Experimental and Numerical Study of Radiant Floor Heating Panels Performance at Different Conditions

Muna S.Kassim¹, Israa A. Abdulghafor², Husam H. Kadhim³
¹Mechanical Engineering Department, college of Engineering, Almustansiriyah University.
²Middle Technical University (MTU), Institute of Technology-Baghdad, Electronic Technologies Department, Iraq.
³Ministry of Iraq higher education:
E-mail: munskassim@uomustansiriyah.edu.iq, Israaaliabudlgaghor@gmail.com, eng.husamhason@gmail.com

Abstract: The performance of radiant floor heating panels with different arrangements in room and different room air temperatures are investigated experimentally and numerically. In addition to study the effect of radiant floor heating arrangement on thermal comfort conditions in occupied zone. The room air and panels temperatures are measured at different heights and locations. The temperature of supplying hot water fluctuates from 35 to 40 °C. The results present that the different radiant floor heating arrangements effect on thermal comfort while the performance of radiant floor heating panel is little affected by arrangements. Experimental results appear good agreement with numerical results.

1. Introduction
Radiant heating system has been used in building for very long period [1]. For the last 50 years, the development in the materials science and process of design led to rise of usage this technology [2]. The thermal comfort conditions and efficiency are the main advantages of radiant heating system also this system reduces the consumption of electric power [3]. Radiant heating system is more efficient than that of forced-air heating system because the radiant system isn’t need to duct and saving energy by more than 30% of that traditional systems [4,5]. Radiant heating system is mounted on ceiling, wall and roof, the radiant floor heating system is used widely since the radiation is the majority mode of heat transfer [6]. The radiant floor heating can be classified according to fluid used to three types: radiant air floor, hot water radiant floor and electric radiant floor. In the radiant floor heating, the warmest place is the floor of space. Radiant floor heating system has quickly start and very good regulation. In comparison between radiant floor heating system and all air system, the radiant floor heating system show more energy efficient than that of all air systems. [7].

Using of radiant heating system in both residential and industrial space dates belong to 1940s. There have been performed some studies about radiant heating system and could be find in the following literature. Lin et al[8] analyzed the thermal performances of radiant heating system that made from shape-stabilized phase change material PCM plates. Also analyzed thermo physical properties of PCM that produced by research team itself. In Beijing, this heating system was built as a prototype in tested room. The results presented that the upper surface temperature of PCM plates could be protected near temperature of transition phase during whole day, and costs of operational could be lowering by using this mode of heating. By utilized finite element method Sattari et al [9] investigated numerically the modes of heat transfer for radiant floor heating system. The results proved that the radiation was the main mode of heat transfer in radiant floor heating system. Comfort...
conditions and energy demand were analyzed by computer simulation too. Boyer et al [10] Presented numerical computational for using radiant heating system in different locations that were floor, wall, ceiling, and floor-ceiling panel heating systems in forms of energy, exergy and CO₂ emissions.

The temperatures of room air, floor and wall were investigated. Results were concluded of this study that the best system was floor–ceiling since this system offered lowest energy, CO₂ emissions and exergy and operation cost while the worst system was ceiling system. Lue et al [11], studied experimentally heating characteristics and control strategies for radiant floor heating system, also ground source heat pump was used in an office building. Indoor temperature of the system was measured by using the instrument fixed at different heights. Experimental results presented that the indoor temperature achieved human thermal comfort, and the indoor room temperature which received the solar radiation could be still constant more than 18 °C in time of work during two days when the system was closed.

Ergur et al [12], presented numerical and experimental investigation on output heat of radiant heating system. The inlet-outlet temperatures were 50/30°C, 60/40°C, 70/50°C, 80/60°C and 90/70°C in a space where temperature was controlled. The comparison between experimental and numerical results was made, and an adjuster agreement was obtained. Constant surface temperature in range of 40 – 150°C was assumed. The numerical results appeared that the heat transfer by radiation was about of 80% of the total heat transfer also the results appeared that the output heat of radiant heating system increased linearly as temperature increased. As notices from past studies, no published studies are found to investigate effect of radiant floor heating panels arrangement on its performance and on thermal comfort conditions in occupied zone. Objective of this study is to investigate performance of radiant floor heating panel under different indoor air temperature and different radiant floor heating panel arrangement. Also, numerical study is made to obtain comparative and validation to the experimental work.

