Simulating People Moving in Displacement Ventilated Rooms

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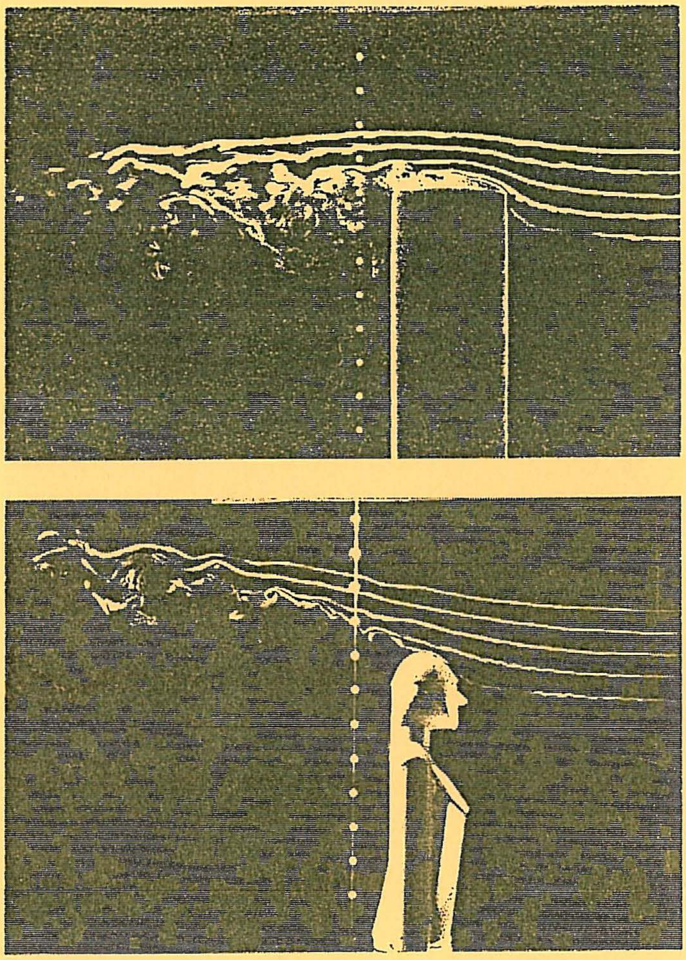

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Proc. of "Healthy Buildings '97", 5th International Conference on Healthy Buildings, September 27 - October 3, 1997, Washington DC, USA

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SIMULATING PEOPLE MOVING IN DISPLACEMENT VENTILATED ROOMS

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ABSTRACT

A displacement ventilation system works better the more uni-directional the air flow through the ventilated room is: from floor to ceiling. Thus, from an air quality point of view, there should be as little vertical mixing of the room air as possible. It is therefore comprehensible that physical activity in the room – like peoples movements – in previous studies has been shown to influence the effectiveness of the ventilation. In this study we have compared results from previous tests, where a cylindrical person simulator was used, to results obtained when using a person simulator of more human-like shape. The main results verify previous findings: if the movements are not very slow, they have a detrimental effect on ventilation effectiveness and on the air quality in the breathing zone of the inhabitants. Some quantitative differences were found between using the simple and the detailed person simulator, although the qualitative results were about the same.

INTRODUCTION

The performance of a displacement ventilation system can be strongly affected by the physical activity of people in the ventilated space; a systematic investigation is reported in (1)&(2). High level of activity seems to cause air qualities corresponding to a more or less mixed system, thus reducing the motives for installing the relatively expensive displacement ventilation system in such cases. In (1)&(2) a simple cylindrical person simulator was set into motion in a test room. One may however suspect that a real human being, as it moves through the room, cause another air flow field – and hence another pollution concentration pattern – than a simple cylinder does. See also (3),(4)&(5).

As a first step to investigate how detailed a person simulator one should use in this matter, full scale tests, similar to the ones in (1)&(2), where performed also with a more human shaped model. Tracer gas was used to measure the air quality in the test room, also in the "breathing zone" of the simulators, for different levels of activity. Visualisation of the air flow pattern around the bodies, using smoke in a wind tunnel, was also performed.

