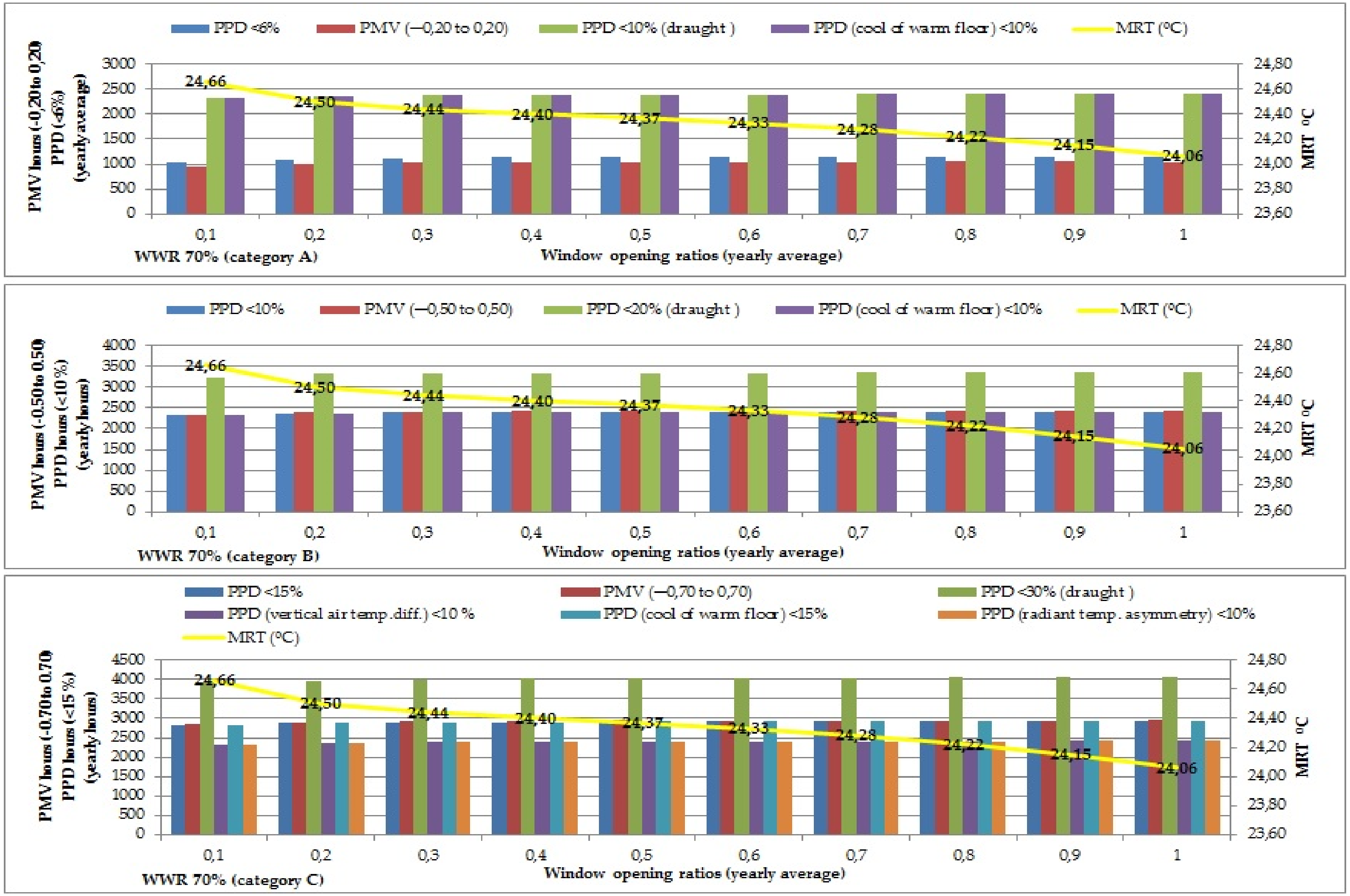

Figure 8. Predicted Mean Vote (PMV) and Predicted Percentage of Dissatisfied People (PPD) for categories A,B, and C by means of hours (out of 8760 h in a whole year) for WWR 70% with all window opening ratios (from 0.1 to 1) with M: 1.2 met, air speed of 0.15–0.3 m/s, clothing value with 0.6–0.95 clo.

