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Recent developments and findings in the Personalized ventilation system design and performance

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Abstract

Total volume ventilation methods do not account for individual comfort preferences, thus personalized ventilation (PV) systems are considered to be an effective alternative method for delivering cool air directly to the occupants breathing zone. This approach significantly enhance the ventilation efficiency, occupant's perceived air quality (PAQ) and comfort, while reducing exposure to pollutants in inhaled air. This paper reviews recent publications and aim to asses key research and benchmark studies on comfort and air quality in relation to various PV system designs. We aim to present how these designs effectively create an acceptable thermal environment in the occupant's immediate surroundings.

Key Innovations

- Highlights the factors that influence PV performance through analytical study.
- Discusses key strengths of PV from broad range of studies.

Practical Implications

This study highlights the most effective strategies, methods, and approaches in "Personalized ventilation" studies. By focusing on what's already proven to work, this review synthesizes the PV impacts on occupant micro thermal environment, which, in turn, helps researchers make necessary adjustments to their current work, allowing them to refine their research questions and develop frameworks for future investigations.

Introduction

In response to the growing demand for comfortable indoor conditions, buildings are responsible for 40 % of energy globally, a large percentage is consumed to maintain the buildings thermally comfortable (Yang et al. 2014). Especially in tropical countries like India, heating, ventilation and air conditioning (HVAC) systems in commercial buildings accounts for 31% of total energy (Manu et al. 2016). Traditional methods of total volume ventilation aim to condition the entire space equally, ignoring individual requirements in comfort preferences. Therefore, an alternative air conditioning principle based on targeted areas have been widely explored since more than three decades (Bauman, et al. 1993). Initially, researchers (Akimoto, et al. 1996) called them with several names such as task conditioning, spot cooling etc. they studied desktop-based task conditioning system in a laboratory experiments and later in real dynamic field environment. these systems are now better known as personalized environmental control systems (PECS). PECS are small devices developed to provide heating, cooling, ventilation. Author Godithi et al. (2019) presented PECS devices in thermal, visual, acoustic and controllable plug load aspects. In their review, Rawal et al. (2020) categorized personal comfort systems (PCS) into five types: heating, cooling, heating & ventilation, cooling & ventilation, and ventilation-only types. These systems encompassed a wide range of devices, from garments and radiant panels to heaters, personalized ventilation nozzles, and desk fans. In the same year, another review paper by André et al. (2020) emphasized the critical need for automated control of such systems to achieve maximum energy savings and superior thermal comfort, especially given their localized effects.

Personalized ventilation (PV) systems designed to provide cooling and ventilation directly at occupant breathing zone using an air terminal device with personal controls over supply conditions in occupant's hand. The advantage of the personalized ventilation (PV) systems are that, they cool the occupant immediate surroundings, and ensures high ventilation efficiency. In literature, researchers explored various personalized ventilation (PV) systems, each of these include one or more air stream nozzles that use to deliver the conditioned air close to occupant breathing zone. These are known as 1. Desk mounted PV systems: these have nozzles that directed airflow towards seated occupant, often with individual controls. 2. Chair mounted PV systems: supply nozzles are integrated to chair and deliver the air close to occupant breathing zone. 3. Partition based PV: these systems are installed either side of the seated occupant, within the partition. 4. Ceiling mounted PV systems are placed above occupant seating position and deliver the air through a supply nozzle. These PV systems hold a great potential in supplying occupant's preferred comfort conditions.

In the past fifteen years, there has been an increased interest observed in the PV application in controlling the pollutant contaminants in the space, researchers Yang et al. (2013) introduced personalized ventilation (PV) in conjunction with personal exhaust (PE) system to maximize the PV air reach to the occupant and exhaust the exhaled air pollutants before it mixes with room air. A typical PV system essentially consists of an air terminal device (ATD), a small axial fan, duct unit, filter element,