METHODS

The measurements were performed in an insulated full scale test room, equipped with displacement ventilation, Figure 1. Room size: 4.20x3.59x2.50 m (LxWxH). Air flow rate: 20.9 l/s, corresponding to an air exchange rate of 2.0 room volumes / hour. The temperature of the inlet air was held about 7 °C below average room air temperature. A person simulator (PS) was placed on a small trolley in the middle of the room. By means of a conveyor belt and a computer controlled motor the trolley could be moved back and forth in the room, at a predetermined speed and amplitude. The trolley was equipped with a mechanism which could turn the PS on each change of movement direction, thus always keeping the "face" in "forward" direction. Two different PSs were used: one of simple cylindrical shape (Cylinder) and one more detailed person simulator (DPS), Figure 2. Cylinder size: H=1.63 m, D=0.333 m, making a surface area of 1.88 m^2, which is about the same as a "normal" man. The DPS, shown in Figure 2, was of height H=1.69 m, "trunk" width = 0.47 m, and surface area 1.44 m^2, corresponding to a "normal" woman. When put on the trolley, the Cylinder's and the DPS's top of their heads were raised to 1.71 m and 1.72 m respectively. Both PSs had an internal (electrical) heat production of 100 W, simulating human metabolism. The results presented here concern continuous "walks" back and forth across the room, the PS movements spanning 2.50 m, running parallel to the 3.59-m wall.

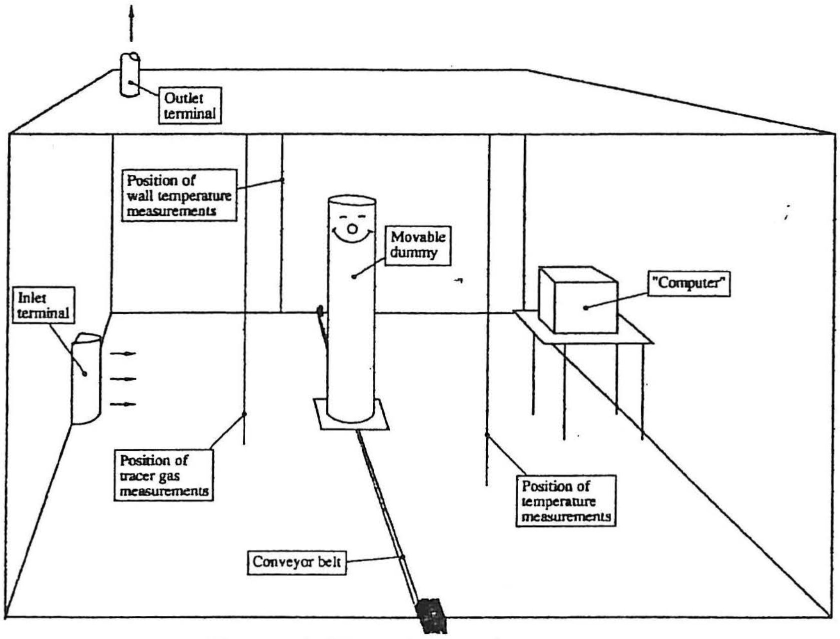

Figure 1. Experimental set-up.

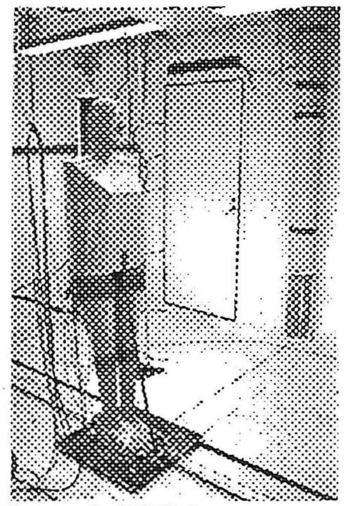
Figure 2. DPS in test room

In the room was also installed a perforated metallic computer simulator, with an internal heat production of 50 W, placed on a small table. Besides constituting a normally occurring extra heat source in the room, the "computer" also acted as a pollution source, to which some of the ventilation effectiveness values were related. The third, and last heat source in the room was ceiling lightning of 145 W.

Temperatures were measured in inlet and outlet terminal. Also the vertical temperature profiles were measured in room air and along the surface of one wall. Tracer gas concentrations were measured in outlet terminal and in the "breathing" zone of the PS, and also the vertical concentration profile in room air was measured in one location.