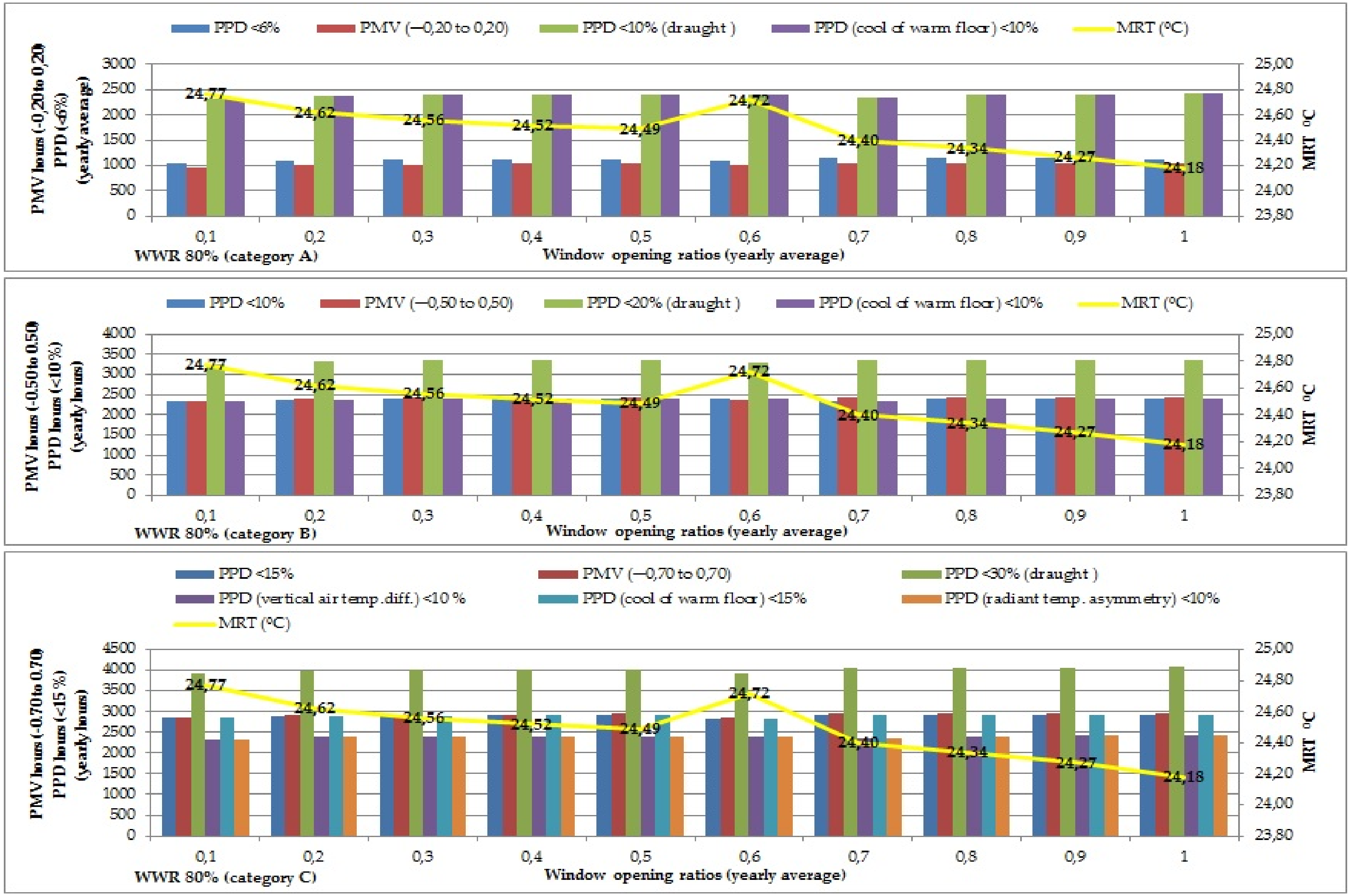

Figure 9. Predicted Mean Vote (PMV) and Predicted Percentage of Dissatisfied People (PPD) for categories A,B, and C by means of hours (out of 8760 h in a whole year) for WWR 80% with all window opening ratios (from 0.1 to 1) with M: 1.2 met, air speed of 0.15–0.3 m/s, clothing value with 0.6–0.95 clo.