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controllers. The personalized air delivery to the occupant is enhanced by using one or more air terminal devices in conjunction with mixing ventilation and displacement ventilation systems, primarily, desk mounted PV system used widely in previous studies (Cermak, et al. 2006 & Al Assad et al. 2021). The PV system air delivery effectiveness is evaluated by means of inhaled air quality, contaminants concentration and PV ability to adjust and control the airflow rate. PV system studies carried in control chambers under steady state conditions, using both mannequin and subjective response to PV supply conditions are assessed, the control of supply conditions were mainly limited to airflow rate through damper opening area and ATD adjustments due to technical challenges involved in temperature control. Numerous studies (Schiavon & Melikov, 2009 & Schiavon, et al. 2010) proved that by increasing background supply temperature at slightly higher level due to PV targeted cool air delivery, the systems can deliver significant energy savings. The increased background room air temperatures can lead to increase of PV airflow rate according to a study by (Chen et al. 2012). Authors (Veselý & Zeiler, 2014) reviewed PV systems and highlights that PV performs better in terms of thermal comfort than other methods to elevate air movement such as ceiling fans, standing fan and desk fan.

Research gap

Previously, authors in literature presented the broad review studies on "Personalized environmental control systems" covering vast range of devices in thermal, visual, acoustic aspects. However, targeting only on personalized ventilation systems category, are not up to date, though few were covered in other papers. Hence, this paper aims to fill this gap.

Research objectives

The objectives of the paper are: 1) to analyse the physical design characteristics of PV system 2) to assess the PV impact on occupant micro thermal environment 3) evaluate the role of PV in achieving relatively high air quality.

This study focuses exclusively on PV systems, components, specifically examining thermal environment and air quality aspects along with design strategies. It does not encompass the full range of personalized environmental control systems (PECS).

Methodology

This study through a systematic review approach found the relevant research papers from differnt scieentific databases like ScienceDirect, Scopus, Google Scholar and others sources. The search was initiated using key words like "Personalized ventilation", "Air terminal device", "Personal environmental control systems" and the resutls were filtered at different levels to align the most impactful papers according to the research objectives. Additionally, relevant papers known to authors were also included. The selected papers were carefully categorized based on their approaches, evaluation methods with primary emphasis on indoor air quality and comfort studies.

This paper systematically reviews key developments in personalized ventilation (PV) systems to inform future research. We analyze selected studies from 1993 to 2024, covering theoretical perspectives, climate chamber experiments, and computational fluid dynamics (CFD) simulations.

Developments in PV design over the years

The idea of personalized ventilation (PV) was introduced in early 2000's by Fanger to cater the individual's comfort preferences. PV system can deliver conditioned outdoor air directly at the occupant breathing zone. This creates a localized micro-thermal environment, allowing occupants personalized control over air supply temperature, flow rate, and velocity. A key benefit of delivering cool air near the occupant's breathing zone is that it maximizes ventilation, and improve occupant health and well-being.

Initially, the optimal design conditions, energy saving potential providing individual comfort by supplying high ventilation rate and airflow characteristics were presented to assess the system effectiveness (Melikov, Cermak & Majer, 2002, Melikov 2004). Thermal environment acceptability and perceived air quality under PV were tested in a personally controlled environmental chamber using human subjects and thermal manikins along with the sensory measurements. The authors highlighted the interaction of personalized air stream with the surrounding room air, mixing and entrainment of pollutants in the personalized air stream. The interfacial effect of surrounding room air with the personalized air jet is crucial to supply occupants high quality air. Several studies suggested the minimum air velocity to penetrate into the surrounding room air is between 0.2 m/s to 0.3 m/s (Melikov 2004) indicating the personalized airflow sensitivity at the occupant upper body parts. The increase of supply air temperature decrease the personalized exposure reduction as claimed by the literature. The supply temperature range from 18°C to 26°C is the range, the maximum studies tested for thermal acceptance and also previous research found a strong relation between PV supply temperature and rising thermal plumes in the occupant micro thermal environment (Melikov, Cermak & Majer, 2002) The air movement of 0.2 m/s is strongly recommended to protect the occupant from contaminants.

Several studies carried subjective responses under personalized conditions. Authors (Melikov & Knudsen 2007) investigated the subjective responses under the flowrates varying from 5 l/s to 15 l/s depending on their background temperature and PV supply temperatures. The PV reduced inhaled air temperature up to 5°C compared to the same temperature by background air conditioning without using PV, the acceptability of air quality improved significantly. More than 80% of people prefer the distance between ATD to occupant is from 0.3m to 0.5 m in previous studies. Many authors claim the potential of PV energy with a primary air conditioning system that is operating at an ambient temperature range of 26°C with PV temperature as variable slightly around the 23°C with flowrate of up to 15 l/s (Sekhar et al.2005).

