Flow impact of an air conditioner to portable air cleaning

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ABSTRACT

In order to reduce indoor pollutant exposure, people become increasingly interested in portable air cleaning devices, which can be positioned with flexibility. Such purification devices usually discharge cleaned air with strong momentum, which can interrupt indoor airflow created by air-conditioning units. If a well-organized air circulation to a portable air cleaner is not achieved, indoor air purification cannot be fully ensured. This study has used both measurement and computational fluid dynamic (CFD) modeling to investigate the flow interaction between an air conditioner and a portable air cleaner to purify indoor gaseous pollutants. A workshop environment conditioned by an air conditioner and cleaned by a portable air cleaner was mimicked in an environmental chamber to obtain data for validation of a CFD program. Then CFD was applied to evaluate factors that may affect air purification including: positioning of the air conditioner and air cleaner, air conditioner diffuser types, air-conditioning cooling or heating running mode, and location of pollutant sources. The study finds the simulation results are in good agreement with the corresponding experimental data. The positioning coordination of an air conditioner and an air cleaner and selection of air

1
1 conditioner diffuser types shall assure a good air circulation cycle to the air cleaner to
2 improve air purification efficacy. In addition to the cleaner effectiveness, it is also
3 recommended to evaluate an air cleaning device in terms of the absolute pollutant
4 concentration, if the portable air cleaner is under the interaction of an air conditioner and the
5 local performance data are interested.

6 **Keywords**: Portable air cleaner; Air purification; Flow interaction; Contaminant distribution;
7 Measurement; CFD

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1. **Introduction**

Indoor air quality (IAQ) is always threatened by various releases of airborne pollutants. In
order to maintain IAQ in an acceptable level, three typical control means are commonly
applied, including elimination or isolation of pollutant sources, ventilating indoor spaces, and
purification of contaminated air. As the third category of IAQ control technique, portable air
cleaners are getting more and more popular with flexibility in positioning and running on
demand. Portable air cleaners may be capable to remove both gas- and particle-phase indoor
pollutants. The mechanism for pollutant removal is typically as drawing air through various
filter media, electrostatic precipitation, air ionization, and finally collecting particles; whereas
for gas-phase species, sorption and chemical reaction are mostly used [1]. The survey from
the Association of Home Appliance Manufacturers (AHAM) shows 30% of households in
developed countries like the US use the portable air cleaners [2]. It is therefore necessary to
extensively investigate the related issues with respect to portable air cleaning to ensure the
targeted air purification efficacy can be acquired.
There are three key elements that affect air cleaning efficacy including room size, clean air delivery rate (CADR), and particle sizes if concerned pollutants are in particle phase [1]. CADR is proposed to describe the equivalent volume of clean air provided to the space by an air cleaner that can actually dilute indoor pollutants. Numerous researches have been carried out on air cleaners study, such as on mechanism [3], on calculation of the CADR [4, 5], on definition of cleaning effectiveness [6], on performance of air cleaners themselves [5, 7], and on impacts to indoor air conditions [8, 9]. Most published researches are typically based on the assumption of well-mixing air condition, which means no matter where the portable air cleaners are located the cleaning efficacy is not impacted. However, the perfect air mixing may not be valid in many situations as revealed by Kang et al. [10] and Novoselac and Siegel [11] recently, where they found different positioning of portable air cleaners can produce difference in air cleaning effectiveness of an apartment up to a factor of three. Similar conclusions were also obtained earlier by Miller-Leiden et al. [12], where they pointed out air flow configuration through air cleaners and their placement within the room is important, by influencing room air flow patterns and the spatial distribution of concentrations. In addition, portable air cleaning devices are usually equipped with fans to provide driven movement of air motion and also to distribute clean air appropriately to an indoor space. The very strong momentum discharged out during operation can interrupt indoor airflow pattern created by air-conditioning units. If a well-organized air circulation to a portable air cleaner is not achieved, a good air purification efficacy cannot be fully ensured. Unfortunately, few researches have focused on this point of study.

This paper has therefore adopted both measurement and computational fluid dynamic (CFD) modeling to investigate the impacts of flow interaction between a portable air cleaning device
and an air-conditioning unit, the positioning of the devices, and other issues in resulting flow pattern change to efficacy of indoor air purification.

