Evaluation of Ventilation Metrics for Naturally Ventilated Spaces from Flow Patterns Generated in a Water Table Apparatus

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Abstract
Wind driven ventilation in buildings is an effective way of diluting the indoor air for maintaining thermal comfort and acceptable indoor air quality. Visualization of wind induced flow patterns in a building with a water table apparatus is a relatively easier method producing instantaneous results. This work focuses on quantifying the flow patterns obtained from the water table experiments in terms of ventilation metrics like percentage of dead spots, absolute ventilation efficiency, and air changes per hour. These metrics will aid in making design decisions in terms of appropriately orienting the building, sizing, and placing of openings in the building.

Introduction
As people in modern technological societies spend 90% of their time in artificial environment (Awbi, 1991), providing a healthy indoor environment is very important. Indoor air is contaminated by human activities and release of pollutants such as carbon dioxide, formaldehyde, odour, particulate matter from materials used in buildings (Sundell, 2004). Indoor building materials like paints, furnishings, adhesives, clothing, and varnishes emit volatile organic compounds (VOC’s) (Jones, 1999). Exposure to these VOC’s has a short and long-term impact on health. Inadequate ventilation also causes Sick Building Syndrome (SBS) (Jones, 1999). It is therefore of vital importance to provide the healthy indoor environment, as it has an impact on the productivity of people (Tham, 2016). As per the ASHRAE 62.1 Standard (2016) Ventilation for Acceptable Indoor Air Quality, fresh air requirement in buildings needs to be calculated based on the number of occupants and per square metre of the floor area of the space. Providing fresh air with dedicated systems contributes to the energy use of the air-conditioning systems. If designed carefully, achieving the fresh air requirement with natural ventilation is cheap and effective. Natural ventilation not only dilutes indoor pollutants (Chenari et al., 2016) but also removes heat from indoor sources depending on the climate. Airflow pattern in a room is considered to be an important parameter while determining thermal comfort (Fulpagare & Agrawal, 2013) and indoor air quality (Sekhar & Willem, 2004). In this context passive strategies like natural or hybrid ventilation decrease the dependence on air-conditioning, which in turn reduce energy use for cooling and ventilating (Jones, 1999). To study natural ventilation in a building, it is important to understand the impact of incoming air into the existing indoor air.

Physical modelling with a smoke chamber or full-scale prototypes give flow patterns using markers and require additional instrumentation to measure quantities for calculating any metrics of effectiveness. The water table apparatus developed uses a displacement approach that gives quick results for flow patterns for different shapes and complicated geometries. It is an apparatus that is easily accessible, cheap and gives instantaneous two-dimensional flow patterns results of inside and outside the building. It helps to analyze natural ventilation in buildings due to wind effect. The potassium permanganate dye solution as it passes through the apertures in the model, provides a scaled simulation of air movement in a building of the same geometry as shown in Figure 1. Study conducted by Edwina Royan G, Vaidya, & Damle (2017) suggested that the flow patterns observed in the water table are in quite agreement with the patterns obtained from the smoke chamber test. This suggests that water table gives accurate results.

Previous studies of the water table approach used qualitative analysis of flow patterns, and quantified the ventilation effectiveness using a simplified binning of pixel values of the photographic documentation. No standard ventilation metrics were calculated, and the relationship between pixel values and dye concentration was not investigated (Mundhe, Damle, Vaidya, & Apte, 2018). This study establishes a method to extract pixel values, calibrate them for concentration, use the data to calculate ventilation metrics and compare the results. This method aids in evaluating simple and complex building configuration for natural ventilation effectiveness, beyond airflow patterns established in previous studies. The photographic data and video recordings obtained from the experiment can be used for comparing the different design options. This will be useful for energy consultants, students, architects, engineers in taking design decisions at different stages of building development.