2. Experimental Work

2.1. Description of Radiant Floor Heating System

In this study the radiant floor heating system is installed in indoor room at fourth floor of Mechanical Engineering Department building, Collage of Engineering, Mustansiriy University, Baghdad. Dimensions of room is 200×200×300 cm in width, length and height respectively. The radiant floor heating system is arranged in three configurations that are denote as case 1, 2 and 3 as shows in fig.(1) and plate (1). Case 1 consists of one panel of 180×180 cm in width and length respectively wood floor. The wood floor is covered by two layers of cork with thickness of 5cm and aluminum of thickness of 0.6cm. Polyethylene (PEX) pipe has inner and outer diameter are 12.7 and 15.7mm respectively is fixed in serpentine shape by hollows that are made in cork and aluminum. The pitch between pipes is about 22.85cm. Seventeen thermocouples are fixed in surface of both pipe and aluminum by grooves are made in surface of pipe and aluminum. Also two thermocouples are fixed at inlet and outlet of PEX pipe. While for both case 2 and 3 consist of wood floor has dimensions of (180×180) cm. The wood floor is divided to nine panels, each panel has dimensions of (60×60) cm in width and length respectively. Only Five panels are operating. Operated Panel is made of cork and aluminum layer. The thickness of cork and aluminum is 5cm and 0.6 mm respectively. PEX (polyethylene) pipe with inner and outer diameters are of 12.7mm and 15.7mm respectively is fixed in serpentine shape through hollows that are made in both cork and aluminum. The distance between each two pipes is 20cm. Twenty seven thermocouples are distributed on three panels that panels locate at different locations, each panel has nine thermocouples, seven thermocouples are fixed at middle of panel in grooved on surface of PEX pipe and between PEX pipe on aluminum surface of panel. Also, two thermocouples are fixed at inlet and outlet of PEX pipe. The remaining four panels consist of cork only with thickness of 5cm. Finally, outer surfaces of all panels in three cases are covered with 1.5cm of wood. The length, width of radiant floor panel and diameter of PEX pipe are chosen according to ASHREA standard [13]. The thermal conductivity of materials that used can be shown in table (1). The radiant floor heating panel details can be shown in fig.(2) and plate (2).
Table 1. The thermal conductively of materials that utilized in experimental work([14,15])

| Material | k (W/m.K) |
|----------|-----------|
| Cork     | 0.04      |
| Aluminum | 205       |
| PEX      | 0.43      |
| Wood     | 0.04      |

Figure 1. schematic diagram of different configuration of radiant floor heating system

Plate (a). Photographic of 1st configuration radiant floor heating panels that denote by Case 1
Plate (b). Photographic of 2nd configuration radiant floor heating panels that denote by Case 2
Plate (c). Photographic of 3rd configuration radiant floor heating panels that denote by Case 3

Plate 1. Photographic of different configurations of radiant floor heating system
2.2 Description of Hydraulic Circuit

Hydraulic circuit is built to provide hot water to radiant floor heating panels. Same hydraulic circuit is used for all cases are studied. The components of hydraulic circuit are: insulated plastic tank with capacity of 200 litter is used to store and circulate hot water, one filter, one pump with peak head of 4m and pumping rate of 30 l/min, flow meter with range of 10-70 l/min, heater with controller to heat water and various fitting as needed are used. CPVC connection pipes of 25.4mm inner diameter are used to connect between hydraulic circuit components. The components of hydraulic circuit can be shown in figures 3 and 4.
2.3 Description Experimental Work
In Occupied zone, average room air temperature is measured in three different locations by distributing three stands each stand has four thermocouples at height of 10, 60, 110 and 170 cm from floor. Thermocouples of type K are used and connected with a selector switch. To obtain an approximately constant radiant floor heating temperature around 28 °C, temperatures of supplied heated water change from 35 to 40°C by using temperature controller. Flow rate of supplied heated water for all experimental tests is fixed at 0.28 kg/s. The required flow rate is controlled by using valve and flow meter. Tests of experimental work are studied can be summarized in table (2). The distribution of thermocouples in occupied zone can be shown in figure (5).
Table 2. Tests are studied in experimental work.