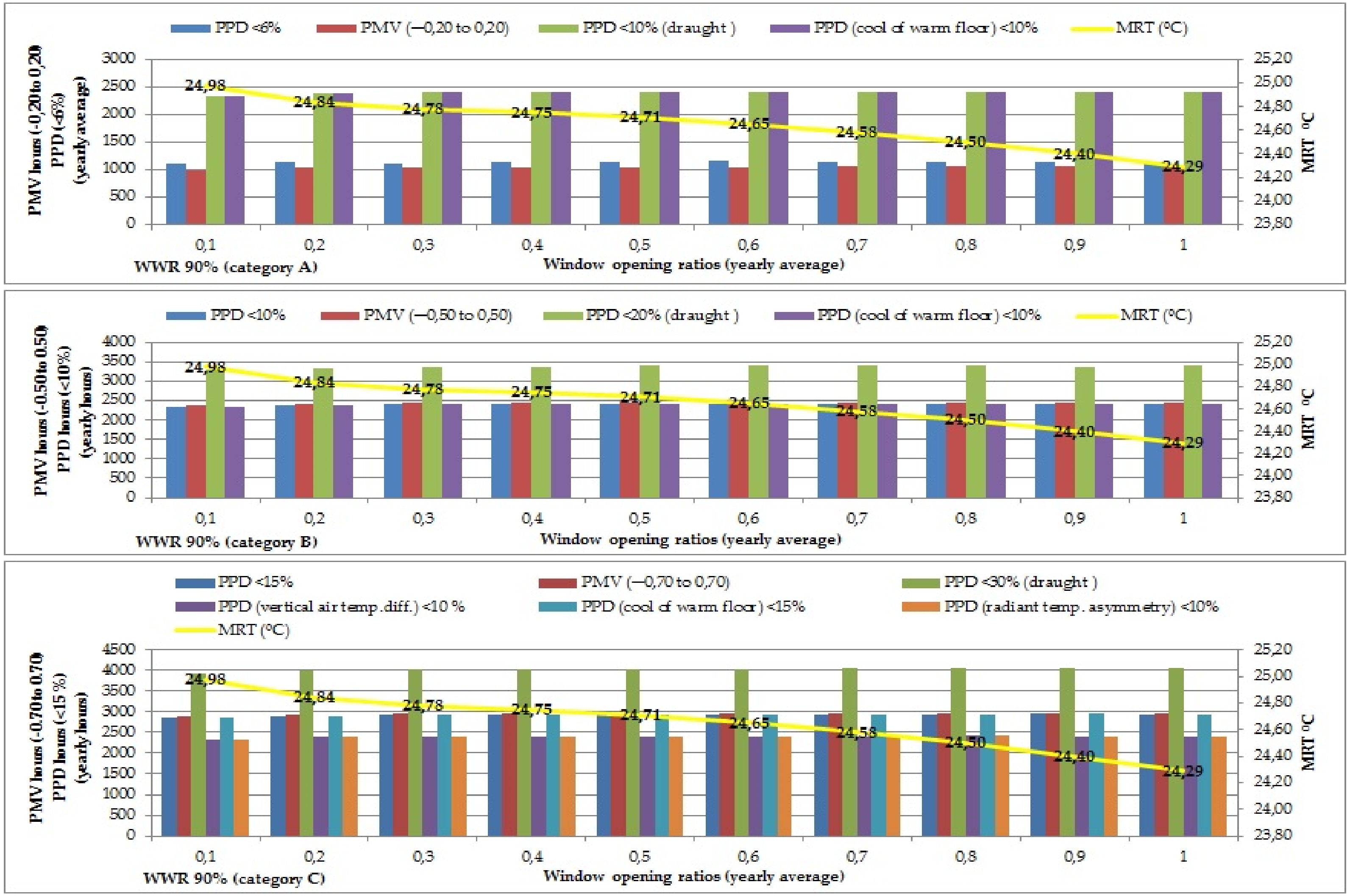

Figure 10. Predicted Mean Vote (PMV) and Predicted Percentage of Dissatisfied People (PPD) for categories A,B, and C by means of hours (out of 8760 h in a whole year) for WWR 90% with all window opening ratios (from 0.1 to 1) with M: 1.2 met, air speed of 0.15–0.3 m/s, clothing value with 0.6–0.95 clo.