Figure 1: View of the Water table apparatus with dye solution flowing towards the scaled building model
Methods

To quantify the airflow pattern observed in the water table experiment, initially, a scaled physical building model is simulated in the water table apparatus. The photographic data recorded from the water table experiment are then converted to ventilation metrics. Finally, these metrics are verified for three single rooms having basic window configurations and a complex geometry 3-bedroom apartment by comparing the quantitative results with the visual airflow patterns.

Simulating building model in water table apparatus

For this study three single rooms having different window configurations and a 3-bedroom apartment building is selected. The room with single-sided window configuration would be referred as ‘SS’, room with windows on adjacent walls as ‘AS’ and a room with windows on opposite walls as ‘OS’. The scale of the model is 1:20 and the details are shown in Figure 2. The details of 3-bedroom apartment are shown in Figure 3 and the scale of the model is 1:50.

![Figure 2: Three single rooms with basic window configurations](image)

![Figure 3: 3-bedroom apartment floor plan with dye movement resembling airflow patterns](image)

Photographic data to ventilation metrics

The image obtained from the water table as seen in Figure 3, consists of gradation of dye that represents air movement in a space. Therefore, to convert the photographic data to ventilation metrics following steps were carried out.

Extracting images as per desired time frames

Initially, the images from the experiment video were extracted as per the desired time frames. To extract an image from the video, it is important to crop the interior portion of each room excluding walls of the physical model. This was done to avoid the contribution of white (255-pixel value) PVC (Poly Vinyl Chloride) foam board walls in the metric calculation. Pixel values represent the brightness or darkness of an image, however in this study, it represents the optical density of dye. The value ranges from 0 to 255, where 0 is the darkest point and 255 is the brightest point. Further, VLC software (VideoLAN, 2018), was used for taking snapshots from the video at any time frame. This helped in taking the snapshots of the cropped video and saving it in PNG (Portable Network Graphics) format. The images obtained from the above process at every second were post-processed further for their pixel values.

Extracting pixel values

To easily obtain pixel values, visualize, and reduce the computing time, the RGB (Red, Green, Blue) image obtained from the water table experiment was converted into a grayscale using MATLAB (Matrix Laboratory) (MATLAB, 2017). The pixel values were then extracted from this grayscale image. By doing this, only one value was obtained for each pixel, i.e., a weighted sum of RGB values.

Post processing pixel values

This was an important step in deriving the ventilation metrics. Based on the equation of metric and the input values needed for evaluating it, the pixel values were post-processed. Another important step was to identify right grid size of pixel values used for calculation of metric, for example, only a single pixel value or by averaging few pixel values as per grid size. This was based on the rows and columns size, and according to the point of interest in a room. It is also important to note that as the grid size increases the accuracy of the results decreases.

Establishing the relation between pixel and concentration values

In this work, the pixel values represent the dye concentration at different points and the metrics are derived based on the relative difference in concentration values. To identify the relation between pixel values and dye concentration a calibration curve was developed, as illustrated in Figure 4. This curve was developed by conducting experiments and capturing videos for each dye concentration and checking the pixel values when the dye is uniformly mixed throughout the room. This helps to calculate the dye concentration based on the pixel value and can be used for calculations using Equation (1).

Finally, the ventilation metrics were calculated based on the concentration values.

![Figure 4: The relation between dye concentration and pixel values](image)

\[ C = 1.42 \times P_x^{-1.06} \]  \( (1) \)
Ventilation Metrics

Ventilation metrics help to predict the performance of a ventilation system. The conditions in the water table experiment represent the conditions in a room. Before starting the experiment, there is only clear water inside the room model i.e., zero dye concentration (0 g/l). This value keeps on increasing as the dyed water enters the room. Thus, the initial clear water condition resembles to be a room filled with contaminated/stale air and infiltration of dye is the fresh air coming inside the room. For a given room, pixel values were extracted and converted to concentration values using the calibration curve as shown in Figure 4. The relative spatial concentrations were used to evaluate three metrics as follows.