2. CFD modeling of flow interaction

To model the flow interaction between an air-conditioner and an air cleaner, a set of partial differential governing equations shall be solved. These equations are usually casted into the general scalar format according to the Reynolds-averaged Navier-Stokes (RANS) CFD theories as,

\[
\frac{\partial}{\partial t}(\rho \phi) + \frac{\partial}{\partial x_j}(\rho u_j \phi) = \frac{\partial}{\partial x_j} \left( \Gamma_{\phi,\text{eff}} \frac{\partial \phi}{\partial x_j} \right) + S_\phi
\]  

(1)

where \( \rho \) is the air density, \( \phi \) is a scalar variable, \( t \) is time, \( u_j \) is the velocity component in three directions \( (x_j, j=1,2,3) \) of a Cartesian coordinate system, \( \Gamma_{\phi,\text{eff}} \) is the effective diffusion coefficient, \( S_\phi \) is the source term. With different values of \( \phi \), the above equation can represent continuity, momentum, energy, turbulence and contaminant concentration equations.

We have chosen the renormalization group (RNG) \( k-\varepsilon \) turbulence equations model proposed by Yakhot et al. [13] for turbulence modeling. Chen [14] and Zhang et al. [15] have compared a couple of eddy-viscosity models in simulating indoor airflow and concluded the RNG \( k-\varepsilon \) model behaves generally best.

Three distinct numerical solution techniques are available for CFD: finite difference, finite element, and finite volume method. The finite volume method is the most well-established and widely used in commercial CFD codes due to a clear relationship between the numerical
algorithm and the underlying physical conservation principle. This investigation has thus employed the finite volume method. The finite volume method divides the domain into many CFD cells, and then integrates the governing equations over all CFD cells (control volumes). The integral equations are discretized with a variety of finite-difference-type approximation that converts the integral equations into a system of algebraic equations. The solution for boundary cells can be simplified with the standard wall function method. Finally, these algebraic equations are solved with suitable solvers via the semi-implicit method for pressure-linked equations (SIMPLE) algorithm.

With its high efficiency and relatively low cost, CFD modeling has been well applied to study indoor air flow and pollutant dispersion. However, the modeling uses a significant amount of assumptions, it is therefore necessary to validate CFD modeling of flow interaction between a portable air cleaner and an air conditioner with measurement data to ensure reliable results can be obtained.

3. Validation of a CFD program

The validation procedure should include both flow and pollutant dispersion as such is encountered when investigating the air cleaning devices. Because the focus of this paper is on modeling of flow interaction between an air conditioner and an air cleaner, only flow distribution has been extensively measured and compared with CFD modeling. However, the authors have reported the validation of pollutant dispersion elsewhere [16], with good agreement between CFD simulation of a contaminant dispersion and the measurement. Hence, the following only briefs comparison in flow motion between measurement and CFD.
Fig. 1. A workshop environment for CFD validation: (a) the test site, (b) schematics of the test case (all dimensions in meters), (c) sketch of the air conditioner, (d) sketch of the air cleaner.

The flow measurement has selected a workshop environment with cooling provided by a cabinet type of air conditioner and the room air cleaned by a portable air cleaner as shown in Fig. 1. The workshop environment is mimicked in an environmental chamber with dimensions of 7.5 m × 5.6 m × 3.6 m. There are four persons inside the room simulated by box-shaped manikins who are doing moderate intensity of an assembling work. Each heat box
in front of a person is to represent the heat generation from the assembling line. There is no other furnishing or appliance except for four fluorescent lamps mounted on the ceiling to provide illumination. The air cleaner and air conditioner are positioned on the floor against the northern and southern wall, respectively, in the middle. The air conditioner supplies air through the rectangular bilateral vents located on the air-conditioner upper front corners, as shown in Fig.1(c), and the air is returned to the slot openings just beneath. Similarly, as shown in Fig. 1(d), the air cleaner discharges the cleaned air from the rectangular vent at the top, and extracts the contaminated air at the bottom intake.

![Figure 2(a)](image1)

![Figure 2(b)](image2)

Fig. 2. Smoke visualization of flow paths for momentum sources: (a) cleaned air discharge from the portable air cleaner, (b) conditioned air discharge from an air conditioner bilateral vent (top view).

