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Published in:
Proceedings of Indoor Air 2016

Publication date:
2016

Document Version
Peer reviewed version

Subjective Evaluation of the Microenvironment Generated by a Hospital Bed with Localized Ventilation System

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SUMMARY
A novel method for local hospital bed ventilation, called HBIVCU (Hospital Bed with Integrated Ventilation and Cleansing Unit), was studied in a human subject experiment. The goal of this study was to identify human response to the microenvironment generated by a hospital bed with installed HBIVCU and to compare with human response to the micro-environment at a hospital bed without local ventilation. 32 participants took part in two experimental conditions - hospital bed with and without installed HBIVCU. Subject's votes on the bed microenvironment were collected via standardized questionnaires. The subjects evaluated the perceived air quality in the ventilated bed as better compared to that in the non-ventilated bed. The whole body thermal sensation (WTS) and acceptability votes were decreasing over time for the non-ventilated bed condition. Significant differences in the local thermal sensation LTS and the LTS acceptability votes between the two conditions could be found only for some body parts and time intervals. No draught was reported.

PRACTICAL IMPLICATIONS
The total volume mixing ventilation strategies recommended by the present standards for reduction of the risk of airborne cross-infection is inefficient. Advanced ventilation methods, such as the HBIVCU, can improve the bed micro-environment. The exposure of medical staff and visitors to exhaled air from a sick lying in bed person will be reduced.

KEYWORDS
Human subject response, hospital bed ventilation, cross-infection control, perceived air quality, thermal sensation

1 INTRODUCTION
In modern hospitals ventilation is one of the most important methods for control of the spread of cross infection. The existing strategies for space ventilation in hospital facilities aim to dilute the polluted room air by supplying more outdoor air. The international standards and guidelines recommend total volume room air distribution with ventilation rates of up to 12 ACH in infectious and 6 ACH in recovery wards and normal patient rooms (CDC guidelines, 2005; ASHRAE 170, 2008). Supplying more clean air by increasing the ventilation rates would dilute the polluted room air, but this method for reducing the risk of airborne transmission increases the energy consumption of the mechanical ventilation. The airflow distribution and interactions in the room, the distance between the source and the recipient, the layout of the room, etc. may have greater influence on the spread of cross–infections than the ventilation rate of the total volume ventilation (Bolashikov et. al, 2010). In fact, the increased ventilation rate may cause complex flow interactions and diffusion which can lead

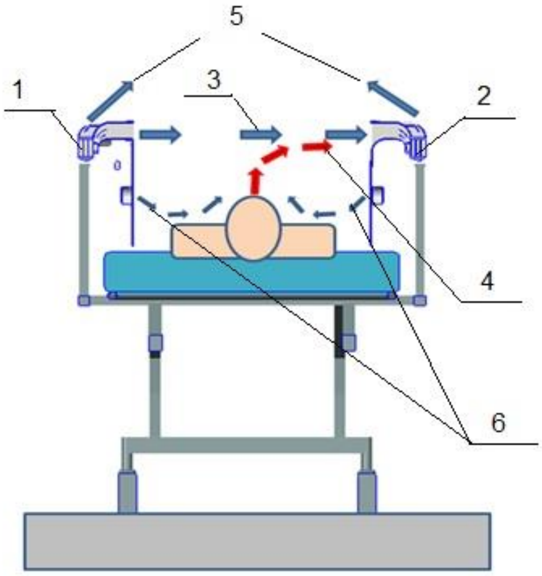
to even higher exposure for the room occupants (Sze To et al, 2009). Increase of the ventilation rate may also cause risk of draught discomfort for the patients due to the elevated background velocities in the occupied spaces.

At present no reliable ventilation strategy for reduction of the airborne cross-infection in hospital rooms exist. A possible solution to avoid the spread of contaminants in hospital premises is the use of personalized ventilation (PV). Personalized Ventilation is reported to be one of the most effective ways for improving occupants' inhaled air quality and reduction of exposure to indoor generated pollution sources, (Melikov et. al, 2003; Melikov, 2004, Kaczmarczyk et. al., 2006; Cermal et. al., 2007). A novel method for advanced hospital ventilation, named HBIVCU was developed (Melikov et. al., 2011). The working principle of the HBIVCU is based on both pollution source control and airflow control. The HBIVCU can provide better indoor air quality and decrease the risk of airborne cross- infection at lowered background ventilation rates by employing more effective air distribution method. The HBIVCU supplies clean air at low velocity close to the breathing zone of the patient in the bed and locally exhausts the air from the pulmonary activity of the patient. This leads to reducing the spread of contaminated air in the room.