Percentage of Dead Spots

Dead spots mean the air is stagnant, and little/no mixing up of incoming fresh air. This will be seen as a zone or room with no movement of air and with low dye concentration. It is a metric that quantifies the mixing of the incoming fresh air with the indoor air and determines the dead spots (%DS)/zones in a room which is not adequately ventilated (Edwina Royan G, Vaidya, & Damle, 2017) and is calculated using Equation (2). In addition to this, it shows the amount of fresh air infiltrated in a room. Lesser the infiltration more are the DS and vice versa.

\[ \% \text{DS} = \frac{C_{\text{max}} - C}{C_{\text{max}}} \]  

Absolute Ventilation Efficiency

Absolute ventilation efficiency (AVE) is a metric that helps to determine the ability of the system to decrease contaminant concentration in a room. This can be calculated based on Equation (3) (Awbi, 1991). The system is said to be most effective if the value is 1 and least effective when it is 0.

\[ \text{E}_{\text{a}} = \frac{(C_0 - C)}{(C_0 - C_s)} \]  

In this case, the supply air concentration is the maximum concentration of dye (g/l). The initial concentration at a point \( c \) is zero, i.e., clear water with no fresh air inside the room. The duration of calculation is considered when dye starts to enter the room and stops at the steady state, which is considered to be at the end of the experiment in this work. Using Equation 3, the value of absolute efficiency is calculated at the point of interest (C) in a room. The point of interest could be a single point in a room, zone, or whole room. As the fresh air penetrates inside the room through the windows, the contaminant concentration decreases.

Air Changes per Hour

Air changes per hour (ACH) is the number of times the air within the room is renovated. This is calculated by using the mass balance Equation (4) (Dockery & Spengler, 1981). This equation considers the inside and outside concentration over the evaluation period.

\[ dC = P \times \text{ACH} \times C_s \times dt + \frac{5}{v} \frac{d}{dt} (\text{ACH} + k)C_i \times dt \]  

For this study it is assumed, that all the particles enter the room without any loss at the window, so \( P \) is 1. The ratio of \( S/V \) is said to be zero as there is no source inside the room. In addition, there is no reaction taking place between the dye water and the walls of the model, so \( k \) i.e. the reactivity constant is zero. This metric is calculated when there are well-mixed conditions inside the room. To do this, the average concentration values at a given time frame are considered. The outside concentration (\( C_s \)) is averaged near the window and inside concentration (\( C_i \)) is the average room concentration as shown in Figure 5. Using the Equation (4) inside concentration values are predicted based on the outdoor concentration values. Further, a curve is fit to this experimental data according to the Equation (4) by minimizing the sum of the square of differences i.e., chi (\( \chi^2 \)) between the experimental and predicted indoor concentration values. The value of ACH is such, that it minimizes the chi (\( \chi^2 \)) values so that the experimental and predicted indoor concentration values come as close as possible, as shown in Figure 6. For this, Solver from Microsoft Excel (Microsoft Excel, 2016) is used.

![Figure 5: Visual representation of ACH parameters for Room 1 of a 3-bedroom apartment](image)

![Figure 6: Curve fit for Room 1 till the steady state, having chi (\( \chi^2 \)) value of 0.1145](image)

The ACH in case of the water table is dependent on the velocity, density, viscosity of water, characteristic length, area of the window and volume of the room i.e. ACH = \( f \) (\( v, \rho, \mu, d, A, V \)). The characteristic length is the total length of the wall facing the incoming dye. The velocity in water is 0.003m/s and that in air 0.001m/s. Thus, to identify the relation of ACH in the air to that of ACH calculated from the water, a dimensional analysis is carried out which results in Equation (5). After doing dimensional analysis it is found that the dimensionless number \( \Pi_1 \) (\( \frac{\text{ACH}_{\text{air}}}{\nu} \)) is a function of Reynolds number \( \Pi_2 \left( \frac{\mu}{\nu} \right) \) and two other numbers \( \Pi_3 \left( \frac{A}{d^2} \right) \) and \( \Pi_4 \left( \frac{d}{D^2} \right) \) which depend on the geometry of the model. This relationship is given by Equation (5). Therefore, to get the (ACH)\text{air} from (ACH)\text{water}, \Pi_2, \Pi_3, \Pi_4 need to be
same for the model and the prototype so that Equation (5) is true. From the Equation (6), ACH in the air is evaluated.