| Case Number | Indoor Temperature (°C) | Heating Floor Temperature (°C) |
|-------------|------------------------|-------------------------------|
| 1           | 12.3                   | 28.19                         |
| 2           | 12.3                   | 28.19                         |
| 3           | 12.3                   | 28.19                         |
| 1           | 14.3                   | 28.20                         |
| 2           | 14.3                   | 28.20                         |
| 3           | 14.3                   | 28.20                         |
| 1           | 16.5                   | 28.20                         |
| 2           | 16.5                   | 28.20                         |
| 3           | 16.5                   | 28.20                         |
| 1           | 18.5                   | 28.19                         |
| 2           | 18.5                   | 28.19                         |
| 3           | 18.5                   | 28.19                         |
| 1           | 20.2                   | 28.20                         |
| 2           | 20.2                   | 28.20                         |
| 3           | 20.2                   | 28.20                         |

3. Mathematical Model

Radiation and convection heat flux are determined to analysis performance of radiant floor heating system as following:

1-Radiation heat flux is calculated from following equation [16]:

\[ q_r = \sigma [T_{p,ave}+273]^4 - (T_{a,ave}+273)^4 ] \tag{1} \]

Where \( \sigma \) is Stefan-Boltzmann constant and equal to 5.10\(^{-8}\)

2- To determine the convection heat flux must be calculated at first heat transfer coefficient as following [17]

\[ h_{c,natural} = 0.704 \times \frac{(T_{a,ave} - T_{p,ave})^{0.133}}{\frac{W}{m^2 \cdot \mathcal{K}}} \tag{2} \]

\[ D_h = \frac{4 \times \text{Apanels}}{P \text{panels}} \tag{3} \]
\[ q_c = h_{c,natural} (T_{p,ave} - T_{a,ave}) \]  \hspace{1cm} (4)

3- Capacity of radiant floor heating system is determined as following[16]:

\[ q = q_t + q_c \]  \hspace{1cm} (5)

\[ T_{a,ave} = (T_{a,ave1} + T_{a,ave2} + T_{a,ave3}) / 3 \]  \hspace{1cm} (6)

\[ T_{a,ave} = (T_1 + T_2 + T_3 + T_4) / 4 \]  \hspace{1cm} (7)

\[ T_{p,ave1} = (T_{p1} + T_{p2} + T_{p3} + T_{p4} + T_{p5} + T_{p6} + T_{p7} + T_{p8} + T_{p9}) / 9 \]  \hspace{1cm} (8)

\[ T_{p,ave} = (T_{p,ave1} + T_{p,ave2} + T_{p,ave3}) / 3 \]  \hspace{1cm} (9)

where:

- \( T_{a,ave} \): average room air temperature (°C)
- \( T_{a,ave1}, T_{a,ave2} \) and \( T_{a,ave3} \): average room air temperature at stand 1, stand 2 and stand 3 respectively.
- \( T_1, T_2, T_3 \) and \( T_4 \): room air temperature at height of 10, 60, 110, 170 cm respectively for each stand.
- \( T_{p1}, T_{p2}, T_{p3}, T_{p4}, T_{p5}, T_{p6}, T_{p7}, T_{p8}, T_{p9} \): temperature of radiant floor heating panels at different locations.
- \( T_{p,ave} \): average radiant floor heating panels temperature.

\( T_{a,ave2} \) and \( T_{a,ave3} \) are determined from equ. (7)
\( T_{p,ave2} \) and \( T_{p,ave3} \) are calculated from equ. (8).

To check best arrangement achieves thermal comfort conditions, PPD and PMV are calculated as following equations [18]:

\[ PPD = 100 - 95 e^{-(0.03353PMV + 0.2179PMV^2)} \]  \hspace{1cm} (10)

\[ PMV = (0.303e^{-0.036M} + 0.028)[(M-W) - H - E_c - C_{res} - E_{res}] \]  \hspace{1cm} (11)

4. Numerical Study

To validate experimental work, numerical simulation of three-dimensional temperature and air flow in occupied zone is done by using ANSYS FLUENT 14.5[18]. The dimensions of room are used in numerical study of 200 x 200 x 300 cm in width, length and height respectively. Three configurations are simulating. These configurations are the same as the configurations that used in the experimental study as shown in figure (1). The following assumption are assumed in solution:

1- Steady state
2-Newtonian flow
3-Incompressible flow
4-Laminar flow

Triangular element and tetrahedron element are utilized kinds for surface and volume mesh respectively. Figure (6) show kinds of mesh are used in this work.