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In a recent study by Zhao et al (2021) used two types of individually controlled systems called low velocity radiant panels (LVRP) and a personalized ventilation combined with radiant panel (PVRP) system and investigated the subjective responses, the results of the study indicate that the PVRP demonstrated higher thermal sensation than LVRP, as PV system can create strong impact on personal exposure effectiveness (PEE).

The preferred air velocities of PV play a role in subject's sick building syndrome symptoms like eye irritation, skin dryness, tear film quality, and the ability to perform in an office activity. It is noted from the studies that the air velocites preferred by the subjects in tropical climates is about 0.3 m/s to 0.45 m/s minimum, this can increase up to 0.9 m/s with the increase of PV supply temperature up to 26°C (Gong et al.2006). Draught discomfort is a significant concern in PV system design. This often stems from thermal asymmetry between an occupant's lower and upper body, leading to discomfort. To address this, PV systems can provide controls for the air terminal device's supply flow rate, offering the flexibility to adjust target conditioning. This allows occupants to modify airflow and velocities using control dampers, significantly improving their comfort.

Room air pollutant entrainment into a PV air stream can reduce inhaled air quality. To assess this, previous studies have used the tracer gas method. This involves introducing gases like SF6, N2, or CO2 into the air stream and then measuring their relative decrease in the inhaled air. This approach helps evaluate the concentration of inhaled pollutants and assess ventilation efficiency.

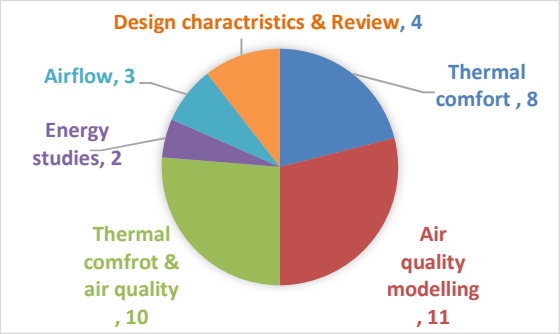

Fig. 1 PV reference paper study areas

Air terminal devices and developments

Air terminal device (ATD) is one of the major components of PV system. The amount of fresh air supply to the occupant breathing zone depends on type of ATD, positioning height and placement. Previously, authors (Melikov et al. 2002) tesetd the five differnet air terminal devices: round movable panel (RMP), vertical desk grill (VDG), horizantal desk grill (HDG) and personal environmental module (PEM) and computer monitor panle (CMP).

Researchers are actively exploring new and innovative devices to improve the ventilation efficiency and comfort parameters. Their understanding benefits of PV system led to prioritize the focus on developinbg advanced devices. Muhič & Butala (2006) developed a new prototype and called it personal microclimate system (PERMICS) which is similar to an ATD. Few years later, (Kalmár & Kalmár, 2013) developed a new ATD called ALTAIR that features two disks, one connects to ducts and the other one features a single orifice that rotates in a programmed time interval. Zhu et al (2017) introduced another type of device called spot type personalized air conditioning (SPAC).

The ATD design, structure and diffuser holes, spacing between holes and shape influence the airflow charecteristics, the small losses near the openings is aniticipated. Kaczmarczyk, et al (2006) experimental study reveals that 70% of subjects satisfied with the use of round movable panel (RMP) ATD, its shape and opening area (100mm dia) makes PV flow stream less turbulent. Sun et al (2007) conducted study on circular perforated panel (CPP) ATD performance in terms of thermal comfort at two tubulence intensities 15% and 40% and found that low tubulent air coming from the device resulted in high facial velocity but did not effect whole body sensation. Authors (Chludzińska & Bogdan, 2017) discussed the loss of kineteic energy due to rectangular type of holes and introduced a new perforation coefficient value between 1.52-3.38 and stresses on perforation hole strong influence on thermal sensation. In their consequent study, authors claim that small diameter holes can allow even outflow while hole diameter size 15 mm can lead to outflow from central part of the nozzle. Al Assaad et al. (2021) also carried the study on evaluting the CMP, RMP, VDG type ATDs in its ability to reduce the inhaled air pollution and their results conclude that CMP device reduced 89% exposure, RMP 97% and VDG 91% at a supply flowrate of 10 l/s.