The performance of the HBIVCU was studied with human subject experiment. The goal of the study was to identify human response to the bed microenvironment generated by a hospital bed with installed HBIVCU and to compare it with the response to the environment at a standard hospital bed without local ventilation. The subjective vote of 32 participants was collected and compared for statistical significance. Some of the obtained results are presented in this paper.

2 MATERIALS/METHODS

The principle of operation of the HBIVCU, which was evaluated during the experiments, is presented in Figure 1. The unit is installed on a class - A hospital bed. The HBIVCU is mobile and able to follow the bed adjustments. Two air terminal devices (1 and 2) are installed on the two sides of the bed close to the patient's head. The Supply Air Terminal Device (S – ATD, 1) supplies fresh air horizontally above the patient at low velocity. The supplied air guides the polluted air exhaled/coughed by the patient toward the Exhaust Air Terminal Device (E - ATD, 2), located on the opposite side, where it is exhausted before mixing with the room air. The two ATDs are mounted on the bed support frame. They are connected to air conditioning and distribution box (main unit), installed at the back of the bed on the side of person's head. The air expired from the pulmonary activities of the sick person in the bed is captured by the E – ATD and is cleaned from pathogens via UVC light or other cleansing techniques inside the main unit. The cleansed air is then discharged back into the room. As presented on Figure 1, the clean air is supplied by the HBIVCU in horizontal direction (3), in upward vertical/inclined direction (5) and in downward direction (6) on the two sides of the person lying in the bed. The air from the horizontal jet (3) can be heated or cooled at three different levels. Control of both the temperature and the flow rate of the horizontal jet and control over the flow rate of the vertical air curtains is provided to the person in the bed. The purpose of the two upward vertical air curtains (5) is to prevent the patient from being exposed to contaminated air coming from a sick person (doctor, nurse or other occupants) in the room. The two downward vertical curtains (6) provide fresh air close to the patient's berating zone



a)

b)

Figure 1.a) HBIVCU working principle: 1- S-ATD; 2- E-ATD; 3- horizontal air jet; 4 –exhaled air by the patient; 5 – vertical upward/inclined air curtains; 6 – vertical downward air curtains , b) The HBIVCU prototype used in the experiment

The human subject experiments were designed and performed in two neighbouring full-scale test rooms each with dimensions of 6 m x 3 m x 3 m (L x W x H). The rooms were furnished to simulate a hospital isolation room with a bed, a desk with chair and a clothes changing partition. Figure 2 presents the layout of the two test rooms. Mixing type ventilation without recirculation was used to condition the air in the rooms. The thermal conditions for both cases were identical. The room air temperature was set to 23 ^{o}C with air change rate of 9 h^{-1}. The relative humidity in both rooms was not controlled, but it was continuously measured (42%).

32 persons (17 male and 15 female) participated in the experiment. All participants were healthy and non-smokers. The participants were divided into 16 groups. Each group consisted of 2 persons who participated in two experimental sessions – one session every week. Each session was with duration of 2 hours. During the experiments the subjects were exposed randomly to one of the tested conditions (one person per condition): 1) Hospital bed with integrated ventilation unit (Ventilated Bed - VB) and 2) Hospital bed without ventilation unit (Not Ventilated Bed - NVB)

The experimental procedure, which was followed during the experiments, is presented in Figure 3. Upon arrival the subjects acclimatized in the test room for a period of 30 min. During this time they were asked to fill in the first set of questions, printed on paper. After this they changed their clothes with pajamas that resemble standard hospital garments. At the end of the 30 minutes acclimatization the subjects were asked to lie in the bed. Both VB and NVB were equipped with bed sheet, a pillow and a quilt. There was individual bed sheets provided for every person. The subjects were given the opportunity to adjust the position of the bed according to their body posture preference. During the 60 min exposure time, they were filling software based questionnaires every 20 min using tablets. Overall 4 sets of software based questionnaires were filled. In between two sets of questionnaires the subjects were reading a book or a magazine. The subjects exposed to the VB condition were encouraged to adjust the temperature and the flow rate of the flow generated by the HBIVCU so that they felt comfortable. After one hour in the bed the subjects got up from the bed and filled in the last set of questions on paper. The subjects were asked to comment on the experienced bed microenvironment during the exposure in the VB and the NVB condition. Then they changed back to their everyday outfit and left. The described procedure was identical for all experiments.