**Figure 6.** The elements type
Total cell count is two million cells. Basic equations are solved numerically in this simulation can be summarized as following:
1-Continuity equation : as shown in eq. (12) [20]
2-momentum equation : as shown in eq. (13) [21]
3-energy equation : as shown in eq. (14) [22]

\[
\frac{du}{dx} + \frac{dv}{dy} + \frac{dw}{dz} = 0
\]  

\[
\rho \left( \frac{du}{dt} + u \nabla u \right) = \rho g - \nabla P + \mu \nabla^2 u
\]  

\[
\rho \left( \frac{dh}{dt} + \nabla (h^\nu) \right) = \frac{dP}{dt} + \nabla \left( k \nabla T^s \right) + \varnothing
\]

\[u, v\text{ and } w\text{ : velocities in } X, Y, Z\text{ direction respectively.}\]

Since incompressible flow is assumed , the pressure base solver is used. Also the SIMPLE algorithm with Second Order Upwind scheme for energy and momentum equations are utilized for solving Pressure–Velocity Coupling.

5. Experimental Results

Figures (7) and (8) show the relationship between vertical air temperature difference (VATD) that is measured between level 10 and 110 cm and difference average radiant floor heating panels temperature and average room air temperature and relationship between vertical air temperature difference (VATD) that is measured between level 10 and 170 cm and difference average radiant floor heating panels temperature and average room air temperature respectively. It’s clear from figures that as difference average radiant floor heating panels temperature and average room air temperature increases the VATD increases for all cases. This is due to transfer of heat from floor to air is not enough. Also can be noticed for each difference average radiant floor heating panels temperature and average room air temperature that the VATD for case 1 is higher than that of case 2 and case 3 since temperature distribution in case 2 and case 3 are more uniform than that of case 1.

Figures (9) and (10) present the relationship between VATD is measured between levels 10 and 110 cm with average room air temperature and the relationship between VATD is measured between levels 10 and 170 cm with average room air temperature respectively. For both figures, it’s clear that as average room air temperature increases the VATD decreases. This is because the difference average radiant floor heating temperature to average air room temperature decreases with average room air temperature increases. For each average room air temperature, it’s clear from figures that the VATD for case 1 is higher than that of case 2 and case 3 since temperature is distributed more uniform than that of the case 1.

Figures (11), (12) and (13) describe the average room air temperature distribution with room height for cases 1, 2 and 3 respectively. For all cases can be seen that the room air temperature at floor level (10 cm) is higher than that of 60, 110, and 170 cm. Since the floor level affects by heating floor. In comparison between average room air temperature for all cases can be concluded that the distribution of average room air temperature with room height is the same for all cases.

Figure (14) demonstrates for cases the relationship between average room air temperature with radiation heat flux. For all cases, it’s clear that the radiation heat flux decreases with average room air temperature increases. Also can be noticed that for each average room air temperature, the radiation heat flux is approximated the same for all cases.

Figure (15) describes for cases the relationship between average room air temperature with convection heat flux. For all cases, it’s clear that the convection heat flux decreases with average room air temperature increases. Also can be noticed that for each average room air temperature, the convection heat flux is approximated the same for case 2 and 3. This is because heat transfer
coefficient is approximated constant for both case 2 and case 3, in case 1 the convection heat flux is the lowest due to heat transfer coefficient in case 1 is lower than that of case 2 and case 3.

Figure (16) shows for cases the relationship between average room air temperature with heat transfer coefficient. For all cases, can be seen that the heat transfer coefficient decrease with average room air temperature increases. Also can be noticed that for each average room air temperature, the heat transfer coefficient is constant for case 2 and 3. This is because heat transfer coefficient depends on hydraulic diameter so constant hydraulic diameter for case 2 and case 3 causes constant heat transfer coefficient. Case 1, the heat transfer coefficient is the lowest due to hydraulic diameter in case 1 is higher than that of case 2 and case 3.

Figure (17) shows for both cases the relationship between total heating capacity and average room air temperature. For cases, it’s clear that the total heating capacity decreases when average room air temperature increases. This is due to radiation and convection heat flux decrease when average room air temperature increases. Also can be noticed that for each average room air temperature the total heating capacity is approximated constant for both case 2 and case 3. Since the radiation and convection heat flux is approximated constant for each case. Also can be noticed that the total heating capacity for case 1 is less than case 2 and case 3. This is due to effect of convection heat flux.