The ability of ATDs was evaluated in terms of its efficiency to supply maximum amount of fresh air towards occupant breathing zone. round movable panel type ATD effectiveness is evaluated using mannequin based equivalent temperature (MBET) difference. Generally, modifying ATD positioning and airflow rate can obtain preferred thermal conditions. The performance of round movable panel installing at the occupant front side of the desk at a head level seems to be superior than other four types of air terminal devices, though the VDG type air terminal device achieved greater personal exposure effectiveness at a higher air flowrate of 10 l/s (Melikov, Cermak & Majer, 2002).

Personalized ventilation studies in literature are performed using energy & CFD simulations, climate chamber and field experiments. But, field studies are compartively lesser, indicating more understanding of PV from real field environment.

Fig 2: Methodological approach of PV studies

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CFD Simulation studies

Computational fluid dynamics (CFD) simulations are primary prediction techniques used to assess PV airflow delivery, specifically examining how PV air jet mixing with background room air effect supply temperature and air velocity profiles.

Numerous studies Yang, et al. (2013) focused on occupant segmental and whole body thermal comfort prediction. Furthermore, PV strategies of different flowrates, temperatures, velocities and impact of workplace disturbances like furniture layout arrangement, turbulent movement near the PV core jet, contaminant entrainment into PV jet, sudden movement of the occupant, positioning of ATD, angle, distance between occupant, use of multiple ATDs, intermittent airflow effects, sinusoidal airflow effects were prioritized and explored in detailed in the recent studies. The CFD studies reasonably increased the understanding of occupant micro thermal environment, contaminant distribution, velocity fluctuation, and direct impact on occupant face, upper body parts. The inhaled air quality improvement and removal exhaled air from interacting with the PV air is crucial as it can deteriorate the occupant fresh air breathing levels.

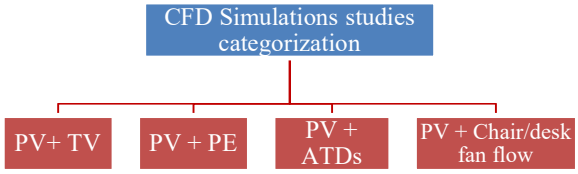

Fig 3: PV studies CFD study areas

Yang, et al. (2013) coupled the PV with personal exhaust system and discretized the energy, continuity and momentum by selecting standard k ε model for airflow analysis. Makhoul et al (2013) carried selected k ε model and predict the room air entrinment into PV air, while Al assad et al. (2017) & Al assad (2019) selected RNG – k ε Turbulence model and discretized the momentum, energy, turbulence, and transport equation to evalute performance of PV. Al assad et al. (2018) selected RANS model to evalute the PV airflow. Thus, CFD studies were helpful in carrying the PV supply conditions, thermal comfort and contaminant control. however, when it comes to real office settings in field, the disturbances, pollutants displacement, the air turbulence due to various reasons in the space, background room air conditions and other irregularities, pressure differences present in the space can cause huge differences.

Experimental studies in environmental chamber

The studies (Chen et al. 2012, Makhoul et al. 2013, Al Assaad et al. 2017) authors, investigated the PV acceptance levels in personally controlled environmental chamber. Priamrily, the PV system was operated in conjunction with a background room air conditioning system operating at slightly higher temperature than the PV. Over past two decades researchers continue to explore on the PV system characteristics, design improvement. the coupling of PV with mixing ventilation, different PV systems from desk mounted to ceiling mounted and chair integrated studies are carried under office setting in a controlled environmental chambers with room air supply conditions monitoring and controlling through BMS integrated system. Though theoritical studies proved the ability of PV system in thermal environment acceptability, the subjective assessments under PV, their behavioral patterns, adjusting personal factors, optimal use are crucial in evaluating its effectiveness.