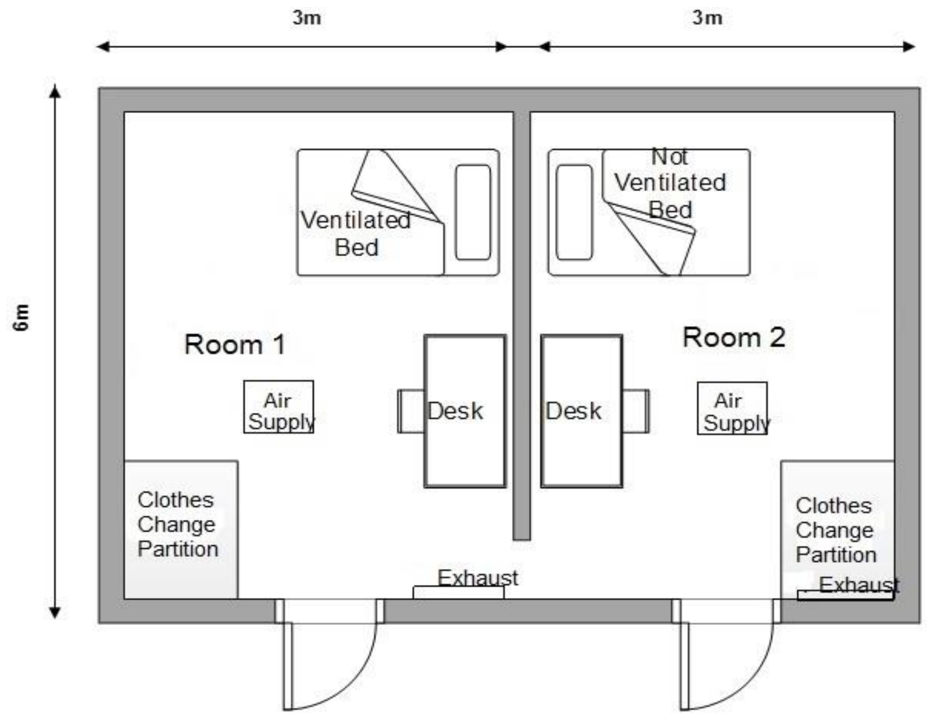


Figure 2 Layout of the experimental set up

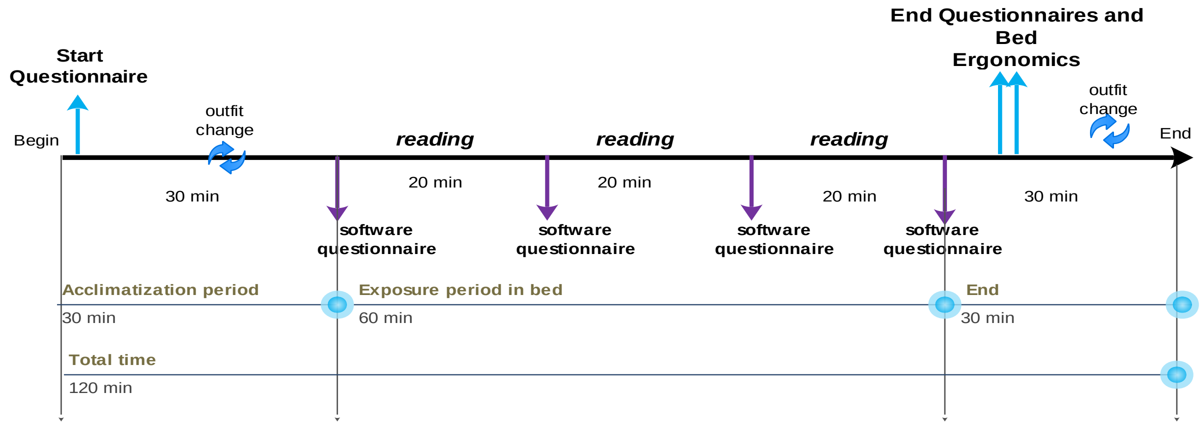


Figure 3 Experimental Procedure

The subjective vote on the microenvironment generated by the HBIVCU was evaluated with standardized questionnaires (EN 1525, 2007). The data base obtained from the questionnaires was analyzed for statistical significance. Each data sample of 32 values (collected from 32 subjects) was tested for normality using the Shapiro-Wilcoxon test. The level of significance (p-value) was accepted to be 0.05. The results from the test showed that the collected data were not normally distributed. For testing significant difference in the results were applied the Wilcoxon signed rank test and the Friedman test were applied.

3 RESULTS

The individual votes reported by the subjects were used to calculate the median vote. The error bars in the figures show the 25 and 75 percentiles. The significant differences ($p<0.05$) of the compared results are denoted with "*". Figure 4 shows the median values of the perceived air quality (PAQ) acceptability. The PAQ acceptability in the VB case increased