A Review of Research on Air Distribution in Conditioned Spaces and Indoor Air Quality for Human Health

Mr. Sunil. M. Mahajan[1], Dr. Vishvendranath. N. Bartaria[2]

[1]PhD Scholar Mechanical Engineering Department, LNCT University, Bhopal-462026, M.P., India

[2]Professor Mechanical Engineering Department, LNCT University, Bhopal-462026, M.P., India

Abstract:

With the development and growth of the standard of living, air conditioning become a necessity in public and residential buildings. The people invested 80-90 percent of their time in indoor space. However, the indoor environment affects the work efficiency and health of the end user. Air conditioning provides comfort to the occupants and goods are protected from being deteriorated. At present it observed heat load ratio per square meter area increases which cause indoor climate problem and health issue for occupants. Without proper air distribution in the conditioned space, the thermal environment can't produce comfort for occupants. To investigate the air distribution effects various experimental and numerical methods are being used by the researchers. In this paper, concern research on air distribution in conditioning spaces and indoor air quality for human health is reviewed. The hurdles in the existing research are listed out and further study is identified on air conditioning systems and indoor air quality for human health.

Keywords: Air Distribution, IAQ, Ventilation, Displacement Ventilation (DV), Mixing Ventilation (MV)

Introduction:

Since last many decades, the air conditioning system has been accepted and used by society in most of part in the world. The main motive behind the use of air conditioning systems is to generate thermal comfort and healthful indoor air quality (IAQ) for end users. With modern society and developed standard of living, peoples wish for more and more comfort and healthful indoor environment. People spend their maximum time [i.e., 80-90%] in indoor spaces for their daily office work, household work, etc. Now air conditioning is becoming a necessity for man and machine both because, not only the human but machine efficiency is also affected by the thermal environment around them. The various factors affecting the indoor environment as air distribution, temperature, humidity, air exchange rate, ventilation, particle pollutants, and biological, and gaseous pollutants. Previous research lists an increase in the prevalence of sick building syndrome (SBS) between 30% and 200% in buildings with air-conditioning systems when compared with natural ventilation systems [1]. Such things are warning for indoor environment problems related to air conditioning systems i.e., the problems related to indoor climate still exist in many conditioned spaces.
A number of investigators have researched in consideration of control aggregation of household contaminants, correct IAQ, and examined the control designs for it. In order to improve the indoor climate in conditioned space is done by changing some factors like air distribution method, humidity level, lighting condition, air temperature, air velocity distribution, and ventilation system. In this paper, concern research will be reviewed on air conditioning systems and indoor air quality control for human health.

Indoor Climate and Thermal Comfort:

As per the ASHRAE norms, thermal comfort is defined as the condition of mind which express satisfaction with the thermal environment. But, the comfort of the occupants differs with their different conditions such as clothing, metabolism, activity, etc. and it is affected by many factors, which include air temperature, air humidity, air velocity, and mean radiant temperature.
The air velocity and supply air temperature both affect the thermal comfort of the occupants. As per the research, it is good to know the flow patterns of indoor air in the conditioned space to analyze the comfort conditions in the space. The widespread use of air conditioning aids in increasing thermal comfort, but health issues linked to poor IAQ are more common.
Numerous specialists believe that IAQ is the ultimate important and fairly overlooked environmental issue of our time. It is indoor contaminants that lead to impure IAQ. Household pollutants include particle pollutants and gaseous pollutants.

Air Distribution:

The air distribution is the supply of conditioned air into the conditioned space to provide comfort conditions in the occupied space. Much of the comfort of occupants depends upon the air distribution method. The selection of diffusers and supply air conditions jointly contribute to effective air distribution. There are various methods of air distribution such as overhead and underfloor air

distribution. Airflow patterns are changed with the type and location of the supply air diffusers and the return air inlets [3]. In a conventional Air Distribution System, the conditioned air is supplied at a particular value of velocity and temperature into the room through diffusers placed at the ceiling. This air is mixed with the room air and produces a homogeneous indoor thermal environment. The air is returned through the return air vents.