\[ \Pi_1 \left( \frac{ACH + d}{V} \right) = f \left( \Pi_2 \left( \frac{\mu}{\rho_{air}} \right) \Pi_3 \left( \frac{A}{\varphi} \right) \Pi_4 \left( \frac{V}{\varphi} \right) \right) \]  

\[ (ACH)_{air} = \left( \frac{ACH + d}{V} \right)_{water} \times \left( \frac{V}{\varphi} \right)_{air} \]  

Results and Discussion

In this study, the dyed water that is entering the room represents air. Therefore, for ease of understanding flow development and explanation of metrics, the incoming dyed water is referred to as air. Each metric is evaluated for simple geometries, i.e., three single rooms with basic window configurations, and then for complex geometry, i.e., a 3-bedroom apartment. The flow patterns within each of the configuration and 3-bedroom apartment were documented, analysed and quantified using the three above metrics. The calculations were done considering the average outside and inside room concentration as shown in Figure 5. Moreover, understanding the airflow patterns for different rooms helped to relate the quantitative metric results. The results obtained in terms of flow patterns and different metrics for the three cases and 3BHK apartment are discussed below.

Visual flow pattern analysis of three single rooms with different window configuration

The flow patterns along with the line diagrams for rooms SS, AS and OS are shown in Figure 7, Figure 8, and Figure 9 respectively. The scale of the room model is at 1:20. Each photograph it at an interval of 1 min. The first frame corresponds to the time when the air enters the room, which is after 1 min. The steady state is considered at the end of the experiment, which is at 16:40 min. In case of ‘SS’, the air entering is distributed centrally and then flows into the different parts of the room. This air moves towards the two sides, and then it flows towards the opposite wall. Due to the incoming air touching the side walls, eddies are formed at the left top and left bottom corners as seen in Figures 6b and 6c. The air in these corners continuously recirculates and is mixed with the incoming air causing large eddies. As there is only one window opening on the windward side, the air that reached the opposite wall starts to flow back.

![Figure 7. Flow patterns observed in SS after every 2mins](image)

Fresh air entering the ‘AS’ room tries to spread centrally and leaves from the side window as seen in Figure 8a. Thus, the corners near the windward window are less ventilated and can be observed in Figure 8b. This air moving towards the side and opposite walls, cause eddies in the left top and bottom corners as shown in Figure 8c. The air flows from the opposite wall, as it has no opening. Out of all the corners, only the top left corner as seen in Figure 8c is not properly ventilated. At that point, there is continuous recirculation, due to short-circuiting of the flow from a window on the windward side to the side window.

![Figure 8. Flow patterns observed in AS after every 2mins](image)

In case of room ‘OS’, a tunnel effect occurs when the air enters the room due to the window on the leeward side, see Figure 9. As the air continuously short circuits (passes directly) from the windward window through the window on opposite side, it causes a clockwise recirculation in the lower portion and anti-clockwise recirculation in the upper portion as shown in Figure 9b, 9c.

![Figure 9. Flow patterns observed in OS after every 2mins](image)

Percentage of Dead Spots

The %DS were calculated for the whole room by considering the average room concentration. This was done to understand the impact between SS, AS, OS having same room area, but different number of windows and positions. It can be observed in Figure 10, that AS has least % DS for a maximum duration of time. This is due to uniform fresh air distribution throughout the room. This was followed by OS, and is maximum in SS, as the air is not distributed uniformly in the room. At steady state, the percentage is least for AS, as it achieves maximum fresh air concentration. Furthermore, if we consider that the outdoor air quality is good, then, AS has good IAQ, followed by OS. Whereas, it is poor in SS as the room was filled with contaminated air.