with time (p=0.000 Friedman Test). The PAQ acceptability in the VB case was higher compared to the NVB case, but significant difference between the results could be observed only for some time intervals.

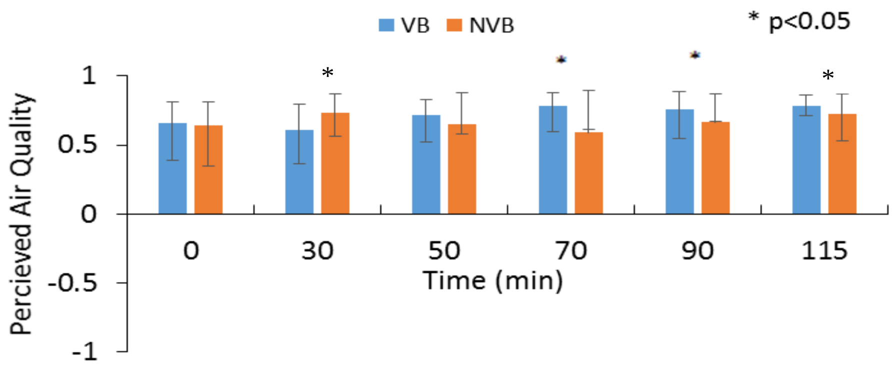


Figure 4 Median vote for the perceived air quality. The acceptability scale is from -1 "Clearly unacceptable" to -0,01 "Just unacceptable" and from 0,01 "Just acceptable" to 1 "Clearly acceptable" (DS EN 15251 2007)

Figure 5 a) presents results on the whole body thermal sensation (WTS) vote of the subjects. The WTS votes for both VB and NVB case decreased over time, but there was statistical significance in the votes only for the NVB case. For the NVB case the WTS vote was significantly decreasing over time (p=0.049 Friedman Test). Figure 5 b) presents results for the WTS acceptability. In the VB case the WTS acceptability was increasing over time (p=0.043 Friedman Test).

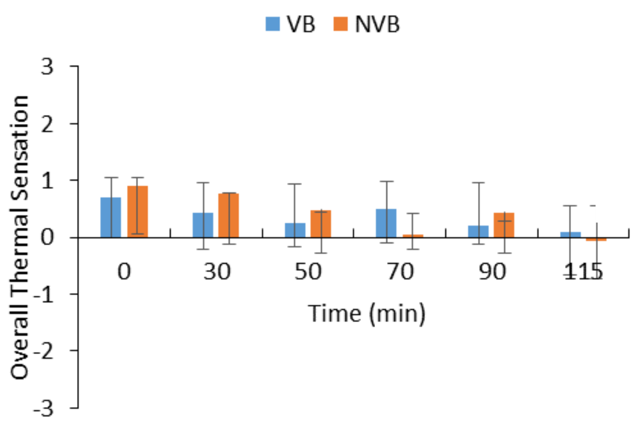


Figure 5 a) Voted whole body thermal sensation. The thermal sensation scale is: -3 "Cold", -2 "Cool", -1 "Slightly cool", 0 "Neutral", 1 "Slightly warm", 2 "Warm", 3 "Hot"