Ventilation is defined as the change of air to and from any space for controlling and maintaining the temperature of the space, air contaminants, and humidity level. By ventilation, the outdoor air is supplied into the building spaces with the help of air handling devices and mechanical systems in conventional systems of air ventilation. Renewable sources of energy may also be used through which air could be exchanged from the building spaces.

Therefore, the ventilation commonly used in buildings may be of the following types:
1. Natural ventilation

2. Mechanical ventilation and

3. Hybrid ventilation

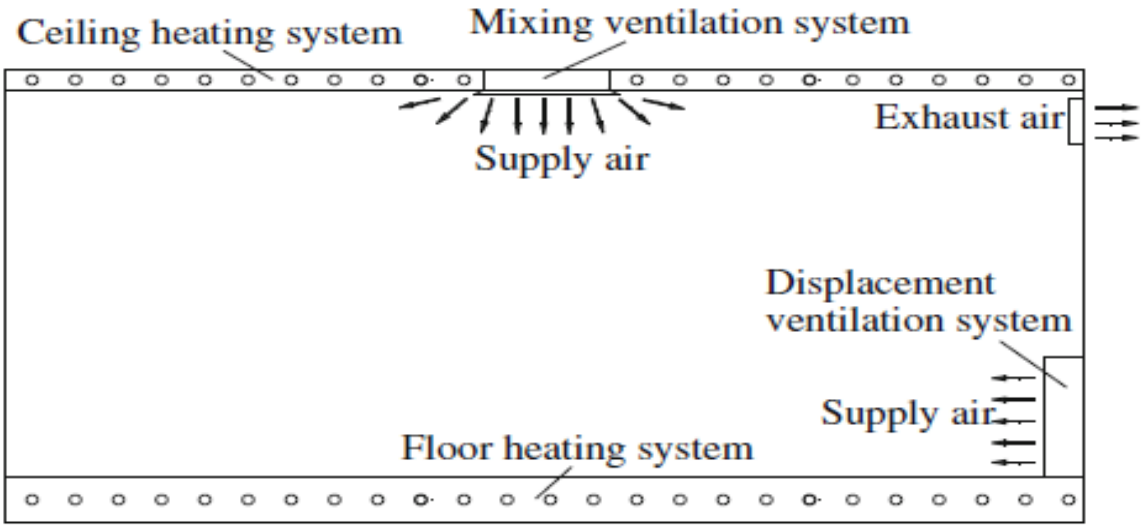

Figure: Schematic Diagram of CC/MV and DV [4]

Better indoor air quality has been associated with stratified air distribution systems like Traditional Displacement Ventilation (TDV) and Under-Floor Air Distribution (UFAD) systems

Traditional Displacement ventilation (DV)

DV is an air supply method that improves the environment in an occupied zone but does not cover all the space. In comparison with mixing ventilation (MV), DV has higher ventilation efficiency and IAQ due to its piston flow effect and temperature stratification [1]. So, the DV is used to save energy as well for better IAQ.

Under Floore Air Distribution Ventilation (UFAD)

UFAD is an air supply mode with better flexibility and energy-saving advantages. A number of researchers have concentrated their research on various types of diffusers because they have a significant impact on airflow characteristics. 95% of the surveyed people showed their satisfaction with UFAD, and nearly 2/3 of them indicated a preference for UFAD over conventional overhead air distribution. For the rooms with high ceilings, stratified air distribution systems work better, and at low throw height traditional displacement ventilation, underfloor air distribution ventilation works with the same effect [2] [3].