To this extent, several studies (Al Assaad et al. 2019) examined human response to PV conditions and found that subjects were able to modify the flowrate, ATD direction, clothing to make them feel comfortable. The breathing thermal manikin based studies are investigated largely to predict the occupant segmental level and whole body level thermal comfort. Since last decade, the occupant protection from respiratory infections, bioeffluents carrying into the breathing zone, pollutants spread across the workstations, the plume generation and exhausting the polluted air from breathing zone using a personal exhaust system were studied and results indicate the positive outcome. In addition to office setting, the occupant exhaled air exhausting from reaching the second person in a hosptial consulting room was also studied. Reserachers used breathing thermal manikin and a personal exaust unit that is integrated to a seating chair, the exhaust grill was fixed at different locations (above occupant head, shoulder level, near breathing zone) with different exhaust flowrates of up to 10 l/s. These devices not only helped in removing the contminants from breathing zone, but also helped to pull more PV air towards occupant. Several other studies conducted on PV in combination with mixing ventilation , displacement ventilation with supply temperatures ranging from 20°C to 28°C and flowrates varying from 0 to 20 l/s. the impact of personal fan flow in propagating PV flowrate across the occupant micro thermal environment was also examined and proved to improve the reach of cool air to the occupant maximum body area, the chair integrated PV impact on rising thermal plumes and influence on inhaled air quality were studied in controlled chamber studies. The performance of different types of PV systems in terms of achieving comfort, high air quality, energy consumption was evaluted and compared with previous studies.

Indoor air quality evaluation under PV

Maintaining healthy indoor air quality in workspaces became extremely important, especially in confining the airborne cross contamination in the space. IAQ is crucial factor in designing the PV in office setting. The human respiratory activities like coughing, sneezing, inhalation, exhalation, bio effluent release in the air, VOCs, other harmful gases release into the space deteriorate the air quality and lead to greater cross contamination risks.

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Therefore, design of PV in occupant micro environment needs to consider several factors in order to confine the transmissions. Primarily, the design of air terminal device, diffuser diameter, front shape and pattern, supply conditions and its flexibility to adjust accroding to the user's preference in terms of positioning and height of its placement are essential. Various types of PV systems have to be coupled with the background air conditioning systems. when PV is placed at head level infront of the desk, the supply nozzles target towards the upper body parts, thus convective flow around the human body needs to break to insert the fresh air supply.

Melikov (2004) discussed on personalized venitlation design principles, emphasized on key parameters and recommended optimum supply conditions of 23°C to 26°C temperature with a minimum targeted velocity of 0.3 m/s to penetrate the PV jet through surrounding room air. Consequently, authors (Kaczmarczyk et al. 2004) compared the PV system performance at 20°C, 23°C with mixing ventilation system at 23°C and 26°C temperature in terms of perceived air quality, comfort, and the effects of sick building syndrome and found that PV singificantly improved the conditions than the mixing ventlation system alone case.

The modelling of particle dispersion is effectively studied using CFD simulations along with comfort chamber studies. According to (Zhao & Guan 2007) study, for particles size smaller than 2µm, a strong personalzied airflow is effective in diluting. Pollutants investigation and transmission under different background air conditioning systems are studied with five types of air termina devices and evaluted using an index called ventilation effectiveness. The inhaled air quality is being assessed with the index called personalized exposure effectiveness introduced by Melikov, (2004). The assessment of fresh air in the breathing zone is evaluated using an index called personalized exposure effectiveness (PEE). The impact of convective forces around the human body, air mixing effect and vertical temperature gradient in case of displacement ventilation and underfloor air distribution (UFAD) with PV was also studied (Li et al. 2010) to investigate the airflow patterns. the supply air temperature and flowrates when comparing with UFAD cases, the acceptability rate of air quality and whole-body sensation are positively affected the major findings from these studies highlight the temperature stratification due to air mixing effect leading to inhale the exhaled air in the breathing zone. Similarly, personalized exposure index (PEI) was also used largely. The assessment based on two thermal manikins indicate that high PEI is achieved with the high airflow rate when two persons were facing each other in an office setting. Typically, when PV flowrate is increased from 5 l/s to 8 l/s the expsoure index is improved (Nielsen et al. 2007).

