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Cabin Ventilation, Code Requirements and Experimental Results

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Abstract. If a lift cabin is built in accordance with the ventilation requirements specified in EN 81, it is almost universally assumed that the cabin is adequately ventilated. Experiments were conducted to confirm this assumption.

The experiments involved simulated entrapments of passengers for a period of 30 minutes in lifts installed at the Dubai, United Arab Emirates. Air quality was monitored during the entrapments. Several of the experiments had to be stopped before completion of 30 minutes as the air quality had degraded to levels considered to be unhealthy by occupational health authorities.

The experimental methods and their results are reported.

Recommendations for improved cabin ventilation are made based on the experimental results.

INTRODUCTION

If a lift cabin is built in accordance with the ventilation requirements specified in EN 81, it is almost universally assumed that the cabin is adequately ventilated. Experiments were conducted to confirm this assumption.

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BACKGROUND

EN 81-1 prescribes the following minimum ventilation requirements [1].

1. Cabins must have ventilation perforations in the upper and lower portion of the cabin.
2. The area of the perforations in the upper portion of the cabin must equal 1% of the cabin floor area.
3. The area of the perforations in the lower portion of the cabin must equal 1% of the cabin floor area.
4. The gaps around the car door can account for up to 50% of the required area.

EN81-1 makes no reference to forced ventilation (car fans).

The ASME A17.1 requires the following minimum ventilation (ASME, 2007) [2]:

1. Ventilation openings must be located within 300mm above the floor and in the space 1825mm above the floor. 50% of the openings must be in the lower portion of the walls and 50% must be in the upper portion.
2. The total natural ventilation must be equal to 3.5% of the floor area.
3. All of the gap around the doors can be considered.
4. The unrestricted opening around forced ventilation can also be considered.

In the simplest of terms, ASME requires 50% more natural ventilation than EN81-1.

The United Arab Emirates is in the process of developing a lift code. The author was part of the committee developing this code. The code is based upon EN81-1. However, many lifts have been installed according to the code in the country of origin of the lift. Therefore, many lifts are built in accordance with Japanese and Korean codes.

It is common practice in the Middle East for a lift manufacturer to provide an unfinished cabin shell. The interior decoration is provided by local contractors. As a result the only ventilation is from fans and door gaps.

INCIDENT

After filming a video scene, approximately 15 dancers entered a 1275 kg lift. A 1275 kg lift can carry 17 passengers. The dancers continued dancing or jumping in the lift and caused the safety gear to actuate. As a result, the dancers were trapped in the car.

Service technicians arrived on the scene and rescued the passengers in less than 15 minutes. The building was well air conditioned and the lift was in the interior of the building. However, some of the dancers reported that they were suffering from a lack of oxygen and one requested medical treatment. After observation the dancer was released.

When the author was informed of the incident, he dismissed the incident as hyperventilation but suggested that an investigation be started to identify what caused the breathing problems.

INVESTIGATION

The cabin design was reviewed and it was found to be in compliance with EN81-1, the code required by the building specifications. In fact, the natural ventilation exceeded the EN81-1 code by 16.5%.

It was decided that an experiment be conducted with another lift in the complex. The lift was manufactured in accordance with the Jordanian Lift Code. Asian lifts tend to have cabin fans that pump air into the cabin whilst European and American lifts tend to have exhaust fans. This lift had 2 fans that pumped air into the cabin.

The lift was filled to capacity with passengers. The passengers were a mixture of lift technicians and building maintenance personnel. The passengers were given full details of the experiment.

With a technician on the car top, the car was moved to a point between floors and stopped.

This lift was located in a car park and was exposed to the outside air. The experiment was conducted in late March when the temperature was mild, around 22˚ to 24˚C. During the experiment, the wind was blowing at between 10 to 20 kph. The lift was in a common hoistway with another lift.

Air quality was sampled at the start of the experiment and every five minutes during the experiment. Measurements of temperature, relative humidity, carbon monoxide, total volatile organic compounds (TVOC), and, carbon dioxide were taken using a Grey Wolf IQ-610 tool.

After 15 minutes the experiment was terminated because some of the passengers complained that they were feeling bad.

The result was totally unexpected.

It was decided to conduct further experiments on the original lift where the entrapment occurred. In addition, only lift technicians were used as passengers so there would be no fear associated with stopping a lift between floors.

Parameters measured

Carbon Dioxide and Carbon Monoxide

A consulting group, Foster-Miller Inc., produced a report for the US Bureau of Mines titled *Development of Guidelines for Rescue Chambers* [3]. Rescue Chambers are built in mines as places of refuge in case of emergencies. A rescue chamber is a small confined space not unlike a lift car. This report discusses air quality requirements and the origins of the gases found in these chambers.

The two factors that were considered the most critical in Rescue Chambers are Carbon Dioxide and Carbon Monoxide.

The power source of human functions is produced by the oxidation of carbon and hydrogen [3]. Hydrogen is provided by food and oxygen is provided through inhaled air. Water and carbon dioxide are the products of perfect combustion. In a totally closed environment, oxygen would be converted into carbon dioxide until the passengers died of carbon dioxide toxicity or lack of oxygen. Carbon dioxide (CO_2) is toxic at a level of 50,000 ppm. However, at levels above 1,000 ppm adverse effects are observed. Many researchers believe that these effects are not the result of carbon dioxide but rather a lack of oxygen [3].