Two tracer gas methods were used in each test case: a step-up followed by a step-down. At the step-up method a continuous flow of tracer gas (N_2O) was released in the "computer" until at least one hour of steady state concentrations had been recorded in the measuring points. The room air was then mixed in order to measure the mean concentration in the room. At the step-down method a small amount of tracer gas was released and mixed with the room air, after which the mixing was stopped, and the concentration decay in the measuring points was recorded until almost all tracer gas had been ventilated out of the room.

RESULTS

The influence of the PS movements on overall room air quality is depicted in Figure 3, where two different measures of ventilation effectiveness are shown. Figure 3a shows the Normalised Mean Concentration in the Room (NMCR) of the "pollution" released in the "computer"; the values being normalised with the concentration in the outlet. With this definition one gets a comparison to the reference case "a perfectly mixed room", which would give the value NMCR=1. A room where the pollution is locally "trapped" in high concentrations is likely to result in NMCR>1. (Thus NMCR is the reciprocal of the often used "Pollution removal effectiveness" or "Ventilation effectiveness"). The speed of the PS is marked on the abscissa. This is the sustained maximum speed, u_{sm}, which was preceded by a constant acceleration phase and ended by a constant retardation phase for each "walk" across the room; the average speed was consequently somewhat lower than u_{sm}.

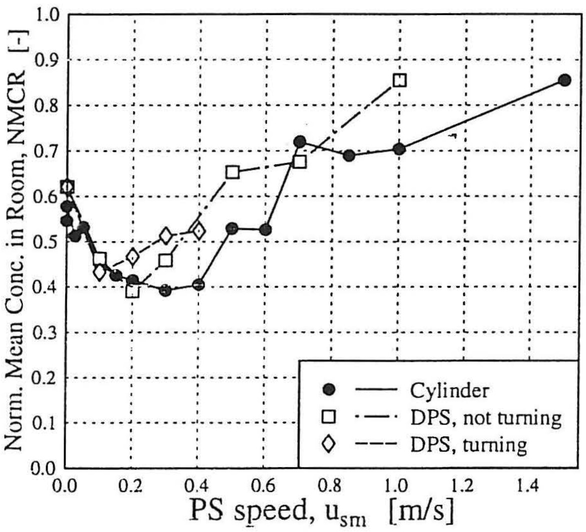

Figure 3a. Mean conc. in room vs. PS speed

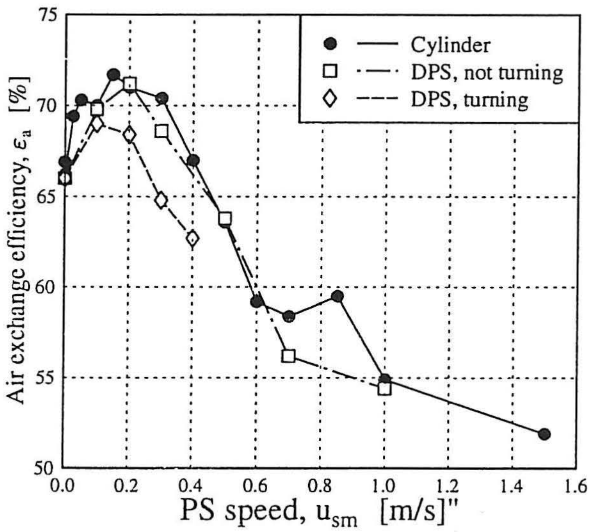

Figure 3b. Air Exch. Eff. vs. PS speed

Comparison is made, in Figure 3, between the three cases: "Cylinder", "DPS, not turning" (i.e. DPS "walking" backwards in one direction) and "DPS, turning". We see that for a steady standing PS, NMCR≈0.6. Then, a low speed of the PS is shown to result in lower NMRC: a minimum value of ≈0.4 is attained at u_{sm}= 0.1–0.3 m/s. Further speed increase cause again higher values, but still at the highest speeds tested the NMCR values are below 1.0, indicating better ventilation than for a mixed system. (Limited strength of the transportation equipment put an upper speed limit, unfortunately being rather low for the turning DPS.) The moving DPS seem to cause a somewhat more polluted room than the moving Cylinder.

