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Journal of
The Arab Institute of Navigation
Semi Annual Scientific Journal
Issue 44 (volume 2) July 2022
ISSN (2090-8202)
INDEXED IN (EBSCO)

Contents

Effect of Occupancy on Air Outlet Design Alternatives in Ship's Crew Cabins

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المستخلص

عادة ما تكون أماكن الإقامة على متن السفن صغيرة الحجم ، مما يقلل من إمكانية الاختلاط المناسب بين الهواء النقي والهواء الحالي. بالنسبة للسفن ذات الأطقم الكبيرة ، يشغل أربعة من أفراد الطاقم بعض الكبائن ، مما يزيد من الأحمال الحرارية في مثل هذه الأماكن. من أجل الاستخدام السليم لهذه الكبائن عادةً ما يتم استخدام أسرّة بطابقين ، مع ركود الهواء المحبوس بين الأسرة السفلية والعلوية تقريبًا. من ناحية أخرى ، و عادة ما تكون الأسرة العلوية قريبة جدًا من السقف مما يجعل الوضع أسوأ.

تم النظر في القياسات الميدانية لمعامل الهواء داخل مقصورة طاقم سفينة حقيقية ومحاكاتها باستخدام برنامج Cfd لدراسه العلاقة بين عدد الركاب ومعاملات التصميم الرئيسية. أظهرت النتائج أنه يمكن الوصول إلى الراحة الحرارية من خلال مزيج مثالي من معايير التصميم الرئيسية. سيتم أخذ العلاقة بين الحمل الحراري ومعاملات التصميم الرئيسية في الاعتبار لدراسة الجدوى المستقبلية

Abstract

Accommodation spaces onboard ships are normally of small dimensions, which reduce the possibility of proper mixing between fresh and existing air. For ships with large crews, some cabins are occupied by four crew members, which increases heat loads in such spaces. For proper use of these cabins bunk beds are usually used, with the air trapped between lower and upper beds almost stagnant. On the other hand, the upper beds are usually very close to the ceiling which makes the situation even worse. Field measurements of air parameters inside a real ship crew cabin were considered and simulated using a well-known Computerized Fluid Dynamics (CFD) software to study the relationship between number of occupants and main design parameters. Results showed that thermal comfort can be reached through an optimal combination of main design parameters. Correlation between heat load and main design parameters would be taken into consideration for future feasibility study.

Keywords: human factors, crew comfort, indoor air quality.

1-INTRODUCTION

Ship volume is directly related to propulsion energy, i.e. engine capital and running costs. That is why ship owners prefer to give the most of the ship size to commercial needs. The Maritime Labor Convention (MLC) which came into force in 20 August 2013 and amended 2016, forces shipbuilders to maintain minimum detailed requirements for accommodation needs. These rules compromise between the ship owners and crew needs (ILO, 2020). Therefore, accommodation area is relatively small, and ceiling height is also low i.e., small air volume within the accommodation spaces. For ships with large crew number, there are rooms inhabited by four crew members, which increases heat load for such cabins. Also, due to the optimal utilization of ship spaces, usually these cabins are provided with two upper and lower level bunk beds, posing areas where the air is almost completely stagnant, such as cabin corners and the spaces between each upper and lower level bunk bed. Additionally, it should be observed that the two upper level beds are always very close to the ceiling of the cabin. Consequently, using the traditional methods of handling the air in ships cabins "where air enters from a distributor located in the center of the cabin ceiling and exists from a register located in the lower part of the cabin door", it is necessary for achieving good air distribution in the space within each upper and lower bunk beds to increase the inlet air speed significantly, which negatively affects the area above the two upper level beds.

2- LITERATURE REVIEW

The following section discusses the previous research efforts through available Litreatur Review. Jinob Chen et al analyzed experimentally and numerically the ship cabin air-conditioning heating characteristics with respect to cabin inlet air velocity and direction through air distribution evaluation index. The study found out the suitable of supply air angl of ship cabin in high air velocity heating conditions (Chen et al, 2015). Nawaz et al studied thermal comfort in a ship airconditioning system by evaluating the performance of different types of air supply outlets. The researchers have performed Thermal comfort analyses using Simulation software where they could change the number, type and position of air supply outlets and the comfort was optimized by evaluating the values of temperature, velocity, and diffusion percentage. They concluded that air supply outlet is a vital part in any type of (HVAC) Heating ventilation & Air conditioning system design, as its number, type and position has a significant effect on the air distribution and thermal comfort in a subject space (Nawaz et al, 2013). Makhoul A. et al studied room air ventilation patterns experimentally and numerically. They introduced ceiling-mounted personalized ventilation nozzle assisted by small desk-mounted fan. Their comparative study has revealed the advantage of what is called personalized ventilation over the traditional mixing ventilation pattern. The desk-mounted fans were able to reduce the convection plumes around the occupant and improved the performance of the single jet Personalized Ventilation (PV) nozzle by doubling the ventilation effectiveness and improving comfort. They could also achieve a reduced energy saving by up to 13% when compared with conventional mixing ventilation systems (Makhoul et al, 2013).