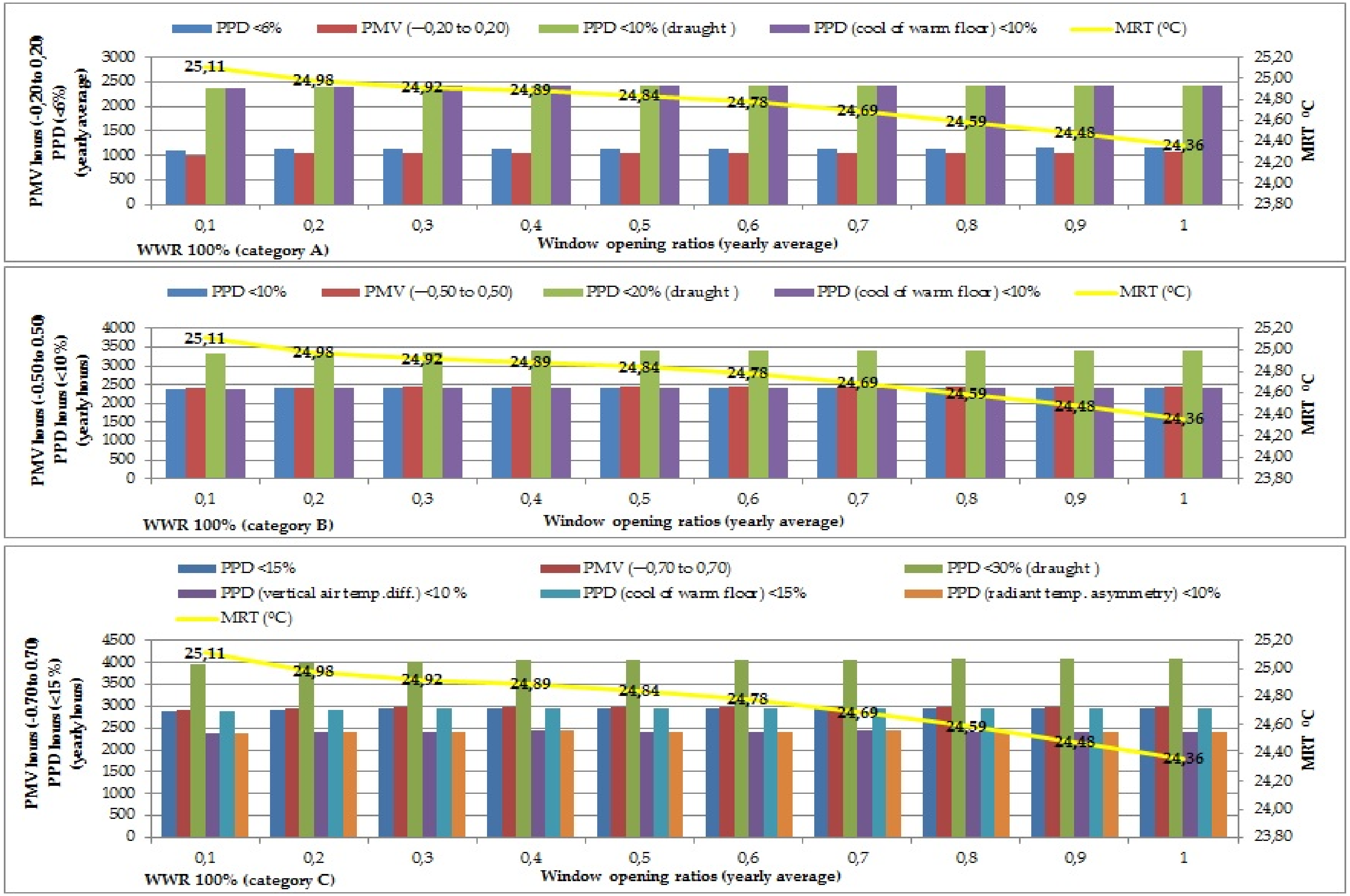

Figure 11. Predicted Mean Vote (PMV) and Predicted Percentage of Dissatisfied People (PPD) for categories A,B, and C by means of hours (out of 8760 h in a whole year) for WWR 100% with all window opening ratios (from 0.1 to 1) with M: 1.2 met, air speed of 0.15–0.3 m/s, clothing value with 0.6–0.95 clo.