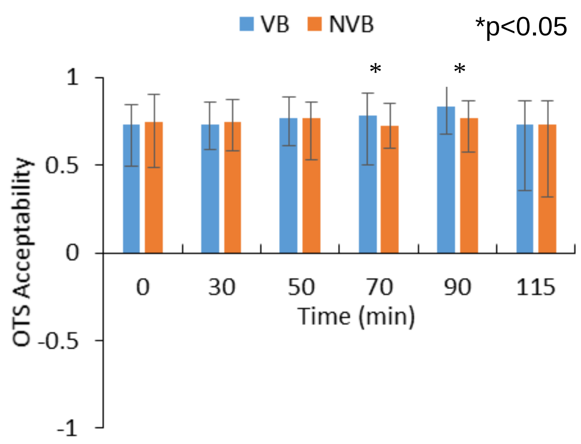


Figure 5 b) Voted whole body thermal sensation acceptability. The thermal acceptability scale is: -1 "Clearly unacceptable", -0,01 "Just unacceptable", 0,01 "Just acceptable", 1 "Clearly acceptable"

The median response for the local thermal sensation (LTS) and LTS acceptability of the body parts exposed to the flow generated by the HBIVCU are shown Table 1. Exposed body parts are – top of the head, left and right face and ear, left and right lower arm and hand and left and right shoulder. The LTS and LTS acceptability was evaluated only for the period of exposure in bed. The presented results show the median vote of the subjects from the beginning of the exposure (30^{-th} min) till the end of the exposure (90^{-th} min).

Table 1 Median vote of subjects from the 30^{-th} min till the 90^{-th} min of the exposure

		VB Case				NVB Case			
Body Part		**30-th min**	**50-th min**	**70-th min**	**90-th min**	**30-th min**	**50-th min**	**70-th min**	**90-th min**
top of head	LTS	-0.02	0.07	0.05	0.05	0.23	0.07	0.10	0.02
	LTS Acceptability	0.81	0.86	0.84	0.90	0.78	0.84	0.85	0.87
right face and ear	LTS	0.05	0.03	0.08	0.09	0.19	0.06	0.05	-0.02
	LTS Acceptability	0.81	0.86	0.84	0.85	0.80	0.85	0.81	0.80
left face and ear	LTS	-0.07	-0.01	0.19	0.01	0.06	0.02	0.06	-0.03
	LTS Acceptability	0.85	0.74	0.82	0.85	0.78	0.82	0.76	0.76
right lower arm and hand	LTS	0.05	0.02	0.06	-0.02	0.12	-0.02	-0.05	-0.02
	LTS Acceptability	0.84	0.83	0.76	0.88	0.77	0.78	0.80	0.78
left lower arm and hand	LTS	0.01	-0.01	0.02	-0.03	0.06	0.12	-0.01	-0.03
	LTS Acceptability	0.85	0.80	0.80	0.84	0.76	0.80	0.76	0.76
right shoulder	LTS	-0.01	-0.04	0.01	-0.06	-0.01	-0.10	-0.11	-0.11
	LTS Acceptability	0.81	0.80	0.81	0.84	0.74	0.79	0.70	0.79
left shoulder	LTS	-0.02	-0.03	0.00	-0.08	-0.10	-0.04	-0.06	-0.20
	LTS Acceptability	0.85	0.82	0.77	0.81	0.74	0.74	0.74	0.78

4 DISCUSSION

The perceived air quality showed tendency to be higher during the exposure in the ventilated bed than the exposure in the bed without the prototype installed. However, the difference was statistically significant only during some periods of the exposure time. Nevertheless, most of the subjects commented that the vertical downward flow, generated by the ventilation system, was quite pleasant. The air supplied downward was clean. Although, supplied at the head region close to the breathing zone, some mixing of this clean air with polluted room air occurred. Thus, the better PAQ at the VB might only partly be a result from the cleanness of the micro environment. Another reason for the better PAQ might be the elevated air velocity caused by the vertical downward flow and the temperature of the flow, which was slightly cooler than the temperature in the room. Research has shown that PAQ improves when the inhaled air temperature decreases (Fang et al. 1998, Melikov and Kaczmarczyk 2012) and air velocity at the face region increases (Melikov and Kaczmarczyk 2012). The PAQ acceptability in the VB case was higher compared to the NVB case, but the air supplied in the test rooms by the total volume ventilation was clean and with elevated air change rate (9 ACH). In practice, the air in hospital rooms is polluted with various odorous contaminants and might not be conditioned at all. If the HBIVCU is used under such conditions of decreased air quality, the difference in the PAQ between the VB and NVB case could be even higher. These remains to be studied.