The mathematical models with empirical data emphasized more on building ventilation rate, occupant personal factors and pollutant factors in the space to improve the intake fraction of personalized air which is another evaluation index Habchi et al. (2016) used to assess the fresh air intake by occupant as the intake fraction is defined as *"ratio of mass of pollutants in the inhaled air to the total mass pollutants emitted*". When it comes to controlling the background air pollutant levels from entraining into the occupant breathing zone, the type of ATD selected plays a major role.

Study of convective flow interaction around the human body with differnet combinations of PV nozzles, supply rate, velocity and exhaled air exhaust flowrate is needed to optimally select the supply conditions and couple with mixing ventilation system. Another paper by Katramiz et al. (2020) studied the human breathing interaction with intermittent PV coupled with mixing ventilation, according to author claims, the intermittent flow of PV air and exhaled air caused the contaminants entrainment into the breathing zone. Therefore, the idea of improving personalized flowrate and exhausting occupant exhaled air from breathing zone is crucial to enhance the air quality. Hence, the PV system with personalized exhaust (PE) system carries greater importance.

Thermal comfort evaluation under PV

Occupant thermal comfort was evaluated under PV at segmental and whole-body level thermal sensation. Transient models were developed and coupled with bioheat models to predict the core and segmental temperatures to assess the overall comfort. In a research by (Al Assaad et al. 2018) developed a transient mathematical model for heat and contaminant concentration prediction, authors coupled the displacement ventilation with PV system for optimal comfort and energy savings. A study by (Melikov et al. 2013) in their findings proved that under personalized ventilation, the conditions up to 28°C, 70%RH improved the perceived air quality, and thermal sensation to a greater level. A study (Chen, Raphael & Sekhar, 2012) claimed that under PV temperatures 20, 23, 26°C and background room air temperatures 23 and 26°C revealed that 90% of the subject's thermal sensation votes were within the acceptable range due to PV ATD adjustment options. Traditionally, the PMV based comfort evaluation and dissatisfaction levels calculated using (PPD) method, the multi node-based comfort evaluation is carried using various types of physiological models like Fiala, Tanabe, Stol wijk, UC Berkeley and ThermoSEM. Authors in previous studies carried comfort assessment using one of these physiological models of thermal manikin to estimate segmental and whole-body comfort. most of the studies Lipczynska et al. (2015) used and adopted manikin based equivalent temperature (MBET) to determine the segmental comfort, a segmental level sensation is a function of mean skin, local skin and core temperature and rate of change. the MBET can be obtained by calculating area weighted average of the body segment and whole body (Halvoňová & Melikov 2010).

$$MBET = tsk_{,i} - \frac{Q_{t,i}}{h_{cal,i}} \qquad (1)$$

Where= tsk is the skin temperature, $Q_{t,i}$ = is the sensible heat loss and $h_{cal,i}$ is the heat transfer coefficient.

Similarly, the draught discomfort is measured using draught rate discomfort (DR) index.

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The higher PV flowrate achieved more cooling effect at the upper body parts with an initial low turbulence velocity. The higher MBET is observed with the low turbulence supply. The upper body parts like head, neck, chest achieved cooling mostly by PV while the lower body parts achieved comparatively low cooling. Thus, using a secondary ATD below the table or a small fan suggested, the individual controls over flowrate helps the occupants to adjust the cooling and flexible arm of ATD allows the flow through chest to lower body parts.

PV system performance

Personalized ventilation system performance depends on various factors, primarily, the type of ATD and its effective delivery of air jet in breathing zone. Improving PV jet core region with increased diameter with round diffusing pattern is better in supplying air in its maximum size, the higher the diameter holes make the flow less impact.

The ability of PV can be evaluated in terms of removing pollutant concentration in inhaled air, and the difference in manikin based equivalent temperature for comfort for whole body comfort mainly (Al Assaad et al. 2018). The inhaled air quality is evaluated using an index called personalized exposure effectiveness (PEE) or normalized concentration, which is defined as the concentration of PV air in the inhaled air presented by (Melikov, 2004). It is extremely difficult to control the rising thermal plumes around the occupant body, thus operating PV system in assistance with desk fan helps to control the convective flows and bio-effluents. The energy consumption of the PV system is another crucial indicator of PV performance, comparing PV with traditional total volume ventilation systems, the energy consumption will give a clear picture. The PV has a potential in providing the high ventilation, and comfort at the same time, but if not operated properly with occupancy schedules and controls, PV can consume high energy, further, operating with slightly high background air temperatures and minim ventilation rates were suggested in literature to reduce the load on secondary air conditioning system. It was shown in literature studies that PV operating with MV system has maximum benefits compared to displacement ventilation, chilled ceiling system and underfloor ventilation system. Combining PV system with low energy cooling systems like evaporative cooling, liquid desiccant cooling, applying various control strategies and operating PV only when occupants are present in the space, informing the occupants their comfort range based on their past data, encouraging them to use PV at accurate levels can help to achieve better energy savings.