In category A where the WWR is 20% with 0.1 window opening ratio, a minimum 958 h of thermal comfort conditions and 22.39 °C mean radiant temperature (MRT) are observed as an annual average. When the WWR is 100% with a full (1) window opening ratio, 1156 h are observed as the maximum number of hours for thermal comfort conditions with 24.36 °C as a yearly averaged mean radiant temperature. It should be noted that April, May, June, July, September, October, and November were partly providing thermal comfort under the conditions stated above. For Predicted Mean Vote (PMV) yearly average of 872 h were observed as a minimum, and yearly average of 1065 h as a maximum, for thermal comfort conditions. Both draught and cool or warm floor hours observed as a yearly average of 2154 h as minimum and a yearly average of 2416 h as maximum hours of thermal comfort conditions for above WWR and window opening ratios, respectively. Both vertical air temperature difference and radiant temperature asymmetry do not have any hours of thermal comfort condition during whole year for any WWR and window opening ratio. All details can be observed in Figures 2–11. Table 4 shows non-thermal comfort conditions and Table 5 shows the thermal comfort conditions obtained.

Table 4. In category A, when WWR percentages are as follows, no thermal comfort is obtained.

<table>
<tr><th>Window Opening Ratio</th><th>January</th><th>February</th><th>March</th><th>July</th><th>August</th><th>December</th></tr>
<tr><td>0.1</td><td rowspan="3">10% to 80%</td><td>10% to 60%</td><td rowspan="8">10% to 20%</td><td>10%</td><td>10% to 50%</td><td rowspan="3">10% to 30%</td></tr>
<tr><td>0.2</td><td rowspan="2">10% to 70%</td><td>-</td><td>10% to 20%</td></tr>
<tr><td>0.3</td><td>-</td><td rowspan="2">10%</td></tr>
<tr><td>0.4 & 0.5 (half)</td><td rowspan="3">10% to 90%</td><td>10% to 80%</td><td>-</td><td rowspan="5">10% to 20%</td></tr>
<tr><td>0.6</td><td>10% to 70%</td><td>-</td><td>-</td></tr>
<tr><td>0.7</td><td>10% to 80%</td><td>-</td><td>-</td></tr>
<tr><td>0.8</td><td>10% to 100%</td><td>10% to 90%</td><td>-</td><td>-</td></tr>
<tr><td>0.9 & 1 (full)</td><td>10% to 100%</td><td>10% to 100%</td><td>-</td><td>-</td></tr>
</table>

Table 5. In category A, when WWR percentages are as follows, thermal comfort is obtained.

<table>
<tr><th>Window Opening Ratio</th><th>January</th><th>February</th><th>March</th><th>April & May & June</th><th>July</th><th>August</th><th>September & October & November</th><th>December</th></tr>
<tr><td>0.1</td><td rowspan="3">90% to 100%</td><td>70% to 100%</td><td rowspan="8">30% to 100%</td><td rowspan="8">10% to 100%</td><td>20% to 100%</td><td>60% to 100%</td><td rowspan="8">10% to 100%</td><td rowspan="3">40% to 100%</td></tr>
<tr><td>0.2</td><td rowspan="2">80% to 100%</td><td rowspan="7">10% to 100%</td><td>30% to 100%</td></tr>
<tr><td>0.3</td><td rowspan="3">20% to 100%</td></tr>
<tr><td>0.4</td><td rowspan="4">100%</td><td rowspan="2">90% to 100%</td><td rowspan="5">30% to 100%</td></tr>
<tr><td>0.5 (half)</td></tr>
<tr><td>0.6</td><td>80% to 100%</td><td rowspan="3">10% to 100%</td></tr>
<tr><td>0.7</td><td>90% to 100%</td></tr>
<tr><td>0.8 & 0.9 & 1 (full)</td><td>-</td><td>100%</td></tr>
</table>

In category B, where the WWR is 30% with 0.1 window opening ratio, a minimum of 2137 h of thermal comfort conditions and a mean radiant temperature of 23.04 °C are observed as the annual average. When the WWR is 100% with 0.7 window opening ratio, 2430 h are observed as maximum number of hours for thermal comfort condition with 24.69 °C as yearly averaged mean radiant temperature. It should be noted that March, April, May, June, July, August, September, October, November, and December were partly providing thermal comfort under the conditions stated above. The best thermal comfort conditions were mostly observed in May and October in category B. For Predicted Mean Vote a yearly average of 2162 h were observed as minimum and a yearly average of 2460 h as maximum for thermal comfort conditions in WWR 100% and 0.9 window opening ratio. Draught has a yearly average of 2981 h as minimum for WWR 10% with 0.1 opening ratio and a yearly average of 3413 h as maximum thermal comfort conditions for WWR 100% with 0.9 opening ratio. Cool or warm floor yearly averaged hours observed are 2190 minimum and yearly averaged of 2430 as maximum for thermal comfort conditions. Both vertical air temperature difference and radiant temperature asymmetry provide no thermal comfort conditions hours during the whole year for any WWR and window opening ratio. All details can be observed in Figures 2–11. Table 6 shows non thermal comfort conditions and Table 7 shows thermal comfort conditions obtained.