In addition to improving the PAQ, implementing the HBIVCU in hospital rooms, can also improve the thermal comfort of the occupants. Since the HBIVCU provides three levels of heating and three levels of cooling of the horizontally supplied air and also control over the flow rate of the vertical flow, the unit can be used to satisfy a large range of preferred environmental condition. The results for the WTS vote of the subjects showed tendency for less warm thermal sensation in the bed with ventilation compared to the bed without ventilation. However, the difference was not statistically significant. The lower WTS vote for the VB case might be result from the elevated air velocities, generated by the ventilation unit, which caused more heat loss due to convection. Although, the WTS in the VB condition was felt less warm, the results from the statistical analysis showed that over time the WTS acceptability in the NVB case was decreasing and the WTS acceptability vote for the VB case was increasing. The increase of the WTS acceptability vote over time in the VB case might be due to the fact that the subjects had control over the flow rate and the temperature of the air, supplied by the ventilation unit. The air temperature in both test rooms was kept at 23ºC, which created a comfortable thermal environment. However, if the air temperature in the hospital room is not controlled/improperly controlled, the use of the HBIVCU might be very beneficial, because it will provide the bed occupant with the option to adjust locally the preferred airflow and temperature and thus improve the thermal comfort.

An important focus of the current study is to identify if the HBIVCU creates risk of local thermal discomfort and especially draught. The results show a general tendency for all of the exposed body parts to have the LTS voted as ”neutral” and the LTS acceptability as “clearly acceptable”. Although, there was no significant difference in the LTS acceptability votes between the two conditions, it can be observed that for most of the time the LTS acceptability of the exposed body parts in the VB case was slightly higher compared to the NVB case. This could again be explained with the fact that the subjects had control over the flow rate and the temperature of the air supplied by the ventilation unit. The HBIVCU supplies clean air from the S-ATD, located on the left side of the patient in the bed, and exhausts the supplied air mixed with the exhaled air from the bed occupant, from the E-ATD, located on the right side of the patient. Results from physical measurements, performed with the HBIVCU (not reported), show that the velocities, generated by the supply side of the ventilated bed, are higher compared to the exhaust side. This creates a non-uniform environment which might cause the subjects to evaluate the left side of their body as colder compared to the right. However, a statistically significant result that confirms this observation was found only for the local thermal sensation and acceptability of the left shoulder in the VB case. The LTS and the LTS acceptability decreased over time. The subjects reported that they felt difference in the air velocity coming from the left and the right side of their body, but they did not comment on feeling uncomfortable. There were no complaints of draught discomfort during the exposure time in the VB case.

The HBIVCU supplies clean air close to the breathing zone of the bed occupant, and thus improves perceived air quality. It also improves the thermal comfort by providing individual control of the velocity and the temperature of the personalized flow. However, the greatest benefit of the ventilation unit is in providing healthier working environment for the medical stuff and faster recovery of the patients by reducing the risk of nosocomial infections. The working principle of the system allows it to be easily implemented in practice, even in rooms without mechanical ventilation. The HBIVCU has potential to gain advantage over the use of total volume ventilation with elevated air change rates, because it can significantly decrease the risk of cross-infection in hospital rooms and save energy by using relatively smaller flow rates.

5 CONCLUSIONS

The following conclusions can be drawn based on the results of the current study:

- The use of the bed ventilation unit significantly improved the PAQ compared to the bed without local ventilation installed.
- The WTS votes were close to "neutral" and the WTS acceptability was close to "clearly acceptable". The WTS acceptability vote for the NVB case was decreasing over time and for the VB case – increasing.
- The LTS reported in the two cases, VB and NVB, was not significantly different. However, there was a general tendency for the ventilated bed to provide slightly more cooling compared to the standard bed. The LTS acceptability for both VB and NVB cases was high. Although there was no significant difference in the subjective vote, the LTS acceptability in the VB case was slightly higher compared to the NVB.
- There were no draught complaints reported by the subjects when VB was used.

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