A three dimensional ultrasonic anemometer (type DA-650&TR-92T; Kaijo Sonic, Tokyo, Japan) was applied to measure velocity and temperature distributions inside the space. The accuracy of the ultrasonic anemometers for velocity components is 0.005 m/s with 1% error, while for temperature is 0.025 ℃ within 1% error. This anemometer was also applied to measure jet flow conditions from the portable air cleaner and the air conditioner as the boundary information provided to CFD modeling. To visualize the jet directions, we have also photographed the flow paths after introducing smokes into the air intake of both devices.

Fig. 2(a) has clearly shown that the high-momentum air is discharged upwards from the air
cleaner in an angle with the -Y coordinate of around 70°. Fig. 2(b) illustrates that the jet from one of the air-conditioner bilateral vents. The air is discharged in an angle of 66.5° with the Y-coordinate. Table 1 summarizes all boundary conditions for the validation case, where the averaged solid surface temperatures were taken by many temperature recorders.

Table 1

<table>
<thead>
<tr>
<th>Item</th>
<th>Value</th>
<th>Item</th>
<th>Value</th>
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</thead>
<tbody>
<tr>
<td>Conditioned air supply velocity</td>
<td>4.85m/s</td>
<td>Surface temperature of manikin trunks</td>
<td>32°C</td>
</tr>
<tr>
<td>Conditioned air supply angle with Y</td>
<td>±66.5°</td>
<td>Lighting temperature</td>
<td>40°C</td>
</tr>
<tr>
<td>Conditioned air supply temperature</td>
<td>17.5°C</td>
<td>East wall temperature</td>
<td>21.7°C</td>
</tr>
<tr>
<td>Cleaned air supply velocity</td>
<td>4.7m/s</td>
<td>West wall temperature</td>
<td>21.6°C</td>
</tr>
<tr>
<td>Cleaned air supply angle with +Z</td>
<td>20°</td>
<td>South wall temperature</td>
<td>22.0°C</td>
</tr>
<tr>
<td>Cleaned air supply temperature</td>
<td>20.5°C</td>
<td>North wall temperature</td>
<td>21.9°C</td>
</tr>
<tr>
<td>Surface temperature of heated boxes</td>
<td>45°C</td>
<td>Floor temperature</td>
<td>20.6°C</td>
</tr>
<tr>
<td>Surface temperature of manikin heads</td>
<td>34°C</td>
<td>Ceiling temperature</td>
<td>21.6°C</td>
</tr>
</tbody>
</table>

The commercial CFD software, FLUENT (http://www.fluent.com), was used for solving flow and temperature distribution inside the room. The geometry domain was created with GAMBIT (http://www.fluent.com), and then suitable meshes were generated with appropriate schemes. The grid size near the air discharge regions is around 0.01m, while in the other regions the grid distance is about 0.1m. A size function was applied to change grid size gradually therein. A total of 675,269 grids with combined hexahedral and tetrahedral cells were generated. Then the RNG k-ε model with the standard wall function was applied for
turbulence modeling. The continuity and momentum equations were thought to reach convergence when the ratio of the sum of the mass gain and loss on all boundary conditions to the overall mass gain in the room is less than 1.0e-6. In a similar method the convergent ratio limit for energy is 1.0e-3.

![Diagram](image)

Fig. 3. Comparison of the flow pattern measured (bold vectors in red color) and computed by CFD (light vectors in black color): (a) in the section along one air discharge vent from the air conditioner, (b) in the section 10 cm above the floor, (c) in the section of the mid-X plane.
Fig. 3 shows the comparison of the airflow distribution in three typical sections as highlighted in each sub-figure on the left. In the section perpendicular to one air-conditioner air supply vent as shown in Fig. 3(a), it can be seen although the air is supplied horizontally from the air conditioner, the supply jets drop towards to the floor as can be captured well by CFD simulation. This is caused by lower temperature of the supplied air and hence larger density as comparing to the surrounding air. It seems that the jet decays faster in the measurement test than in the CFD simulation. Air movement in other parts of the room is relatively weak but some recirculated flows can be observed around the jet surroundings and also on the floor.