The elimination of indoor pollutants and improving IAQ DV show better results. Sometimes it is not capable of meeting indoor cooling load due to the imitation of temperature and velocity of air distribution, which may lower the indoor thermal comfort. In this case cooling ceiling (CC) system performs well on indoor thermal comfort but it can not improve IAQ due to its configuration [1]. The CC and DV system have disadvantages over each other so the combined CC/DV system is used to overcome these disadvantages. In a combined CC/DV system, a vertical temperature gradient should exist because it indicates stratified airflow patterns and vertical stratification of pollutants. On the other hand, the temperature gradient should be small for acceptable thermal comfort. Table 1 presents the vertical temperature gradient in the occupied zone (0.1–1.1m above the floor) obtained from several studies [2].

Table 1- The vertical temperature gradient in the occupied zone (0.1-1.1m) [2]

Researchers	Temperature gradient (K/m)	Research approach
Niu and Kooi (1993)	2	Simulation
Kruhne (1993)	0	Experiment
Kulpmann (1993)	1.5	Experiment
Fitzner (1996)	0	Experiment
Alamdari (1998)	1.2-1.7	Experiment and Simulation
Behne (1999)	0.4-1.2	Experiment

Literature Review:

The air conditioning and air distribution in conditioned space phenomenon studied by many researchers since 1923 for thermal comfort and human health. The problem with air conditioning is substantial and far more complex part. In this review here we focused on some literature regarding the effectiveness of air distribution in a conditioned space and human health.

B.F. Yua, Z.B. Hua, M. Liua, H.L. Yangb, Q.X. Kongb, Y.H. Liu [1] [2009] has reviewed different causes and symptoms of indoor air quality (IAQ). He suggested that the biological effects of different pollutants may change with order and their composition indoors is quite complex. The pollutants in the air expose low concentrations on the human body and it is also unpredictable about the impact of exposure amount and exposure time on human health. The author suggests, if these problems are resolved then the indoor air environment can be controlled accurately and reasonably. The author focused, on DOAS and ICTHS air conditioning system which helps to eliminate microbial pollution and also save energy. Additionally, he brought up the CC/DV system, which not only offers first-rate indoor air quality but also has a remarkable capacity for energy savings.
Wu Xiaozhou, Fang, Lei, and Jianing [2] [2014] investigated various combinations of floor or ceiling heating with mixing or displacement ventilation and their impacts on indoor air distribution and ventilation effectiveness. The experiments were carried out during the heating season in a closed room with the supply air temperature conditioned at 19^0 C. The findings indicate that the indoor vertical air temperature and air velocity variations for various hybrid systems are less than 3^0 C and 0.2 m/s, respectively. Comparatively speaking to floor/ceiling heating systems paired with displacement ventilation systems, mixing ventilation systems have a more uniform interior air distribution but less efficient ventilation. Floor/ceiling heating and mixing/displacement ventilation should be combined optimally to have the least amount of building heat loss, which is enhanced by uneven indoor air distribution and poor ventilation efficiency. The vertical air temperature differential and draught won't affect the local thermal comfort of the air distribution in a space with floor/ceiling heating and mixing/displacement ventilation.

Martin Heine Kristensen [3] [2015] presented that, how high cooling capacities (above 130W/m2) can be achieved while still complying with thermal comfort category B. DCV systems are capable of delivering high ventilation rates (from 6-16 h−1) with minimal risk of draught due to the application of large supply opening areas compared to conventional ventilation systems.
In DCV some preheating of the inlet air should theoretically take place in the plenum above the suspended ceiling due to excess heat from the room underneath, hereby minimizing, or maybe even removing, the need for additional mechanical preheating during the heating season. Furthermore, as many new buildings have significant cooling loads it may prove very efficient that DCV allows relatively high ventilation rates at low inlet velocities, potentially limiting the energy use for cooling, which often is a necessity during working hours in the majority of the year. Based on measurements of surface temperature and measurements of plume cross-sectional profiles the results show that the surface temperature of the human body simulator (thermal manikin) resembles that of a human being

Ajay Kumar, Dr. V. N. Bartaria & Harish Kumar Patel [4] [2016] author studied the design needs of an air distribution system with due consideration of human comfort and energy savings. He said that air distribution is a very important design aspect of air conditioning systems for the thermal comfort of occupants. As per his concern the movement of air inside the room is taking place because of the buoyancy effect and the supplied air will tend to come down due to its density. The supply air should not strike the occupant directly, it is also an important consideration while designing an air distribution or conditioning system.