Figures (18) and (19) show the relationship between average room air temperature with PPD and PMV respectively for cases. From figures (15) and (16) can be noticed that PPD and PMV are affected by average room air temperature for the cases. PPD decreases while PMV increase as average room air temperature increase. Also can be noticed that the PPD and PMV for case 1 is higher than that of case 2 and case 3 for each average room air temperature. Since total heating capacity for case 1 is the lowest.

![Figure 7. The relationship between vertical air temperature difference is measured between level (10 and 110) cm and difference average radiant floor heating panels temperature to average room air temperature.](image)

![Figure 8. The relationship between vertical air temperature difference is measured between level (10 and 170) cm and difference average radiant floor heating panels temperature to average room air temperature.](image)
Figure 9. The relationship between vertical air temperature difference is measured between level (10 and 110) cm and average air room temperature.

Figure 10. The relationship between vertical air temperature difference is measured between level (10 and 170) cm and average air room temperature.

Figure 11. The profile of average room air temperature with room height for case 1 and different wall temperatures.

Figure 12. The profile room air temperature distribution with room height for case 2 and different wall temperatures.

Figure 13. The profile of average room air temperature with room height for case 3 and different wall temperatures.
Figure 14. The relationship between average room air temperature and radiation heat flux for case1, case2 and case3.

Figure 15. The relationship between average room air temperature and convection heat flux for case1, case2 and case3.

Figure 16. The relationship between average room air temperature and heat transfer coefficient for case1, case2 and case3.

Figure 17. The relationship between average room air temperature and total heat capacity for case1, case2 and case3.

Figure 18. The relationship between average room air temperature and PPD for case1 and case2.

Figure 19. The relationship between average room air temperature and PMV for case1 and case2.
6. Validation of Experimental Work

To validate currently experimental work comparison between currently experimental and theoretical work is done. All cases are compression. Good agreement is appeared by compression between currently experimental and theoretical work. Figures (20), (21) and (22) show the comparison between experimental and theoretical work for VATD at level (10-110)cm and average room air temperature for case 1, case 2 and case 3 respectively. Figures (23), (24) and (25) show the comparison between experimental and theoretical work for VATD at level (10-170)cm and average room air temperature for case 1, case 2 and case 3 respectively.

Figure 20. Comparison between experimental and theoretical work for relationship between average room air temperature and VATD at level (10-110)cm for case 1

Figure 21. Comparison between experimental and theoretical work for relationship between average room air temperature and VATD at level (10-110)cm for case 2

Figure 22. Comparison between experimental and theoretical work for relationship between average room air temperature and VATD at level (10-110)cm for case 3

Figure 23. Comparison between experimental and theoretical work for relationship between average room air temperature and VATD at level (10-170)cm for case 1
7. Conclusion

This study concerned on effect of different arrangements of heating floor panels on thermal comfort conditions in occupied zone and its effect on performance of heating floor panels. The results appear that the different arrangements of heating floor radiant panels have little effect on radiation heat flux and performance of heating floor radiant panels. While arrangement of heating floor panels have strongly effect on heat transfer coefficient, convection heat flux and thermal comfort conditions in occupied zone. It’s clear from figures above the third arrangement (case 3) is the best arrangement to achieve thermal comfort conditions in occupied zone. Also effect of air room temperature is studied. Can be observed from above figures that average room air temperature effects on both performance of heating floor radiant panel and thermal comfort conditions. As room air temperature increases the performance of heating floor radiant panels decreases. While as room air temperature increases PPD decreases and PMV increases. At air room temperature are 22.1 and 20.36 °C the thermal comfort conditions are achieved.

Acknowledgements: Authors are grateful to support given by college of Engineering, Mustansiriyah University, where the present experimental work was done in the college.