For further illustration of the flows movement after reaching the side and opposite walls, Fig. 3(b) shows the flow distribution on the plane 10 cm above the floor. It clearly shows after the jets touch the wall, they are divided into two main streams on the floor. One stream flows towards to the portable air cleaner; the other stream flows towards to the air conditioner because the both devices extract air for recycling. The major flow features computed by CFD agree well with measurement, but velocity magnitudes are somewhat larger than the measurement counterparts.

The recirculated air to the portable air cleaner is then cleaned therein by filtration and ionization, and then discharged out with very strong momentum upwards towards to the ceiling as shown in Fig. 3(c). Because the strong jets are intercepted by the ceiling, flows in other regions of the mid-X section are not very strong, which prevents draught risks to occupants. Discrepancy in velocity magnitudes with measurement can also be found, although there is minimal difference in the whole major flow features.

With the above validation in flow modeling with a portable air cleaner and the
aforementioned pollutant modeling in our previous work [16], this study concludes the CFD program with the RNG $k$-$\varepsilon$ model can be applied to investigate the flow interaction to indoor air purification with reasonably good accuracy.

4. Flow impacts to portable air cleaning

With the validated CFD program, the CFD was further applied to evaluate the flow interaction to portable air purification, the resulted flow and pollutant concentration distribution, as well as the air cleaning effectiveness. Investigated factors that may impact flow pattern and thus indoor air purification include: positioning of an air conditioner and a portable air cleaner, air conditioner diffuser types, cooling or heating running mode, and location of a pollutant source.

Table 2

<table>
<thead>
<tr>
<th>Case No.</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
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<tr>
<td></td>
<td>Scenario 2*</td>
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<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
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<tr>
<td></td>
<td>Scenario 3*</td>
<td>✓</td>
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<td></td>
<td></td>
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<tr>
<td>Air conditioner diffuser</td>
<td>Bilateral vents</td>
<td>N/A</td>
<td>✓</td>
<td>✓</td>
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<td></td>
</tr>
<tr>
<td></td>
<td>Grid grille</td>
<td>N/A</td>
<td></td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Heating or cooling mode</td>
<td>Cooling</td>
<td>N/A</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td></td>
<td>Heating</td>
<td>N/A</td>
<td></td>
<td>✓</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Human exhalation</td>
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<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td></td>
<td>Floor</td>
<td></td>
<td></td>
<td></td>
<td>✓</td>
<td></td>
</tr>
</tbody>
</table>

*Note: Scenario 1 represents that only the air cleaner is on while the air conditioner is off; Scenario 2 represents that the air cleaner and the air conditioner are positioned opposite to each other; Scenario 3 represents that the both devices are located perpendicularly.
Fig. 4. Schematics of simulation cases: (a) for Case 1 and 2, (b) for Case 3, (c) for Case 4 and 5, (d) Case 6.

4.1 Case settings

Totally six simulation cases are designed, with scenarios described in Table 2, and layouts illustrated in Fig. 4. In these cases, Case 1 is proposed to show the flow and pollutant distribution when only the air cleaner is on while the air conditioner is off. Such case can only be applicable for a while when indoor temperature condition is acceptable. This case serves as...
a base for comparison to illustrate the extent of flow interaction from an air conditioner to indoor air purification. Cases 2 and 3 are designed to investigate how the positioning of an air conditioner with an air cleaner to indoor air cleaning. Cases 4 and 5 study the impacts of air-conditioner diffuser type and the heating or cooling running modes. In Case 6, there is a pollutant released from the under-floor source rather than from the human exhalation as comparison with the previous five cases.

These cases hold the same flow rates both for the air cleaner and the air conditioner regardless of different supply methods or temperature conditions. The flow conditions of the air cleaner are the same for all the cases, as identical with that in the validation process as shown in Table 1; but supply temperature varies because it is dependent on the room air temperature (see Table 3). The flow condition of the air conditioner in Cases 2 and 3 is the same to the validation case. Although air supply velocities in Cases 4-6 are less than those in Cases 2 and 3 because of larger supply area in the grid grille diffuser, the mass flow rates are the same. An identical intensity of tracer gas contaminant is introduced to the mouth and nose of each person to represent the human exhalation effect in Cases 1-5. Case 6 assumes a pollutant is released from a spot on the carpet while there is no pollutant from the human exhalation. Particle-phase pollutant is not studied as a discrete phase from fluid in this paper for simplicity. Many researchers modeled indoor particle dispersion as passive tracer gases when the particle diameter is in the submicron range such as 0.14 μm [17], 0.7 μm [18] and 1 μm [19], and found in general good agreement with the corresponding experimental test [17-18]. However, for particles as large as 10 μm the tracer gas model may only be able to predict the general tendency of the concentration distribution, while the specific concentration values at some particular locations can be over predicted by trifold as comparing to the measurement.
[20]. Therefore the tracer gas models shall be sufficiently valid to represent the gas pollutants and particle-phase pollutants in the submicron range.