$$\varepsilon = \frac{C_e - C_i}{C_e - C_{IPV}} \qquad (2)$$

Where, $C_{I,0}$ = Concentration of pollution in inhaled air without PV, C_I = Concentration of pollution in inhaled air and C_{PV} = Concentration of pollution in personalized air.

PV system performance

Research gap for future framework

Apart from the technical challenges and control algorithms integration, lack of comprehensive field data on PV performance under real dyanmic conditions is yet to explore. Further, subjective adaptability, behaviroal pattern, differnet age people, physiologies need to be investigated. There is still more scope in investigating PV under differnet scenarios, its operation with schedules and controlling strategies etc. In addition, coupling PV with low energy cooling systems like liquid desiccant systems are more promising to improve indoor air quality.

Future of Personalized ventilation

PV performs superior to many traditional air distribution (mixing ventilation, displacement, underfloor air distribution systems) systems in terms of providing occupant centric thermal environment and energy savings. Previous studies on human responses, manikin-based experiments together with sensory measurements confirm the same.

Despite the significant developments and research results, PV system has not been able to adopt widely in practice, this is due to large inconsistencies present in the realistic environment. there are scaling gaps in terms of its efficient operation, controls and challenges involved in technical aspects. Also, there are no design guidelines on PV operation. Therefore, the necessity in examining these aspects, can give a better idea to implement in practice.

Further scope of the work can be extended to PV performance in field studies, different operating strategies and controls for better energy savings. Capturing an individual's comfort preferences over a longer duration is key to categorizing occupants with their optimum personalized ventilation (PV) operating conditions. More accurate data on factors like occupant adaptability, behavioural patterns, personal adjustments, and differences among individuals can significantly help to improve the PV control algorithms.

Discussion

Personalized ventilation is an efficient way to deliver clean and cool air close to occupant breathing zone, it was found that the performance of the system depends on several aspects. Previous research studies explored the PV system under different operating conditions and acceptance levels of thermal environment. Initially, studies targeted to improve the thermal comfort and used humans and manikins as testing subjects to evaluate PV system ability. CFD prediction techniques were adopted largely to assess the airflow behaviour under different supply conditions. At the same time, the air quality was also given highest priority. Since then, the number of studies coupling with mixing and displacement ventilation were examined largely, the energy saving potential with these air distribution methods are realized after several years.

Conclusion

This paper through systematic review, evaluates the progress on personalized ventilation (PV) system over

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several years, discussed the developments in its key component, the air terminal devices (ATDs), PV impact on occupant micro thermal environment, comfort, inhaled air quality and contaminants distribution, air quality evaluating parameters. Personalized ventilation study key developments were highlighted in the experimental and CFD simulation studies and in comfort chamber studies.

A central theme of the PV's contribution is its ability to provide segmental and overall thermal comfort. A manikin based equivalent temperature (MBET) equation is used to calculate the segmental comfort. Furthermore, PV plays a crucial role in reducing the airborne cross contamination risks. Occupant respiratory activities, bio effluents compromise the air quality, the effectiveness of PV jet in delivering unmixed air is a major factor in improving ventilation efficiency.

The assessment of inhaled air quality under PV in occupant breathing zone is evaluated using an index called personal exposure effectiveness, personalized exposure index, and intake fraction. The paper also highlights the need of more field studies, PV performance under different strategies, scenarios, development of control algorithms. Further, the scope of future research lies in exploring PV combining with low energy cooling systems like liquid desiccant system. Overall, significant achievements over the years presented in the study to enhance the understanding and point out the present state of research in the domain.

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