Makhoul. et al extended their study of room air ventilation patterns experimentally and numerically by introducing an integrated ceiling diffuser and personalized ventilator coaxial nozzle system to localize the air conditioning and fresh air needs around the occupants. The coaxial nozzle minimized air entrainment between the fresh air stream and the room air and allowed effective delivery of clean air. Practical verification was performed with ten human participants who have undergone three different experiments and the survey showed good agreement with the predicted numerical results. The study has also concluded that localized air conditioning system reduced the energy consumption by up to 34% when compared with conventional mixing systems and would provide the same level of thermal comfort (Makhoul et al, 2013).

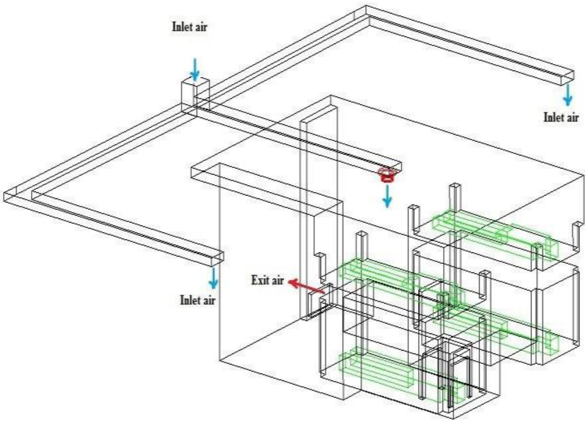
Rees. et al set up a test chamber equipped with displacement ventilation and chilled ceiling panel systems. Further, the vertical temperature gradient and air velocities for different experiments were investigated. The results of displacement ventilation were consistent with other studies and linear temperature gradients were found in all cases. In addition, significant mixing, indicated by reduced temperature gradients, was evident in the upper part of the room in the chilled ceiling results at higher levels of heat gain. Visualization experiments, velocity measurements and related numerical studies indicated that with greater heat gains the plumes have sufficient momentum to drive flow across the ceiling surface and down the walls. Furthermore, in cases with moderately high internal gains, comparison of the temperature gradients indicated that the effect of ceiling surface temperature on the degree of mixing and the magnitude of the temperature gradient were of secondary importance. A thorough review of the open literature has revealed lack of research on ship crew cabins air quality, although classification societies concerned with the maritime industry have shown persistent interest, while both American Bureau of Shipping (ABS) and Det Norske Veritas-Germanischer Lloyd (DNV-GL) societies set up a compulsory crew habitability codes to be implemented onboard their certified ships. The codes contain detailed crew thermal comfort in addition to many other comfort ratings. The aim of the paper to determininig effect of ooccupancy on air outlet design alternatives in ships crew cabins. (ABS, 2016) & (DNV-GL, 2017) And to investigate the relationship between heat load and design alternatives for compact cabins, using CFD.

3. CASE STUDY

The selected cabin belongs to an existing ship called “Ocean Taba”, shown in Fig. (1), serving in Abo-Quir gulf, Alexandria, Egypt, territorial water, in the Mediterranean Sea

Figure(1). Ocean Taba ship, general view.

Air is supplied to each cabin through a duct and a single diffuser and returns to the fan coil unit by means of an exhaust fan extracting the exit air from the cabin door to the hallo ways, as shown in Fig. (2). A typical “Ocean Taba” ship crew cabin was selected to investigate experimentally the airflow pattern and temperature distribution within the cabin. The cabin is 2.85 m width, 4.03 m length and 2.1 m height. The furniture incorporates two bunk beds, one suitcase, one big table, one small table, and a sofa. The cabin incorporates two critical compartments, which are the spaces between upper and lower levels in each bunk bed. Only one wall is insulated, which is the external wall. Air enters the cabin through a 25 cm diameter diffuser placed in the middle of the ceiling, and exits from (43.8 cm wide x 22.5 cm height) register in the middle of the door, 1.5 cm apart from the lower edge of the door, as shown in Fig.(3).