Figure 3b shows how the air exchange effectiveness, ε_a, depends on the movements. ε_a is a measure of how "young" the air in the room is on average, assuming it being "born" as it enters the room. A high value indicates relatively "young" and "fresh" air; perfect mixing result in ε_a=50%. ε_a was calculated from the step-down measurements in the outlet (see e.g. (6)). The course in Figure 3b is similar to 3a: an effectiveness maximum is attained at u_{sm}≈0.2 m/s; higher speeds making the ε_a-values approaching the mixing value 50%. As in Figure 3a, the DPS seems to cause somewhat worse air quality than the Cylinder, especially the turning DPS.

A more detailed picture of how the "computer pollution" is distributed in the room is shown in Figure 4, where the vertical concentration profiles are depicted for three different values of u_{sm} for the Cylinder and the not turning DPS. According to the studies in connection with (1)&(2)

the air quality is – for this set-up – rather homogeneous in the horizontal plane, thus warranting a look upon the profiles as roughly representing the concentration distribution in the whole room. The concentrations, C, are normalised with outlet concentration, C_0, and, similar to Figure 3a, perfectly mixed room air would give $C/C_0=1$ everywhere in the room. At $u_{sm}=0.1$ m/s no big difference can be seen between the Cylinder and the DPS profiles, except at the height 1.8 m where the DPS cause a remarkable "dip" in the curve. At $u_{sm}=0.3$ m/s the DPS is seen to make the air more polluted at "trunk" height than the Cylinder. At $u_{sm}=1.0$ m/s the curves have come rather close to the 1.0-line, the DPS causing about 20% higher concentrations in the occupied zone than the Cylinder.

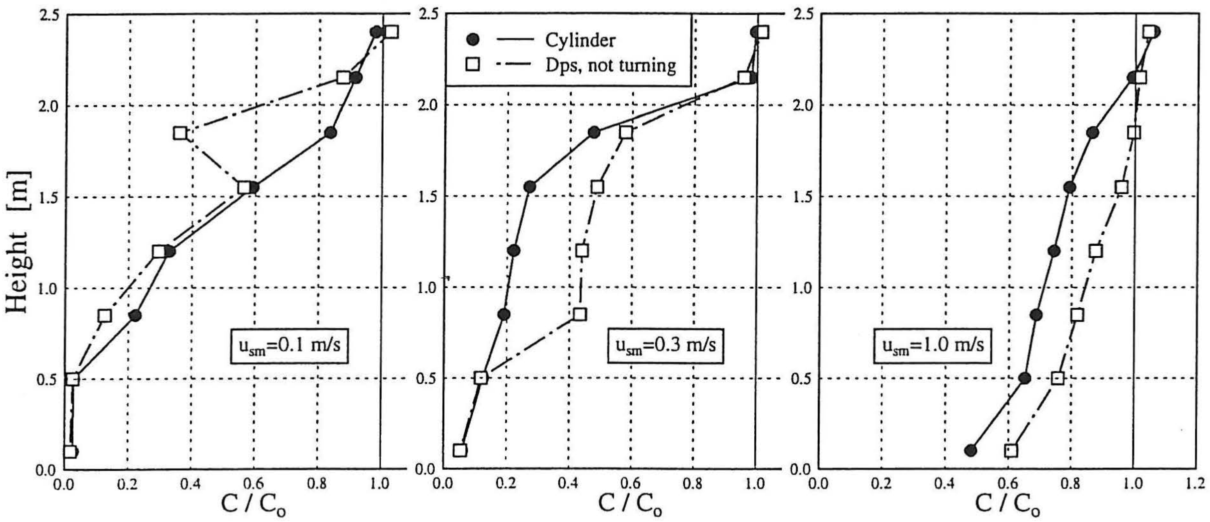

Figure 4. Vertical concentration profiles at different PS speed.