Table 6. In category B, when WWR percentages are as follows, no thermal comfort is obtained.

<table>
<tr><th>Window Opening Ratio</th><th>January</th><th>February</th><th>March</th><th>August</th><th>December</th></tr>
<tr><td>0.1</td><td rowspan="3">10% to 50%</td><td>10% to 30%</td><td rowspan="3">10%</td><td>10% to 20%</td><td rowspan="3">10%</td></tr>
<tr><td>0.2</td><td rowspan="2">10% to 40%</td><td>10%</td></tr>
<tr><td>0.3 to 0.5 (half)</td><td></td></tr>
</table>

Table 7. In category B, when WWR percentages are as follows, thermal comfort is obtained.

<table>
<tr><th>Window Opening Ratio</th><th>January</th><th>February</th><th>March</th><th>April & May & June & July</th><th>August</th><th>September & October & November</th><th>December</th></tr>
<tr><td>0.1</td><td rowspan="3">60% to 100%</td><td>40% to 100%</td><td>30% to 100%</td><td rowspan="4">10% to 100%</td><td>30% to 100%</td><td rowspan="4">10% to 100%</td><td rowspan="4">20% to 100%</td></tr>
<tr><td>0.2</td><td rowspan="3">50% to 100%</td><td rowspan="3">20% to 100%</td><td>20% to 100%</td></tr>
<tr><td>0.3 to 0.7</td><td rowspan="2">10% to 100%</td></tr>
<tr><td>0.8 to 1 (full)</td><td>70% to 100%</td></tr>
</table>

In category C, the WWR is 10% with 0.1 window opening ratio, a minimum 2605 h for thermal comfort conditions and 21.68 °C mean radiant temperature are observed as the annual average. When the WWR is 100% with 0.6 window opening ratio, 2962 h are observed as the maximum number of hours for thermal comfort condition with 24.78 °C as the yearly averaged mean radiant temperature. It should be noted that March, April, May, June, July, August, September, October, and November were partly providing thermal comfort under conditions stated above in category C. For the Predicted Mean Vote a yearly average of 2623 h were observed as a minimum and a yearly average of 2986 h as the maximum thermal comfort conditions for WWR 100% and 0.6 window opening ratio. Draught has yearly averaged of 3720 h as minimum for a WWR 10% with 0.1 opening ratio and 4074 as maximum hours providing thermal comfort conditions for WWR 100% with 1 (fully open window opening ratio). Both vertical air temperature difference and radiant temperature asymmetry have a yearly average of 2190 h for thermal comfort conditions as minimum hours and yearly averaged of 2430 h as maximum hours. Cool or warm floor hours observed were yearly averages of 2605 as minimum and yearly averages of 2962 as maximum. All details can be observed in Figures 2–11. These numbers of hours above were maximum for category C but minimum (starting points) for fourth category of EN 15251 [4]. Table 8 shows non thermal comfort conditions and Table 9 shows thermal comfort conditions obtained.

Table 8. In category C, when WWR percentages are as follows, no thermal comfort is obtained. (It should be noted that the following values show minimum non-thermal comfort ranges for the fourth category of EN 15251 [4]).

Window Opening Ratio	January	February	December
0.1 0.2 to 1 (full)	10% to 40%	10% to 20%	10% -

Table 9. In category C, when WWR percentages are as follows, thermal comfort is obtained. (It should be noted that the following values show minimum thermal comfort ranges for the fourth category of EN 15251 [4]).