Figure(2). Air handling ducts to/from selected cabin.

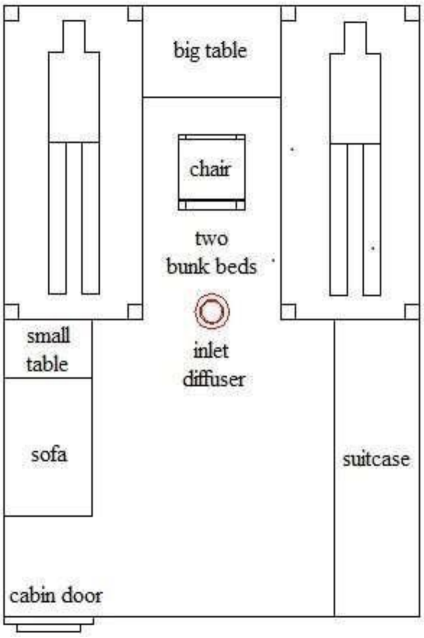


Figure (3). The selected test space.

3.1 SURVEY POINTS DEFINITION

In order to assign symmetrical survey points, the x, y and z increments were taken all equal to 0.85
m. Fourteen points were excluded, however, because they were located out of the interior air domain. Table 1 defines the thirty-one survey points, S-1 to S-31, considered at predefined horizontal planes (Z-1 to Z-3); 0.2 m, 1.05 m and 1.9 m above the cabin floor.

Table (1). Survey point coordinates.

Point designation	Coordinates (m)			Point designation	Coordinates (m)		
	x	y	Z		x	y	z
S-1	0.575	0.32	0.2	S-17	1.425	3.72	1.05
S-2	1.425	0.32	0.2	S-18	2.275	3.72	1.05
S-3	1.425	1.17	0.2	S-19	0.575	0.32	1.9
S-4	1.425	2.02	0.2	S-20	1.425	0.32	1.9
S-5	1.425	2.87	0.2	S-21	0.575	1.17	1.9
S-6	0.575	0.32	1.05	S-22	1.425	1.17	1.9
S-7	1.425	0.32	1.05	S-23	0.575	2.02	1.9
S-8	0.575	1.17	1.05	S-24	1.425	2.02	1.9
S-9	1.425	1.17	1.05	S-25	2.275	2.02	1.9
S-10	0.575	2.02	1.05	S-26	0.575	2.87	1.9
S-11	1.425	2.02	1.05	S-27	1.425	2.87	1.9
S-12	2.275	2.02	1.05	S-28	2.275	2.87	1.9
S-13	0.575	2.87	1.05	S-29	0.575	3.72	1.9
S-14	1.425	2.87	1.05	S-30	1.425	3.72	1.9
S-15	2.275	2.87	1.05	S-31	2.275	3.72	1.9
S-16	0.575	3.72	1.05				

3.2 EFFECT OF HEAT LOAD

Previous work had been conducted for the selected cabin , modifying air cabin inlets and exits as shown in Fig. (4). A typical proposed diffuser is shown in Fig (5). It is seen to consist of 81 perforations, each of 30 mm diameter and a pitch of 50 mm. As such, the total inlet area per diffuser is 0.057 m2.

Based on the performance of design alternatives, the best design was singled out. The potential capabilities and salient features of this best design are further investigated through studying the effect of varying the heat load on Air Diffusion Performance Index (ADPI) which based on acceptance and recongination that it is not possible to achives acomfortable level of 100 prcent but 70 prcent acceptance and designer should plan to have an ADPIof grater than 80 . The final proposed design was investigated to study the relation between cabin heat load (number of occupants) and the ADPI. While in real situation the number of occupants is subject to change, it is necessary to predict the response of air diffusion performance to the change of number of occupants. In each case of the prediction study the load is reduced by 25% (one occupant). More important still, the study assumes 2 cases, namely a) constant mass flow rate (Pattern 1-1 to Pattern 1-4) and b) variable mass flow rate (Pattern 2-1 to Pattern 2-4) i.e.

reducing the mass flow rate with the reduction of number of occupants.