Shivani Sharma, Dr. V. N. Bartaria [5] [2016] have reviewed the research experimental and numerical methods available in the literature for the representation of flow and thermal patterns. The author noticed that the numerical methods have been selected by most researchers in the investigation of performances of air conditioning system components and performance analysis.

Manish Shankar, Suresh Kumar Badholiya, Rohit Kumar Choudhary [6] [2017] has studied the CFD simulation method for research on indoor thermal environments. The results of numerical simulation for a conditioned space having three different values

of airflow have been shown using CFD analysis. The results obtained in the form of vertical velocity and temperature distribution for the same supply air conditions and changed air return location are compared. The results show that the velocity of 0.1 m/s is sufficient to produce a uniform thermal environment in the occupied space.

Mohan [7] [2017] has introduces an air treatment system (ATS) to enhance indoor air quality while lowering the energy use of air conditioning units. The three subsystems that made up this system as

- an energy-efficient oxygen production subsystem
- an ozone-based oxidation treatment subsystem and
- an air scrubbing subsystem.

The combined air treatment system is able to realize improved indoor air quality due to the activation of an air-purification process. Experimental studies have been conducted to investigate the performance of the primary equipment of the ATS. The proposed ATS enables the air-conditioning system to employ a lower outdoor ventilation rate due to the air-cleaning function. In addition, the proposed ATS can be implemented in both new and existing air-conditioning systems to realize immediate improvement in energy efficiency and indoor air quality. Experimental studies on the whole proposed system are highly recommended for future work.

Anshu Raj, Neelesh Soni [8] [2017] reviewed of Design of Air Conditioning System for Commercial and Domestic Applications. This study helps to determine and find out exact or near about the temperature required for the selected room in which we put AC. By using calculation of room, we will able to find out how much we have to give cooling or heating the room.
This work offers tremendous significant for developing new technologies pertains to save energy, in order to achieve hot/cool air at initial cost, no harmful effect and safer in environment aspect. So, more attention is needed in this area and lots of work has to be done based in terms of its background, originality, current status, and researches.

Douaa Al Assaada, Carine Habchib, Kamel Ghalia, Nesreen Ghaddar [9] [2018] has studied the performance of ventilation regarding the protection of occupants from the contaminants present in space. This study was performed with a CFD model to assess the velocity, temperature, and particle concentration fields in space. The experiment was carried out with the conditions; MV flow rate of 63 L/s and room temperature of 28^0 C and PV average flow rate of 3.5 L/s, supply temperature of 24^0 C, and frequencies of 0.3 Hz and 1 Hz. The validated model was used to provide PV operating settings that would ensure occupant protection from the movement of pollutants from the macroclimate to the respiratory zone and the microclimate around the occupant, and prevent particle deposition on surfaces in the vicinity of the occupant.

The design chart for an air distribution system

One of the aims of the design of an air distribution system is to find the limits regarding possible flow rates into the room and temperature differences between the supply and return temperatures, i.e., to find the limits that maintain an acceptable comfort level with small draught and low-temperature gradients in the room. The design chart (q_0-ΔT_0), which is a member of the family tree, has been used to assess a number of ventilation principles. By using the design chart, it becomes possible to compare different systems and enables the user to find the best system for individual demands.