![Figure 10. Percentage of dead spots with time in the entire room for SS, AS, and OS](image)
Absolute Ventilation Efficiency

AVE was calculated for the whole room by considering the average room concentration. It can be observed in Figure 11 that SS has the least AVE, due to the nonuniform distribution of fresh air. Whereas, it is maximum in AS for longer duration. At steady state, AVE is maximum for OS (0.89), as the room fills uniformly with fresh air. This is followed by AS (0.87), and least in SS (0.85), due to non-uniform distribution of fresh air in the room.

![Figure 11. Absolute ventilation efficiency with time in the overall room for SS, AS, and OS](image)

Air Changes per Hour

As ACH is the function of inside and outside supply concentration, ACH for three configurations varies as seen in Figure 12. It can be observed that the ACH in water and air is maximum for AS (24 h⁻¹, 1.2 h⁻¹), because of less recirculation and uniform distribution of fresh air inside the room. This is followed by OS (17 h⁻¹, 0.8 h⁻¹), and SS (13.7 h⁻¹, 0.68 h⁻¹), where the air is not uniformly mixed in the room. Further, maximum the ACH, maximum is the replacement of contaminated air by fresh air. Therefore, in case of AS maximum contaminated air is replaced which improves the IAQ. Whereas, in case of SS, as there is only one window, the ACH is least. This is because the single window is not able to supply enough fresh air, at the same time remove contaminated air. Therefore, the IAQ will be poor in this room.

![Figure 12. ACH in water and air for SS, AS, and OS](image)

Visual flow pattern analysis for a 3-bedroom apartment

The flow patterns along with the line diagrams observed for a 3-bedroom apartment are showcased in Figure 13. The first frame is after 1 minute, which is the time when the air enters the room. Initially, it can be observed in Figure 13 that the flow patterns are similar in R1 and R3 as the number of windows, positions and sizes are same, except that R3 side window has a wing wall. However, after 1 minute due to this wing wall, the air does not enter from the side window as that of R1, where the air also enters from the side window. As the air in R1 and R3 flows out from the side window and door, eddies are formed at the corners near the window on the windward side as seen in Figure 13b. As there are two windows on the windward side for the dining with no barrier on the opposite side, the air flows straight towards the living room. Because of this straight flow, eddies are formed between the area near the windows on the windward side, and at the left top/bottom corners of this room, as seen in Figure 13b. In R2, the air enters from the door and the window, which is parallel to the flow direction so there is an eddy motion. Further, K gets ventilated due to the air coming from the P2 and P3, which leaves towards the windows in the utility room (U). For toilets (T1, T2, T3), windows are parallel to the direction of the flow and the doors are closed, so it takes longer time for air to reach these rooms.

![Figure 13: Flow patterns observed in a 3-bedroom apartment after every 1min](image)

Percentage of Dead Spots

In all the rooms, the % DS goes on decreasing as the time proceeds. It can be observed in Figure 14a, that the % DS after 1min are maximum in R2, L, K, and U, as the fresh air has not reached these rooms. Whereas, the rooms which are in front get ventilated, diluting the contaminated air. The room D, despite having two windows has more % DS (91.7%) as compared to R1 (88.7%) and R3 (90.3%), as there is no barrier on the opposite side which will stop the fresh air. Therefore, these straight flows creating eddies result in more % DS as shown in Figure 14. In case of R2, due to eddies as seen in Figure 14b, the % DS are higher (91%) than L (89.5%) which lacks cross ventilation.

![Figure 14: Percentage dead spots in all the rooms of a 3-bedroom apartment after every 1min](image)
Further, if we consider that the outdoor air quality is good, then the rooms that have good indoor air quality (IAQ) are R1, D, and R3. This is because fresh air replaces the maximum contaminated air in these rooms. Whereas, the IAQ is poor in U because the air accumulating the contaminated air from R3, P3, and K is passed into this room.