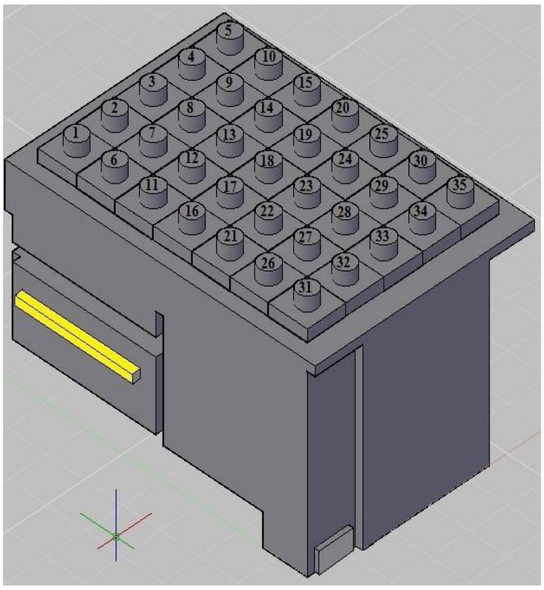


Figure (4). The modified test space.

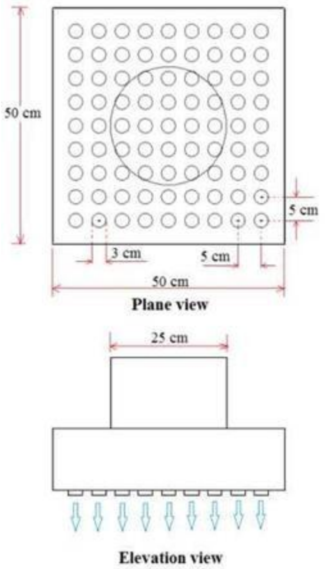


Figure (5). Proposed diffuser details.

3.5 DATA REDUCTION

A parameter called thee effective draft temperature (EDT), combining the effects of uneven space air temperature and air movement, is often used to assess the deviations of local magnitudes from the mean value, and is defined as:

$$EDT = T - Tr \; - a(V - Vrm) \qquad (1)$$

where T and V are space air temperature and velocity, respectively, at a specific location, Tr is mean space air temperature or set point, a is a conversion constant to combine the effects of space air temperature and air movements (its value is 8 when T is expressed in °C and V in m/s or 0.07 when T is expressed in °F and V in fpm), and Vrm is the desirable mean space air velocity, which is closely related to the space air temperature and could be taken as 0.15 m/s (29.5 fpm).

The air diffusion performance index ADPI in percent, which is used to evaluate the performance of space air diffusion, is calculated as:

$$ADPI = \frac{NEDT X 100}{N} \qquad (2)$$

where NEDT is number of points measured in occupied zone in which: -1.7°C<EDT<+1.1°C (3°F<EDT<+2°F) and N is total number of points measured in occupied zone. The higher is the ADPI, the higher the percentage of occupants who feel comfortable will be. Maximum ADPI reaches 90%. In the current study, ADPI is taken to be the main design criterion.

4.Results and Discussion

Table (2). lists values of air velocity, V (m/s) and temperature, T (°C) and EDT (°C) as given by the CFD model output for different heat loads, namely: 100%, 75%, 50% and 25% for Pattern 1 cases (constant mass flow rate). Based on the results listed in Table (2), values of ADPI were calculated and are listed in Table (3). It is clear from this table that the ADPI values are almost constant, which is also shown in Figure 6 representing the relation between ADPI and occupancy (%). Similarly, Table (4). lists values of air velocity, V (m/s) and temperature, T (°C) and EDT (°C) as given by the CFD model output for different heat loads, namely: 100%, 75%, 50% and 25% for Pattern 2 cases (variable mass flow rate). Based on the results listed in Table 4, values of ADPI were calculated and are listed in Table (5). Contrarily to the former pattern (Pattern 1), this pattern (Pattern 2) shows considerable variation of ADPI values with heat load. For instance, by reducing load to 50% a change of 14.3% in ADPI value has been obtained. Further reduction of heat load to 25% resulted in 17.8% ADPI reduction. These results are also depicted in Fig.(7).