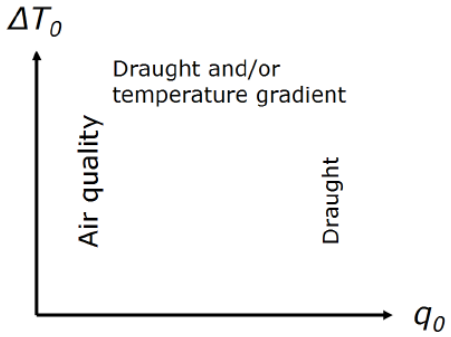

Figure: Design Chart of Flow rate (q_0) vs. temperature Difference (ΔT_0) between return and supply air.

The concept behind a design chart for air distribution in rooms is shown in Figure. The chart is based on the room's maximum and minimum permitted flow rates as well as the maximum temperature differential between the supply and return air. According to the graph, certain air quality can only be achieved in space by introducing a certain amount of fresh air at a specific flow rate. When the air distribution system produces a mixing ventilation, this flow rate is constant and independent of ΔT_0, but when displacement ventilation is used, it might be a minor function of T_0. The generation of mixing in the occupied zone is crucial for the effectiveness of air distribution systems based on momentum flow supply. Some systems, such as diffuse ceiling inlets, produce relatively little momentum flow and, as a result, do not exhibit a q_0 limit. In this instance, the heat loads in the room create a draught, which restricts the product of q_0 and ΔT_0 (thermal load) [3] [6].

As shown in Figure, the temperature difference T_0 between the supply and the return is likewise constrained. A room with an excessive temperature gradient or draughts in the inhabited area might result from a significant temperature differential. A region for the variables q_0 and T_0 as shown in Figure will provide a suitable amount of fresh air, draught-free air movement in the occupied zone, as well as a constrained vertical temperature gradient. For a particular air distribution system, this region is regarded as the design area. The highest air velocity allowed in the inhabited zone is 0.15 m/s, the maximum vertical temperature gradient is 2.5 K/m, and the minimum flow rate allowed is 10 l/s per person. These are the restrictions for the design area [3] [6].

Conclusion:

Most of the occupants prefer a healthy and comfortable indoor environment for their office space or residential space. In current days most research is going on air distribution and air conditioning and its results show a great improvement in indoor thermal climate. Still, the health problems related to impure IAQ are identified frequently. Therefore, air purification is an important way of removing indoor pollutants and improving IAQ. Indoor air purification mostly includes filtration, adsorption, PCO, NAIs, and NTP methods. But all these individually have some limitations due to the complexity of indoor pollutants as poor purification effects, high energy consumption, and secondary pollution induced by the byproducts. This paper-initiated review-based research on air distribution in air conditioning systems and human health related to it. This research work offers tremendous significance for developing new technologies pertaining to saving energy, in order to achieve hot/cool air at initial cost, no harmful effect, and safer in environment aspect.

References:

1. B.F. Yua, Z.B. Hua, M. Liua, H.L. Yangb, Q.X. Kongb, Y.H. Liu, 2009. Review of research on air-conditioning systems and indoor air quality control for human health, International Journal of refrigeration, (32) 3-20.
2. Wu Xiaozhou, Fang, Lei, and Jianing, 2014. Air Distribution and Ventilation Effectiveness in a room with Floor/Ceiling Heating and Mixing/Displacement Ventilation, In Proceedings of the 8th International Symposium on Heating, Ventilation and Air Conditioning (pp. 59-67). Springer.
3. Martin Heine Kristensen, 2015. Impact of Diffuse Ceiling Ventilation Systems on Indoor Environmental Quality in Classrooms, Master Thesis, Aalborg University, Denmark.
4. Ajay Kumar, Dr. V. N. Bartaria & Harish Kumar Patel, 2016. International Journal of Research, p-ISSN: 2348-6848, e-ISSN: 2348-795X, Volume 03 Issue 09, pp 424-426.
5. Shivani Sharma, Dr. V. N. Bartaria, 2016. International Journal of Research, p-ISSN: 2348-6848, e-ISSN: 2348-795X, Volume 03 Issue 14, pp 4215-4218.
6. Manish Shankar, Suresh Kumar Badholiya, Rohit Kumar Choudhary, 2017. CFD Analysis of Velocity & Temperature under variable Flow Condition in an Air Distribution of Air Conditioning, International Journal for Scientific Research & Development| Vol. 5, Issue 07, ISSN (online): 2321-0613.
7. X. Cui., B. Mohan, 2017. Investigation on a combined air treatment process for air conditioning system 9th International Conference on Applied Energy, ICAE2017, 21-24 August 2017, Cardiff, UK
8. Anshu Raj, Neelesh Soni, 2017. Review of Design of Air Conditioning System for Commercial and Domestic Applications, International Research Journal of Engineering and Technology, Volume: 04 Issue: 07, e-ISSN: 2395-0056, p-ISSN: 2395-0072.
9. Douaa Al Assaada, Carine Habchib, Kamel Ghalia, Nesreen Ghaddar, 2018. Effectiveness of intermittent personalized ventilation in protecting occupant from indoor particles, Building and Environment 128, pp 22–32.
10. Wu X, Olesen BW, Fang L, Zhao J, 2013. A nodal model to predict vertical temperature distribution in a room with floor heating and displacement ventilation, Build Environ 59:626–634.
11. Hideyuki Amai, 2017. Experimental study on air change effectiveness Improving air distribution with all air heating systems, Vol.125 ,515-527.
12. A. Jindal, 2018. Thermal comfort study in naturally ventilated school classrooms in a composite climate of India, Build Environment, Vol. 142, 34-46.
13. Causone F, Baldin F, Olesen BW, Corgnati SP, 2010. Floor heating and cooling combined with displacement ventilation: possibilities and limitations. Energy Build 42:2338–2352.
14. Lau, J., Chen, Q.Y., 2007. Floor-supply displacement ventilation for workshops. Build. Environ. 42, 1718–1730.

15. Olesen BW, Simone A, Krajcik M, Causone F, De Carli M, 2011. Experimental study of air distribution and ventilation effectiveness in a room with a combination of different mechanical ventilation and heating/cooling systems. International Journal of Ventilation 9(4):371–384.
16. Zhou Hao Qiao Lifeng, Jiang Yi, Sun Hejiang, Chen Qingyan, 2016. Recognition Of Air Conditioner Operation from Indoor Air Temperature and Relative Humidity by A Data Mining Approach, Energy and Buildings, Pp: 233-241.
17. B. El-Fil, N. Ghaddar, K. Ghali, 2016. optimizing performance of ceiling-mounted personalized ventilation system assisted by chair fans: assessment of thermal comfort and indoor air quality, Sci. Technol. Built Environ. 22, Pp: 412–430.
18. W.A. Hweij, N. Ghaddar, K. Ghali, C. Habchi, 2016. Optimized performance of displacement ventilation aided with chair fans for comfort and indoor air quality, Energy Build. 127, Pp: 907–919.
19. G. Cao, H. Awbi, R. Yao, Y. Fan, K. Siren, R. Kosonen, J. Zhang, 2013. A review of the performance of different ventilation and airflow distribution systems in buildings, Build. Environ. 73, Pp:171e186.
20. ANSI/ASHRAE Standard 70e2006 Method of testing the performance of air outlets and air inlets American Society of Heating, Refrigerating and air conditioning engineers.
21. K. Zhong, X. Yang, Y. Kang, 2010. Effects of ventilation strategies and source locations on indoor particle deposition, Build. Environ. 45, Pp: 655–662.
22. Lucas Franck, Ortega Pascal, David Mathieu, Sinama Frantz, Brangeon Boris and Picgirard Fabien, 2015. A Method to Evaluate Energy Performance of Buildings Cooled by Room Air Conditioners, Energy Procedia, Pp: 1275 – 1283.