Window Opening Ratio	January	February	March to November	December
0.1 0.2 to 1 (full)	50% to 100%	30% to 100%	10% to 100%	20% to 100% 10% to 100%

In categories A, B, and C, the yearly averaged value of mean radiant temperature (MRT) for WWR 10% with all window opening ratios (0.1 to 1) was 21.39 °C. For WWR 20% with all window opening ratios yearly averaged MRT was 22.08 °C. For WWR 30% with all window opening ratios yearly averaged MRT was 22.71 °C. For WWR 40% with all window opening ratios yearly averaged MRT was 23.24 °C. For WWR 50% with all window opening ratios yearly averaged MRT was 23.69 °C. For WWR 60% with all window opening ratios yearly averaged MRT was 24.05 °C. For WWR 70% with all window opening ratios yearly averaged MRT was 24.34 °C. For WWR 80% with all window opening ratios yearly averaged MRT was 24.49 °C. For WWR 90% with all window opening ratios yearly averaged MRT was 24.65. For WWR 100% with all window opening ratios yearly averaged MRT was 24.76 °C. For all WWR (10% to 100%) and window opening ratios (0.1 to 1) yearly averaged mean radiant temperature was 23.54 °C.

5. Conclusions

When an average of the whole year is taken, it is concluded that, in all ranges of WWR (from 10% to 100%) with 0.1 open window, 11.64% thermal comfort is obtained in category A, 25.77% thermal comfort is obtained in category B and, finally, 31.47% thermal comfort, which is the best, is obtained in category C. It is observed that an increase in the window opening ratio positively affects the thermal comfort. When the window is 0.2 open, thermal comfort in category A becomes 12.14%, while in categories B and C it becomes 26.35% and 32.07%, respectively. With 0.3 of the window open, the thermal comfort obtained is 12.32% in category A, 26.62% in category B, and 32.38% in category C. Thermal comfort percentages are 12.47, 26.73, and 32.52 when the window is 0.4 open while they are 12.54, 26.82, and 32.65 when window is half (0.5) open. Again, according to the same PPD order (<6%,<10%,<15%), 12.57%, 26.81%, and 32.63% thermal comfort is achieved when the window is 0.6 open. 12.67%, 26.94%, and 32.77% are percentages of obtained thermal comfort with 0.7 open window. Achieved thermal comfort percentages when the window was 0.8 open are 12.66, 26.94, and 32.78. 12.69%, 26.97%, and 32.82% are the thermal comfort percentages achieved when 0.9 of the window is open and finally when the window is fully open (1) 12.73, 26.99, and 32.82 percentages of thermal comfort are obtained. It should be noted that, as best performances are obtained in April, May, June, September, October, and November, thermal comfort percentages of the mentioned months will be underlined.

In category A when the WWR is 10%, in May, thermal comfort conditions obtained are a maximum 45% with 0.7 open window ratio and a minimum 43% with 0.2 and 0.5 (half) open windows. On the other hand in October, the thermal comfort conditions obtained are a maximum 43% with 0.2 open window ratio and a minimum 40% 0.7 and 1 (full) open window ratio.

In category B when the WWR is 10% again, in May, thermal comfort conditions obtained are a maximum 93% with 0.2 open window ratio and a minimum 88% with 1 (full) open window ratio. In October, thermal comfort conditions obtained are a maximum 86% with 0.1 open window ratio and a minimum 78% with 1 (full) open window ratio. In September, thermal comfort conditions obtained are a maximum 49% with 1 (full) open window ratio and a minimum 40% with 0.1 open windows. In April, thermal comfort conditions obtained are a maximum 45% when WWR is 80% with 0.1 open window ratio and a minimum 39% with 1 (full) open window ratio. In June, a maximum 43% thermal comfort conditions are observed when WWR is 10% with 0.9 and 1 (full) open window ratio and a minimum 32% with 0.1 open windows. In November, a maximum 42% thermal comfort condition is obtained when WWR is 100% with 0.1 open window ratio and a minimum 39% with 1 (full) open window ratio.

In category C, during May, thermal comfort conditions obtained are a maximum 97% while the WWR is 10% with 0.1 open window ratio and a minimum 95% with 1 (full) open window ratio. In October, thermal comfort conditions obtained are a maximum 92% while WWR is 10% with 0.1 open window ratio and a minimum 87% with 1 (full) open window ratio. In September, 51% thermal comfort conditions are obtained when WWR is 10% with 0.1 open window ratio and a minimum 87% with 1 (full) open window ratio. In June, thermal comfort conditions obtained are a maximum 48% where WWR is 10% with 1 (full) open window ratio and a minimum 41% with 0.1 open windows. In November, a maximum 51% thermal comfort condition is obtained where WWR is 100% with 0.1 open window ratio and a minimum 48% with 1 (full) open window ratio. In April, thermal comfort conditions obtained are a maximum 53% when WWR is 100% with 0.1 open window ratio and a minimum 48% with 1 (full) open window ratio.

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