Table 3

Temperature boundary conditions in the simulation cases

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Case 1</th>
<th>Case 2-4, 6</th>
<th>Case 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conditioned air supply temperature (°C)</td>
<td>N/A</td>
<td>19</td>
<td>30</td>
</tr>
<tr>
<td>Cleaned air supply temperature (°C)</td>
<td>24.5</td>
<td>24.5</td>
<td>21.5</td>
</tr>
<tr>
<td>Ceiling temperature (°C)</td>
<td>25</td>
<td>25</td>
<td>22</td>
</tr>
<tr>
<td>Floor temperature (°C)</td>
<td>25</td>
<td>25</td>
<td>20</td>
</tr>
<tr>
<td>South wall temperature (°C)</td>
<td>27</td>
<td>27</td>
<td>13</td>
</tr>
<tr>
<td>Other walls temperatures (°C)</td>
<td>27</td>
<td>27</td>
<td>20</td>
</tr>
</tbody>
</table>

To evaluate how indoor flow influences air cleaning, both distribution of a dummy pollutant concentration and the relevant air cleaning effectiveness is compared. All concentrations are normalized by the values at the recycled air intake of the air cleaner. In addition, the portable air cleaner is assumed to be capable to remove all pollutants, and hence the delivery air is free from pollutants with a CADR of 0.0853 m³/s. The air cleaning effectiveness [12], H, is defined as,

\[ H = 1 - \frac{C_{\text{cleaning}}}{C_{\text{nocleaning}}} \]  

(2)

where \( C_{\text{cleaning}} \) is the local pollutant concentration when the air cleaner is in operation, while \( C_{\text{nocleaning}} \) is the local concentration when turning off the cleaner.
Again, FLUENT and GAMBIT were applied to simulate the above cases. The mesh generation and solution scheme are similar to those in the validation procedure and hence are not repeated for brevity.

Fig. 5. Airflow and pollutant distribution when the air-conditioner is off, i.e., Case 1: (a) airflow pattern in the mid-X section, (b) normalized pollutant distribution on the plane 1.22 m above the floor.

4.2 Air cleaning without running the air conditioner

When the air conditioner is off, the room air motion is only driven by the air cleaner. Fig. 5(a) shows the flow distribution in the mid-X section of the room. The cleaned air is discharged under very high momentum towards to the ceiling, and then the flow is mainly divided into two streams. One stream goes forward along the ceiling and falls down at the opposite wall; the other stream drops into the recirculated region of the cleaner against the wall. Inside the room, the flow mixes very well. This is also indicated by the normalized pollutant distribution on the plane above the floor of 1.22 m, as shown in Fig. 5(b), with a very uniform distribution. The plane coincides with the inhalation height of the seated persons. The more or less identical for pollutant concentration (approaching 1.0) at the inhalation height with that at the
cleaner intake, again confirms the highly mixed condition is created inside the space. Therefore, it concludes that the cleaned air is not very efficiently delivered to the inhalation regions when the air-conditioner is off.

Fig. 6. Comparison of the normalized pollutant concentration and air cleaning effectiveness on the plane 1.22 m above the floor: (a) concentration when the air conditioner and air cleaner are oppositely located, i.e., Case 2, (b) air cleaning effectiveness for case 2, (c) concentration when the air conditioner and air cleaner are perpendicularly located, i.e., Case 3, (d) air cleaning effectiveness for case 3.