References
[1] Bean R, Olesen, B.W. Kim, W.W 2010 History of Radiant Heating & Cooling Systems, Part 2. ASHRAE J. 52, 50–55.
[2] Giovanni Ferrarini, Stefano Fortuna, Alessandro Bortolin, Gianluca Cadelano, Paolo Bison, Fabio Peron and Piercarlo Romagnoni, 2018 Numerical Model and Experimental Analysis of the Thermal Behavior of Electric Radiant Heating Panels, Appl. Sci. 8, 206.
[3] Josef Vaněk, 2010 The Electrical Radiant Panels and Radiant Floor Heating. Intensive Programmer “Renewable Energy Sources”.
[4] Stetiu C, 1999 Energy and peak power potential of radiant cooling systems in US commercial buildings. Energy and Buildings, 30, 127–38.
[5] Yost A, Barbour E, Watson R, 1995 An evaluation of thermal comfort and energy consumption for a surface mounted ceiling radiant panel heating system. ASHRAE Transactions, 101(1), 1221–35.
[6] ZURN, 2018 Radiant Heating Design and application guide, 1-800-872-7277.
[7] Ioan Sarbu1, Matei Mirza 1, Emanuel Crasmareanu, 2017 Performance of Radiant Heating Systems of Low-Energy Buildings. *IOP Conf. Series: Materials Science and Engineering* **245**.

[8] Lin, K.; Zhang, Y.; Xu, X.; Di, H.; Yang, R.; Qin, P., 2005 Experimental study of under-floor electric heating system with shape stabilized PCM plates. *Energy Build.* **37**, 215–220.

[9] Sattari, S.; Farhanieh, B., 2006 A parametric study on radiant floor heating system performance. *Renew. Energy* **31**, 1617–26.

[10] Milorad Bojić, Dragan Cvetković, Jasmina Skerlić, Danijela Nikolić, Harry Boyer, 2011 *Performances of Low Temperature Radiant Heating Systems*.

[11] Linhua Zhang, Xiaokai Huanga, Li Liangd, Jiying Liua, 2017 Experimental study on heating characteristics and control strategies of ground source heat pump and radiant floor heating system in an office building. *Procedia Engineering* **205**, 4060–66.

[12] Eda Ergur, Ankara Serhat Unver, Ankara Tamer Calisir, Ankara Senol Baskaya, 2018 Experimental and Numerical Investigation of Ceiling Mounted Radiant Panels Heat Output for Different Inlet-Outlet Water Temperatures. *International Journal of Scientific Research in Information Systems and Engineering* **4**(1).

[13] ASHRAE Handbook, (2000) HVAC Systems and Equipments (SI) *Panel Heating and Cooling*, Chapter 6.

[14] Plastics Pipe institute, 2014 *R-Value and Thermal Conductivity of PEX and PE-RT*.

[15] Isidoro Martinez, 2017. *Properties of Solids*.

[16] M. Hammad, Al Helo, S. And Khlaif, B., 2010 Investigation of The Performance of Cooling Panels: Ceiling and Floor Panels. *The 7th Jordanian International Mechanical Engineering Conference (JIMEC’7)* 27 - 29 September 2010, Amman – Jordan.

[17] Engineering guide 2011

[18] NNOVA Air TECH Instruments, 2002, *Thermal comfortable*.

[19] ANSYS FLUENT 14.5 2010 program.

[20] A. Salih, 2011. *Conservation Equations of Fluid Dynamics*, Indian Institute of Space Science and Technology, Thiruvananthapuram.

[21] Sylvio R. Bistafa, 2017 *On the development of the Navier-Stokes equation by Navier University of de São Paulo, São Paulo, SP, Brazil*.

[22] R.C.HIBBELER, 2015, *book of Fluid Mechanics*.

### Nomenclature

| Symbol | Description | unite |
|--------|-------------|-------|
| Cres   | Respiratory convective heat exchange | W/m² |
| E      | Evaporative heat exchange at the skin | W/m² |
| Ec     | Evaporative heat exchange at skin | W/m² |
| Eres   | Respiratory evaporative heat exchange | W/m² |
| Eswe   | Evaporative heat loss from evaporation of sweat | W/m² |
| H      | Dry heat loss | W/m² |
| M      | Metabolic rate | W/m² |
| q[c]   | Convection heat flux of radiant floor heating panels | W/m² |
| q[r]   | Radiation heat flux of radiant floor heating panels | W/m² |
| q[t]   | Total capacity of radiant floor heating panels | W/m² |
| T      | Temperature | °C |
| W      | Effective mechanical power | W/m² |

### Abbreviations

| Abbreviation | Description |
|--------------|-------------|
| ASHRAE       | American Society for Heating, Refrigeration and Air Conditioning Engineers |
| PMV          | Predicated Mean Vote |
| PPD          | Percentage People Dissatisfied |