Carbon monoxide (CO), although it is commonly associated with faulty heating equipment, is produced in small amounts when breathing. Carbon monoxide bonds more easily to hemoglobin, the oxygen transporting medium of red blood cells, than oxygen. The World Health Organization recommends that the maximum concentration of carbon monoxide not exceed 10 parts per million (ppm) for 8 hours [4].

Temperature, Relative Humidity and Apparent Temperature

Studies have been made of the combined effects of temperature and relative humidity on the human body [5]. An apparent temperature matrix has been published based on this research. Apparent temperatures of 40˚ C are considered life threatening due to the fact that at this temperature heat exhaustion and heat stroke can occur.

TVOC

The Total Volatile Organic Compounds (TVOC) are human bioeffluents (body odor). Whilst body odor is not toxic, it can be offensive and increase the discomfort level of trapped passengers.

EXPERIMENTAL RESULTS

The experiments involved filling the lift with 15 lift technicians (including the author) and stopping the lift between floors simulating entrapment. A technician was also on the car top who could move the car quickly to a landing and open the doors if needed.

For the first experiment the car fan was operating and the required vent openings were not obstructed. See Table 1.

Air quality Lift 1: 15 passengers, Vents open, Fan operating						
CONDITION	Parameters					
	TEMPERATURE (°C)	RH (%)	Apparent Temperature (˚C)	CO (ppm)	TVOC (ppb)	CO_2 (ppm)
			40 = Life-threatening			
Before start	22.8	53.4	23	1.2	154	1105
After 5 minutes	25.6	70	28	1.8	201	3654
After 10 minutes	27.3	69.1	29	2.2	210	3820
After 15 minutes	28.1	74.8	32	2.5	244	4900
After 20 minutes	28.8	69.5	34	2.5	226	4400
After 25 minutes	29.3	71.4	34	2.6	233	4450
After 30 minutes	29.7	69	36	2.6	229	4585

Table 1

All of the measured values increased during the experiment, but none reached a critical level.

In the second experiment the fan was switched off but the vents were unobstructed. See Table 2.

Air quality Lift 1: 15 passengers, Vents open, Fan not operating						
CONDITION	Parameters					
	TEMPERATURE (°C)	RH (%)	Apparent Temperature (˚C)	CO (ppm)	TVOC (ppb)	CO_2 (ppm)
			40 = Life-threatening			
Before start	24.7	43.7	24	0.9	15	980
After 5 minutes	26.7	66.4	28	1.6	213	3680
After 10 minutes	28.2	71.6	30	2	231	4235
After 15 minutes	29.4	76.5	35	2.3	254	4176
After 20 minutes	30.6	73.2	38	2.5	249	4780
After 25 minutes	30.5	73.7	38	2.7	256	5150
After 30 minutes	30.9	78.5	41	2.8	306	5410

Table2

After 30 minutes, the Apparent Temperature exceeded the critical level. As all the values were increasing over time, an entrapment of over 30 minutes could be dangerous.

The third experiment involved sealing the required vent openings with tape simulating a cabin with a customer installed interior. The car fan continued to operate. The Apparent Temperature reached life threatening levels after 25 minutes. See Table 3.

Air quality Lift 1: 15 passengers, Vents sealed, Fan operating						
CONDITION	Parameters					
	TEMPERATURE (°C)	RH (%)	Apparent Temperature (˚C)	CO (ppm)	TVOC (ppb)	CO_2 (ppm)
			40 = Life-threatening			
Before start	22.8	59	24	1.2	72	1044
After 5 minutes	25.6	79.8	29	2	254	4985
After 10 minutes	27.5	79.8	27	2.7	313	5818
After 15 minutes	28.7	80.1	36	2.9	331	5994
After 20 minutes	29.4	81.7	37	3.1	383	5896
After 25 minutes	30	82.3	41	3.3	430	6789
After 30 minutes	30.5	83.1	42	3.2	492	5888

Table 3

For the fourth experiment the vents remained sealed and the fan was switched off. For ethical reasons, the experiment was terminated after 15 minutes. All of the parameters were increasing and the Apparent Temperature had had reached he life threatening level. See Table 4.

Air quality Lift 1: 15 Passengers, Vents sealed, Fan not operating						
CONDITION	Parameters					
	TEMPERATURE (°C)	RH (%)	Apparent Temperature (˚C)	CO (ppm)	TVOC (ppb)	CO_2 (ppm)
			40 = Life-threatening			
Before start	25	53	25	0.9	70	1336
After 5 minutes	28	77.1	33	1.8	258	5417
After 10 minutes	29.4	83.3	36	3	467	7893
After 15 minutes	30.3	85.7	40	4.1	507	8826
Experiment Terminated						

Table 4

FINDINGS AND CONCLUSIONS

The atmosphere in a lift manufactured in complete accordance with EN 81-1, installed in a fully air conditioned building, with the car fan switched off, became life threatening when occupied with a full load of passengers after only 30 minutes. The passengers were not average passengers, they were lift technicians. Members of the public when suddenly trapped between floors in a lift can be expected to respond less calmly to the situation than the technicians. This would most likely result in faster breathing and higher perspiration rates. Both of which accelerate the deterioration of the cabin environment.

Many lifts are installed in buildings without air conditioning and located in tropical and sub-tropical regions where air temperatures exceed 46˚C and humidity exceeds 50% (Apparent Temperature 66˚C). Even a single person trapped for only a short time is a great risk.

The cabin ventilation requirements in the current codes might need to be revised. More research is needed to determine the appropriate ventilation requirements. Computerized Fluid Dynamics (CFD) software could be used to improve ventilation designs. Perhaps ventilation systems should be viewed as life support systems.

REFERENCES

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