4.3 Positioning of the air conditioner and air cleaner

When turning on the air-conditioner, the discharge flow from the conditioner also drives the room air motion. Two different scenarios for positioning of the air conditioner and air cleaner
are studied: one is Case 2, where the both devices are located oppositely; the other is Case 3, where the both devices are positioned perpendicularly. Fig. 6 shows the comparison of normalized concentration distribution and air cleaning effectiveness on the plane 1.22 m above the floor. The pollutant concentration in Case 2 (Fig. 6(a)) is generally lower than that in Case 3 (Fig. 6(c)) by about 10%, which means when the air conditioner and air cleaner are oppositely located it aids to distribute the cleaned air to the human breathing region. This is also indicated by the air effectiveness as shown in Fig. 6(b) and (d), where the air effectiveness is slightly larger when the air conditioner and air cleaner are oppositely positioned in Case 2. One may also find in Case 2 the effectiveness near the occupants approaches 0.9, which shows the cleaned air is effectively delivered to dilute the pollutants nearby. However, even under such highly effective dilution the pollutant concentration near the occupants is still much larger than the other region as shown in Fig. 6(a). This shows a large air cleaning effectiveness does not necessarily guarantee the absolute low concentration of pollutants after being cleaned at a specific spot, because the cleaning effectiveness is subject to both the concentration before cleaning and after cleaning according to Eq.(2). Only when $C_{no\ cleaning}$ is a constant everywhere does the lower $C_{cleaning}$ lead to the larger $H$. From the human health perspective, one may wish to create an indoor environment with the inhaled pollutant concentration as low as possible. While from the air cleaning efficacy perspective, the cleaner effectiveness shall be as large as possible. It is therefore recommended to evaluate an air cleaning device in terms of both the cleaner effectiveness and also the absolute pollutant concentration after being cleaned, if the portable air cleaner is under the interaction of an air conditioner.

A closer look at the airflow pattern for both cases finds that in Case 2 a good air circulation cycle is formed, as shown in Fig. 7(a), where the jets from the air conditioner go to both sides,
after touching the both side walls (the east and west walls), the streams flow towards the middle of the opposite wall (the north wall) where the portable air cleaner is located and the air is extracted for recycling. Such is also illustrated in Fig. 3 when validating the flow interaction modeling. However, the flow feature is not very evidently characterized when the both devices are perpendicularly located as shown in Fig. 7(b). One can also find there is no significant difference between the contaminant distribution when the air-conditioner is off (Fig. 5(b)) and when the air-conditioner and cleaner are perpendicularly located (Fig. 6(c)). It means in such case, the air conditioner only helps mix the room air rather than aiding to deliver the cleaned air appropriately. Therefore, the air-conditioner and cleaner shall be oppositely located to improve the distribution efficiency of the cleaned air.

Fig. 7. Comparison of the flow patterns on the planes 1.22 m above the floor: (a) when the air conditioner and air cleaner are oppositely located, i.e., Case 2, (b) when the air conditioner and air cleaner are perpendicularly located, i.e., Case 3.

4.4 Types of the air conditioner diffusers

With the previous finding, the following compares the impacts of diffuser types to air purification when the conditioner and cleaner are oppositely located, i.e., the comparison of Case 2 and Case 4. Fig. 8 (a) shows the pollutant distribution still on the plane 1.22 m above
Fig. 8. Simulation results when using the grid grille diffuser at the cooling mode, i.e., Case 4: (a) pollutant concentration on the plane 1.22 m above the floor, (b) air cleaning effectiveness on the plane 1.22 m above the floor, (c) flow pattern in the mid-Y section.

the floor when air is supplied horizontally from the grid grille. The peak concentration is only at around the occupants where the pollutants are released. As compared with Fig. 6(a), it can be seen that when using the grid grille diffuser, the ambient concentration at the inhalation height is lower around 10% than that with the bilateral vents. The cleaner effectiveness as shown in Fig. 8(b) is also comparable or 5% larger than that in Fig. 6(b). In the central part of the room, both the pollutant concentration and cleaner effectiveness are relatively low. This is because this region is under pour of the air conditioner jets as shown in Fig. 8(c), and hence the conditioner supply air exerts dominant impact. The conditioner supplies the air mixture of the recirculated air together with the outside air that can be sufficiently clean. The horizontal
air supply from the grid grille helps to deliver the cleaned air to the occupants. One can also find a better air circulation cycle is created when the grid grille diffuser is applied. As shown in Fig. 8(c), the cleaned air from the cleaner is supplied upwards to the ceiling, flowing against the ceiling, and finally returns to the air conditioner; on the other hand, the recycled air after cooling down in the conditioner is thrust directly to the beneath of the air cleaner, and hereafter a full air cycle is formed. In this occasion, one shall be careful there might be draught risks to the occupants with cool air to the head or ankle level. Nevertheless, these occupants are doing assembling work at a medium metabolic rate, and hence they may prefer a slightly cool air environment.