In addition to ADPI criterion verification, EDT distribution Criterion has also been investigated. Fig. (8) illustrates EDT distribution throughout three different layers for the case of varying mass flow rate (Pattern 2). Results show that reducing the heat load, combined with varying the mass flow rate, has resulted in significant discomfort in the three layers, layer Z-3 being the worst. This result is particularly important, because it implies that reducing the heat load does not necessarily mean that the mass flow rate can also be reduced proportionally.

Table (2). Patterns (1) results.

Point designation	Pattern 1-1			Pattern 1-2			Pattern 1-3			Pattern 1-4		
	V (m/s)	T (oC)	EDT (oC)	V (m/s)	T (oC)	EDT (oC)	V (m/s)	T (oC)	EDT (oC)	V (m/s)	T (oC)	EDT (oC)
S-1	0.06	18.07	-0.17	0.06	18.04	-0.20	0.06	18.03	-0.21	0.06	17.98	-0.25
S-2	0.01	18.10	0.27	0.01	18.07	0.24	0.01	18.07	0.23	0.01	18.02	0.19
S-3	0.01	18.04	0.26	0.01	18.00	0.22	0.01	17.99	0.22	0.01	17.94	0.16
S-4	0.01	18.08	0.26	0.01	18.02	0.21	0.01	18.00	0.19	0.01	17.94	0.13
S-5	0.01	18.34	0.52	0.01	18.28	0.46	0.01	18.26	0.44	0.01	18.20	0.38
S-6	0.03	17.96	0.02	0.03	17.93	-0.01	0.03	17.93	-0.02	0.03	17.87	-0.07
S-7	0.01	17.95	0.10	0.01	17.92	0.07	0.01	17.91	0.06	0.01	17.87	0.02
S-8	0.01	17.90	0.04	0.01	17.85	0.00	0.01	17.84	-0.01	0.01	17.77	-0.08
S-9	0.01	17.86	0.02	0.01	17.83	-0.02	0.01	17.82	-0.02	0.01	17.76	-0.08
S-10	0.01	18.10	0.28	0.01	17.93	0.11	0.01	17.92	0.10	0.01	17.83	0.01
S-11	0.02	17.81	-0.07	0.02	17.77	-0.11	0.02	17.75	-0.12	0.02	17.67	-0.21
S-12	0.01	18.17	0.32	0.01	18.14	0.29	0.01	18.07	0.22	0.01	18.01	0.17
S-13	0.03	18.63	0.69	0.03	18.14	0.19	0.03	18.13	0.19	0.03	17.96	0.02
S-14	0.03	17.97	0.00	0.03	17.94	-0.02	0.03	17.93	-0.03	0.03	17.72	-0.25
S-15	0.03	18.35	0.38	0.03	18.32	0.35	0.03	18.15	0.18	0.03	18.02	0.05
S-16	0.02	18.97	1.06	0.02	18.86	0.94	0.02	18.85	0.94	0.02	18.55	0.64
S-17	0.03	18.71	0.73	0.03	18.70	0.72	0.03	18.70	0.72	0.03	18.43	0.45
S-18	0.02	18.96	1.02	0.02	18.95	1.02	0.02	18.91	0.98	0.02	18.75	0.82
S-19	0.01	18.00	0.21	0.01	17.98	0.19	0.01	17.98	0.18	0.01	17.93	0.14
S-20	0.03	17.48	-0.50	0.03	17.47	-0.52	0.03	17.46	-0.52	0.03	17.43	-0.55
S-21	0.01	17.83	0.02	0.01	17.81	-0.01	0.01	17.80	-0.02	0.01	17.73	-0.09
S-22	0.03	17.45	-0.51	0.03	17.43	-0.53	0.03	17.43	-0.53	0.03	17.39	-0.57
S-23	0.03	17.11	-0.87	0.03	17.10	-0.88	0.03	17.09	-0.89	0.03	16.96	-1.02
S-24	0.04	17.04	-0.98	0.04	17.03	-1.00	0.04	17.03	-1.00	0.04	16.98	-1.05
S-25	0.03	16.93	-1.09	0.03	16.93	-1.09	0.03	16.93	-1.09	0.03	16.93	-1.09
S-26	0.01	18.98	1.18	0.01	18.97	1.17	0.01	18.97	1.17	0.01	17.73	-0.06
S-27	0.04	16.91	-1.13	0.04	16.91	-1.13	0.04	16.91	-1.13	0.04	16.83	-1.20
S-28	0.01	18.54	0.71	0.01	18.53	0.71	0.01	18.53	0.71	0.01	18.50	0.68
S-29	0.01	20.86	3.06	0.01	20.85	3.06	0.01	20.85	3.05	0.01	18.90	1.11
S-30	0.05	16.47	-1.67	0.05	16.47	-1.67	0.05	16.47	-1.67	0.05	16.46	-1.67
S-31	0.01	19.83	1.99	0.01	19.83	1.99	0.01	19.83	1.98	0.01	19.81	1.97

Table (3). Summary of Pattern (1) results (Constant mass flow rate).