It has been shown (see e.g. (7),(8)&(9)) that the air quality in the breathing zone of the occupants in a displacement ventilated room is influenced by the natural convection air stream along the bodies, which tend to bring relatively fresh air from the floor to the nose. This effect was observed also in this study. Figure 5 shows how the concentration of the "computer pollution" in the "nose" of the PSs depends on PS speed. The values are normalised with outlet concentration (dashed curves) and the concentration in the "ambient" air (solid curves); "ambient" meaning a point on the vertical profile line being at the same height (155 cm) as the "nose". Concentrating on the latter curves first we see that, when standing still, the PSs "breathe" air that is in fact only ≈20% as polluted as the air just outside the convection stream. However this "cleaning effect" disappears at $u_{sm}\approx0.2$ m/s according to the Cylinder and turning DPS curves. Under DISCUSSION is explained why the *not* turning DPS doesn't give the same indication. The Cylinders "overshooting" of the 1.0-line is explained in (1)&(2) to be due to the backward movements of the Cylinder every second move, causing air to be swept from a higher, more polluted altitude, down to the breathing zone. The dashed curves, showing the relation to the outlet, indicates that the PSs "breathes" less polluted air than they would if the room air was perfectly mixed; the difference being smaller for higher activity. The DPS seems to be exposed to slightly more polluted air than the Cylinder, if the speed is not very small.

Smoke visualisations of the air flow pattern in the region around the "head" of the PSs is shown in Figure 6. Smoke was injected into the main stream in a wind tunnel to reach the PS on its centreline. The air velocity is 0.3 m/s – the case showing the most noticeable difference between the Cylinder and the DPS. Both PSs receive their usual 100 W heat input, and for the DPS (6c) we can see that the vertical convection flow along the body interferes with the oncoming horizontal air stream, deflecting it slightly upwards. For the Cylinder (6b) however,

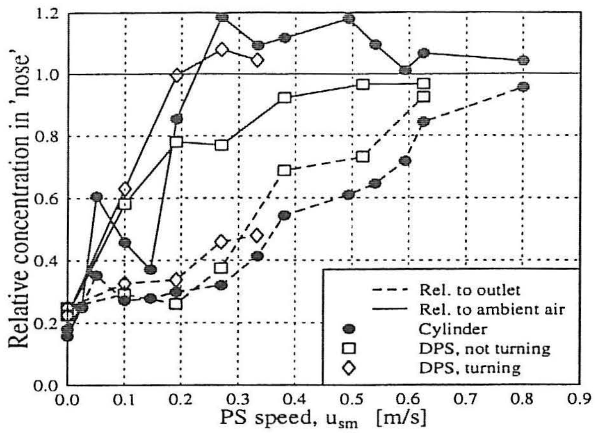

Figure 5. Air quality in "breathing" zone.

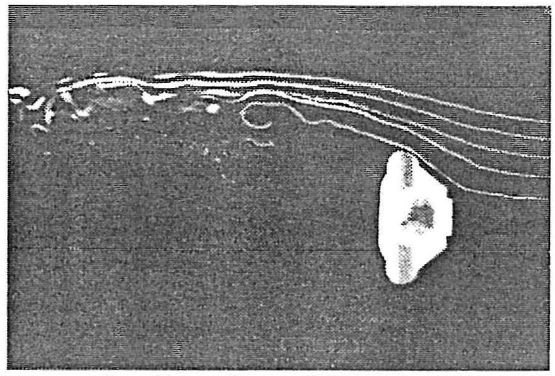

Figure 6a. Top-view of flow around DPS.

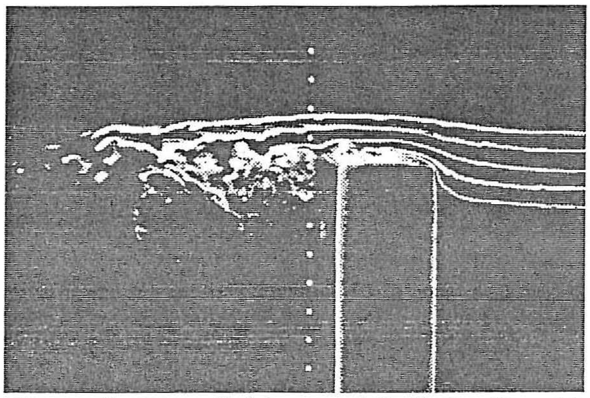

Figure 6b. Flow field around Cylinder "head".