4.5 Heating or cooling modes of the air conditioner

The above reveals the air conditioner with the grid grille has good performance when supplying cool air. How about when the air conditioner supplies warm air in winter season? Case 5 is designed to answer this question. To be comparable with Case 4, the designed indoor temperature is the same, so envelopes in Case 5 hold low temperature as shown in Table 3 in the winter season. Fig. 9(a) shows the pollutant concentration distribution again at the inhalation height for seated persons, where as compared with Fig. 8(a), under the heating mode the concentration is generally higher by around 5-10%. The cleaner effectiveness (Fig. 9(b)) is also slightly lower than that in Fig. 8(b). This lower effectiveness is caused by warm air (30°C) which is supplied in horizontal direction. Owing to this fact, the airstreams are going upwards, towards the ceiling as shown in Fig. 9(c) due to buoyancy effects. The jets from the air cleaner are also thrust to the ceiling, and therefore they collide and do not promote the formation of air circulation cycle to help distribute the cleaned air to the occupants.

![Simulation results](image)

**Fig. 9.** Simulation results when the grid grille diffuser is applied at the heating mode, i.e., Case 5: (a) pollutant concentration on the plane 1.22 m above the floor, (b) air cleaning effectiveness on the plane 1.22 m above the floor, (c) flow pattern in the mid-Y section.

**4.6 Location of pollutant sources**

Indoor pollutant sources may not be always from the occupant exhalation. As a representation, this study has selected a pollutant released on the floor carpet, i.e., Case 6, to investigate different locations of pollutant sources to indoor air cleaning. **Fig. 10(a)** presents the pollutant distribution still on the plane 1.22m above the floor. The whole distribution is relatively uniform, except in the middle region between the right two persons where the concentration is much lower. By comparing with **Fig. 8(a)**, the resulting ambient pollutant concentration is slightly lower when the source is from the floor, although the difference is not significantly
large. And the cleaner effectiveness (Fig. 10(a)) is higher than that shown in Fig. 8(b). Again, this may be explained from the flow distribution as shown in Fig. 8(c). By following the air stream extracted by the cleaner on the floor, the pollutant just after being released on the floor can be efficiently cycled for cleaning, and hence it can prevent the pollutant from being dispersed too far away. If a pollutant source is released somewhere else, one can also imagine there should be no big difference with that shown in Fig. 8(a), because the indoor air is generally well circulated.

Fig. 10. The normalized pollutant concentration and air cleaning effectiveness on the plane 1.22 m above the floor when a pollutant source is from the floor carpet, i.e., Case 6: (a) concentration, (b) air cleaning effectiveness.

5. Conclusions

With a validated CFD program in investigating flow interaction between an air conditioner and a portable air cleaner for indoor air cleaning, the study finds:

1. Positioning of an air conditioner and a portable air cleaner (momentum sources), air conditioner diffuser types selected, and air-conditioner cooling or heating running mode used, pose significant roles in impacting indoor air cleaning.
2. The positioning of momentum sources and selection of air conditioner diffuser types shall assure a good air circulation cycle to the portable air cleaner to enhance the effective delivery of the cleaned air.

3. Air supplied horizontally from the grid grille is easier for coordinating with a portable air cleaner to obtain better air cleaning as compared with the bilateral slot vents based on this study.

4. It has also better air purification efficacy during the air conditioner running under the cooling mode as compared with the heating mode.

5. The location of pollutant source does not much impact to air cleaning when indoor air is well circulated. However, the pollutants released at the low level of a room such as from the floor are found being slightly easier extracted and removed by a portable air cleaner.

6. In addition to the cleaner effectiveness, it is also recommended to evaluate an air cleaning device in terms of the absolute pollutant concentration, if the portable air cleaner is under the interaction of an air conditioner and the local performance data are interested.

It should point out this paper has modeled only gases pollutants for simplicity. The tracer gas models shall be sufficiently valid to depict the gas pollutants and particle-phase pollutants in the submicron range.

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