Pattern	Vi	ADPI	Occupancy (%)
1-1	0.2143	90.3	100%
1-2	0.2143	90.3	75%
1-3	0.2143	90.3	50%
1-4	0.2143	93.5	25%

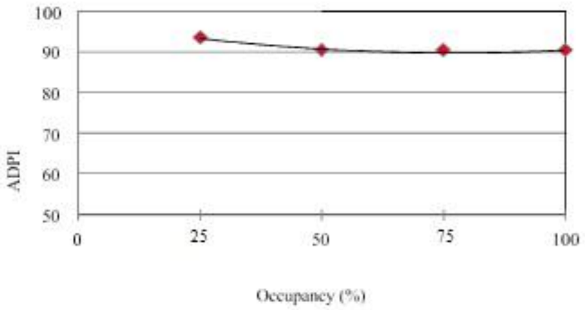


Figure (6). Correlation between ADPI and occupancy percentage for pattern 1.

Table (4). Patterns (2) results

Point designation	Pattern 2-1			Pattern 2-2			Pattern 2-3			Pattern 2-4		
	V (m/s)	T (oC)	EDT (oC)	V (m/s)	T (oC)	EDT (oC)	V (m/s)	T (oC)	EDT (oC)	V (m/s)	T (oC)	EDT (oC)
S-1	0.06	18.07	-0.17	0.05	18.20	0.06	0.04	18.39	0.33	0.03	18.54	0.57
S-2	0.01	18.10	0.27	0.01	18.23	0.41	0.01	18.41	0.61	0.01	18.56	0.78
S-3	0.01	18.04	0.26	0.00	18.17	0.40	0.00	18.36	0.60	0.00	18.52	0.77
S-4	0.01	18.08	0.26	0.01	18.20	0.40	0.01	18.38	0.60	0.00	18.54	0.77
S-5	0.01	18.34	0.52	0.01	18.43	0.63	0.01	18.58	0.79	0.01	18.90	1.12
S-6	0.03	17.96	0.02	0.02	18.11	0.20	0.02	18.31	0.44	0.01	18.49	0.65
S-7	0.01	17.95	0.10	0.01	18.10	0.27	0.01	18.30	0.49	0.01	18.48	0.69
S-8	0.01	17.90	0.04	0.01	18.04	0.21	0.01	18.26	0.45	0.01	18.44	0.65
S-9	0.01	17.86	0.02	0.01	18.02	0.20	0.01	18.24	0.43	0.01	18.43	0.64
S-10	0.01	18.10	0.28	0.01	18.12	0.31	0.01	18.33	0.55	0.00	18.48	0.71
S-11	0.02	17.81	-0.07	0.01	17.98	0.13	0.01	18.21	0.39	0.01	18.40	0.60
S-12	0.01	18.17	0.32	0.01	18.33	0.51	0.01	18.43	0.63	0.01	18.59	0.82
S-13	0.03	18.63	0.69	0.02	18.34	0.44	0.02	18.58	0.71	0.01	18.67	0.84
S-14	0.03	17.97	0.00	0.02	18.18	0.26	0.02	18.48	0.59	0.01	18.59	0.74
S-15	0.03	18.35	0.38	0.02	18.56	0.63	0.02	18.60	0.72	0.01	18.95	1.10
S-16	0.02	18.97	1.06	0.02	19.08	1.19	0.01	19.33	1.48	0.01	19.33	1.51
S-17	0.03	18.71	0.73	0.03	18.98	1.04	0.02	19.33	1.44	0.01	19.46	1.61
S-18	0.02	18.96	1.02	0.02	19.18	1.28	0.02	19.39	1.53	0.01	19.51	1.68
S-19	0.01	18.00	0.21	0.01	18.15	0.37	0.00	18.34	0.57	0.00	18.51	0.75
S-20	0.03	17.48	-0.50	0.03	17.69	-0.24	0.02	17.95	0.06	0.01	18.22	0.37
S-21	0.01	17.83	0.02	0.01	18.00	0.20	0.01	18.23	0.44	0.00	18.40	0.63
S-22	0.03	17.45	-0.51	0.02	17.66	-0.26	0.02	17.93	0.05	0.01	18.20	0.36
S-23	0.03	17.11	-0.87	0.02	17.38	-0.55	0.02	17.73	-0.15	0.01	17.91	0.07
S-24	0.04	17.04	-0.98	0.03	17.29	-0.68	0.02	17.62	-0.30	0.02	17.94	0.07
S-25	0.03	16.93	-1.09	0.03	17.12	-0.84	0.02	17.41	-0.50	0.02	17.81	-0.05
S-26	0.01	18.98	1.18	0.01	19.17	1.38	0.00	19.45	1.68	0.00	18.40	0.64
S-27	0.04	16.91	-1.13	0.03	17.19	-0.79	0.02	17.56	-0.37	0.02	17.87	0.00
S-28	0.01	18.54	0.71	0.01	18.78	0.97	0.01	19.10	1.30	0.01	19.46	1.68
S-29	0.01	20.86	3.06	0.01	21.08	3.29	0.01	21.34	3.57	0.00	19.51	1.75
S-30	0.05	16.47	-1.67	0.04	16.58	-1.47	0.03	16.79	-1.17	0.02	17.21	-0.68
S-31	0.01	19.83	1.99	0.01	20.19	2.37	0.01	20.67	2.87	0.01	21.21	3.42