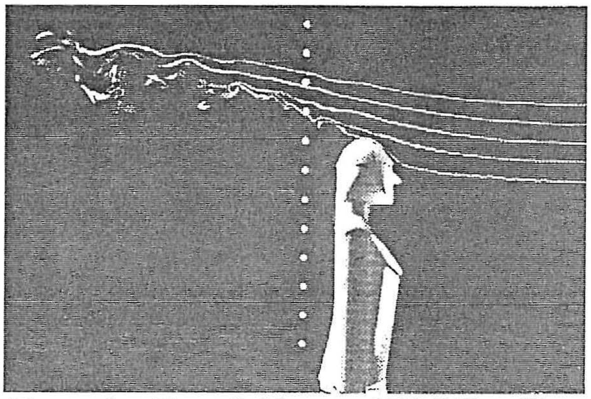

Figure 6c. Flow field around DPS "head".

we can not see this effect; instead the air stream is, to some extent, swept down into the wake of the Cylinder. At higher velocities this flow pattern applied to both PSs, while at lower velocities the upward deflection was obvious also for the Cylinder. Figure 6a shows a top view of the air stream around one side of the DPS, at "stomach" height. It is clear that a big wake is formed behind the DPS: not even the smoke streak released closest to the DPS centre line (8.5 cm apart; DPS width: 470 cm) is directly dragged into the wake.

DISCUSSION

As mentioned, the main purpose of this study has been to get a picture of the influence of body shape of the PS when simulating movements of people. However, first we'll make some brief general statements of how the movements seem to affect the air quality in the displacement ventilated room; most of it being verifications of the findings in (1)&(2).

The interesting effectiveness peaks occurring at a low speed (Figure 3) is probably due to vertical convection flow along the PS being "peeled off" from the body, settling in ambient air of equal temperature. In this way the PS spreads air from the floor horizontally in the room, instead of convecting it to the ceiling, enhancing the macrocirculation in the upper part of the room – a circulation that always exists in displacement ventilated rooms, causing deteriorated effectiveness. However, a fast moving PS will sweep down air from above into its wake, thus making the room air more mixed; something that several figures from above gave an indication of. The effect of locally "fresher" air in the breathing zone due to body convection flow seems to disappear at about $u_{sm} \approx 0.2$ m/s; i.e. it seems that a person walks away form his convective boundary layer already at quite a low speed. (A rather relaxed walking speed is ≈ 1.5 m/s.)

Now to the differences between the Cylinder and the DPS. First we try to account for the strange "dip" in the DPS-curve in Figure 4 at u_{sm}=0.1 m/s. As shown in Figure 6a, there is a big wake behind the DPS. Assume the air closest to the DPS, after being heated by it, getting more of less trapped in its wake. The buoyancy will drive it upwards in the wake – imitating the "chimney" effect – until it reaches "head" level, where it will be "delivered" to the ambient air; perhaps rising a bit before finding its level of neutral buoyancy (i.e. of same temperature). Consequently, at this level we will find relatively "fresh" air, brought up from cleaner areas. Support for the theory is found in Figure 6c, where we get an inkling of the "delivery" of the upcoming convection stream. This could explain the "dip" in Figure 4, and in fact also why the "DPS, not turning"-curve in Figure 5, solid line, approaches the 1.0-line "later" than the other. When "walking" backwards it is likely that portions of wake convection flow will reach the DPS's "nose", and hence provide it with relatively "fresh" air; thus causing the recorded lower mean concentration in the breathing zone. Having the "nose" in the right direction thus seems to have some importance in this kind of measurements.

The DPS causing inferior overall air quality compared to the cylinder can be explained by, at low speed, the DPS "spreading" its convection flow at "head" height, while the Cylinder delivers it at lower altitudes – as described above –, thus purifying the occupation zone more. At higher speeds the DPS is likely to sweep down more air from above than the Cylinder, due to the DPS's "bluffer" body shape; hence causing the room air to be more mixed. It is explainable that the turning DPS cause somewhat lower effectiveness than when it is not turning, since the action of turning adds physical activity, and hence tends to mix the air more.

Summing up, we can conclude that there are some differences in measured air quality between using the Cylinder and the DPS as the moving object, although the qualitative results are about the same. What happens when a real person walks through a room, moving also arms and legs, is on our schedule for coming measurements. One should keep in mind that the results presented here concern continuous movements, and that the problem of imitating indoor movement *patterns* for real people is likely to be more crucial than imitating their body perfectly. However, the results above give a hint on movement impact on air quality in displacement ventilated rooms.

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