**Absolute Ventilation Efficiency**

AVE is maximum in the rooms which have window perpendicular to the direction of the airflow. It is maximum in the rooms which are on the windward side, i.e., R1, D, and R3, and same, i.e., 0.05 for R3, L, K and U after 1min, as seen in Figure 15a. As, these rooms are on the other side of the main source of fresh air supply, which can be seen in Figure 15a. In R2, due to recirculation, the efficiency is less (0.09) as compared to L (0.10) as seen in Figure 15b.

Furthermore, the efficiency is very less, i.e., 0.05% for U until the air enters this room. Once, it reaches this room, i.e., at the end of 2 minutes, due to maximum windows the efficiency increases by 40%, as seen in Figure 15b. Moreover, as the area is small as compared to other rooms, it achieves maximum efficiency in a shorter period. Thus, the efficiency increases and pollutant concentration decreases, as the infiltration of fresh increases. Finally, it can be observed that windows on the windward side are more efficient in reducing the pollutant concentration. This is because of effective delivery of fresh air throughout the room.

**Air Changes per Hour**

The ACH is calculated for various rooms in the apartment having windows perpendicular, (i.e., R1, R2, K), and parallel (i.e., T1, T2, T3) to the direction of the flow. ACH for R1, R3, and K are different, as the supply conditions vary as explained in Figure 13. Further, it can be observed in Table 1 that the ACH is nearly half for R1 than R3. The difference is more due to the varying outside supply concentration. For toilets, the ACH in water and air is maximum in T2 due to a maximum fresh air supply, whereas it is less in T1 and T3 as shown in Table 1. The difference between the ACH for T1 and T3 is less, this is because the supply air concentration near the window is affected by the air coming out from the side window of R1 and R2 respectively.

<table>
<thead>
<tr>
<th>Rooms</th>
<th>ACH in water (h⁻¹)</th>
<th>ACH in air (h⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>R1</td>
<td>13.7</td>
<td>0.33</td>
</tr>
<tr>
<td>R3</td>
<td>24</td>
<td>0.63</td>
</tr>
<tr>
<td>K</td>
<td>54.1</td>
<td>0.4</td>
</tr>
<tr>
<td>T1</td>
<td>65.8</td>
<td>0.52</td>
</tr>
<tr>
<td>T2</td>
<td>113.2</td>
<td>0.5</td>
</tr>
<tr>
<td>T3</td>
<td>17</td>
<td>0.85</td>
</tr>
</tbody>
</table>

**Comparative Analysis**

The results of the comparative analysis done between SS, AS and OS are presented in this section. Figure 16 shows AVE versus DS time for rooms SS, AS and OS. It is observed that as the AVE increases the % DS decreases and vice versa. This means that they are inversely proportional to each other. It can be further observed that, as the AVE is maximum in AS for longer duration, the % DS is least during that time.

Furthermore, the comparative results between the ACH and % DS at steady state can be seen in Figure 17. It can be observed that as ACH increases, the % DS decreases. For example, it can be observed in Figure 17, that as ACH is maximum for AS (24 h⁻¹) the % DS is least (0.17%). Whereas the ACH for SS is least (13.7 h⁻¹), the % DS is maximum (0.26%).