Table (5). Summary of Pattern (2) results (Variable mass flow rate).

Pattern	Vi	ADPI	Occupancy (%)
2-1	0.2143	90.3	100%
2-2	0.1756	83.9	75%
2-3	0.1368	77.4	50%
2-4	0.0980	74.2	25%

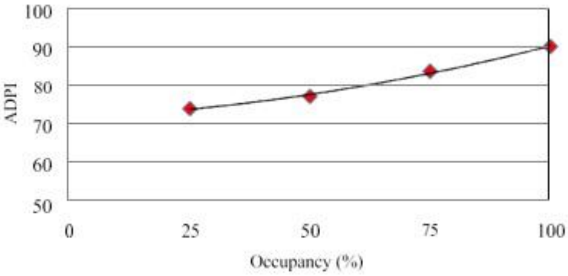


Figure (7). Correlation betwee ADPI and occupancy percentage for pattern 2.

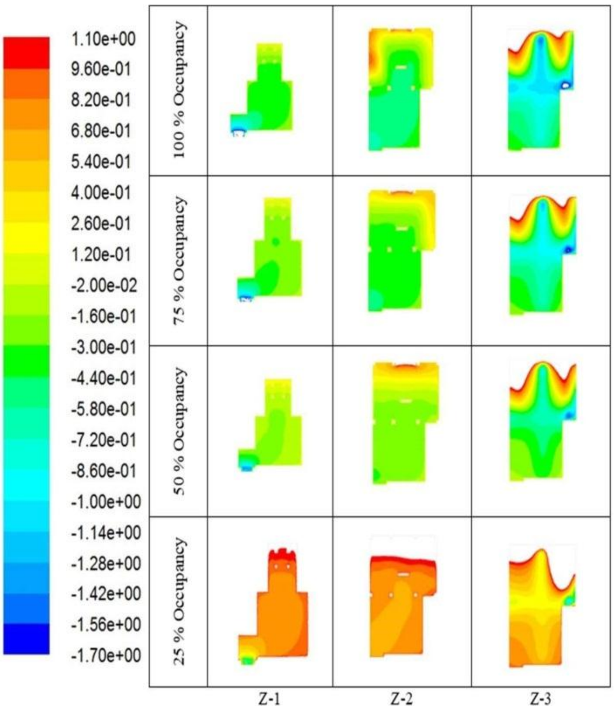


Figure (8). EDT distribution throughout layers Z-1, Z-2 and Z-3, for Pattern 2.

5. CONCLUSION

Based on the results of the current study, crew cabins are compact spaces with low heights, where the crew occupies most of the space volume. That is why inlet air parameters, and air distribution systems for such cabins must be handled very carefully when designing the ventilation system.

Additionally, mass flow rate to cabins occupied with large crew, need to keep constant in case of reducing heat load to maintain the required indoor air quality (IAQ) (ADPI =0.94 & APDIlim=0.9).

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