**Conclusion**

In this work, a photographic method is developed to quantify the flow patterns in a water-table apparatus. The quantification is made in terms of ventilation metrics like % dead spots, absolute ventilation efficiency, and air changes per hour. The metrics are evaluated for three single rooms with different window configurations and
for a 3-bedroom apartment. The metric results for the three configurations are in good agreement when compared with the flow patterns observed in the water table. For example, % DS decrease as the fresh air enters a zone. At steady state, this percentage is least for room AS as it achieves maximum fresh air. As expected, room AS has maximum ventilation followed by room OS, with least for room SS. Further, the air changes per is minimum for room SS. For the 3-bedroom apartment, it is observed that the rooms with windward windows have least % DS and higher ACH as compared to the rooms on leeward side. In case of ACH, it is higher in 3BHK than SS, AS, OS as more openings and small size rooms for the same flow rate. So relative prediction of the ACH is realistic. It is also observed that an increase in absolute ventilation efficiency decreases the percentage of dead spots. Therefore, it is concluded that the derivation of ventilation metrics with the current methodology gives physically realistic results, which agree with visual observation of flow patterns generated in the water table apparatus. This method can serve as a useful tool to compare different geometrical configurations at the design stage. In addition, it is a practical way to understand the flow of air in naturally ventilated buildings.

Nomenclature

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
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</thead>
<tbody>
<tr>
<td>%</td>
<td>Percentage</td>
</tr>
<tr>
<td>µ</td>
<td>Dynamic Viscosity</td>
</tr>
<tr>
<td>ACH</td>
<td>Air Changes per Hour (h⁻¹)</td>
</tr>
<tr>
<td>AS</td>
<td>Room with windows on adjacent walls configuration</td>
</tr>
<tr>
<td>AVE</td>
<td>Absolute Ventilation Efficiency</td>
</tr>
<tr>
<td>C</td>
<td>dye concentration at a point after t, s (g/l)</td>
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<tr>
<td>Cᵢ</td>
<td>average inside concentration (g/l)</td>
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<tr>
<td>Cmax</td>
<td>maximum dye concentration at a point (g/l)</td>
</tr>
<tr>
<td>C₀</td>
<td>initial concentration at a point (g/l)</td>
</tr>
<tr>
<td>Co</td>
<td>concentration in the outdoor supply air (g/l)</td>
</tr>
<tr>
<td>d</td>
<td>characteristic length (mm or m)</td>
</tr>
<tr>
<td>D</td>
<td>Dining</td>
</tr>
<tr>
<td>dC</td>
<td>change in concentration (g/l)</td>
</tr>
<tr>
<td>DS</td>
<td>Dead Spots</td>
</tr>
<tr>
<td>Ea</td>
<td>Absolute Ventilation Efficiency</td>
</tr>
<tr>
<td>g</td>
<td>Gram</td>
</tr>
<tr>
<td>h</td>
<td>time step (s)</td>
</tr>
<tr>
<td>h</td>
<td>Hour</td>
</tr>
<tr>
<td>IAQ</td>
<td>Indoor Air Quality</td>
</tr>
<tr>
<td>k</td>
<td>reactivity rate (h⁻¹)</td>
</tr>
<tr>
<td>K</td>
<td>Kitchen</td>
</tr>
<tr>
<td>L</td>
<td>Living Room</td>
</tr>
<tr>
<td>l</td>
<td>Litre</td>
</tr>
<tr>
<td>m</td>
<td>Meter</td>
</tr>
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</table>

MATLAB Matrix Laboratory

min Minute

mm Millimeter

OS Room with windows on opposite walls configuration

P penetration factor (unit less)

P1 Passage 1

P2 Passage 2

P3 Passage 3

PNG Portable Network Graphics

PVC Poly Vinyl Chloride

Px Pixel value

R1 Room 1

R2 Room 2

R3 Room 3

RGB Red, Green, Blue

S indoor source emission rate(ml/h);

s Seconds

SBS Sick Building Syndrome

SS Room with single-sided window configuration

t time frame (h or s)

T1 Toilet 1

T2 Toilet 2

T3 Toilet 3

U Utility Room

V indoor volume (m³)

v velocity (m/s)

VLC VideoLAN Client

VOC Volatile Organic Compound

χ² Chi-square

ρ Density

Π Dimensionless number

References

ASHRAE 62.1 Standard (2016) Ventilation for Acceptable Indoor Air Quality


