Projet	:	AMS-200911-AFC
Titre	:	Report on critical elevator car ventilation conditions
Concerne	:	Elevator car ventilation – risks in air tight elevator shafts of low energy buildings during elevator break down with passengers blocked in the car. The major risk to be considered being the air tightness of the building resulting in the very weak natural thermal air movements in the shaft while the mandatory ventilation openings of the shaft are closed.
Partenaire	:	AirFlowControl
Auteur	:	Gast Rauchs
E-Mail	:	Gaston.rauchs@tudor.lu
Date	:	20.9.2010
Distribution		Partenaire : G.S. CRP : SBe, GRa, SQu

CENTRE DE RECHERCHE PUBLIC
HENRI TUDOR
ADVANCED MATERIALS & STRUCTURES | AMS

Table des matières

Introduction 2
Elevator Data 2
Data on air and oxygen consumption 2
Calculations 3
Graphics 4

Introduction

This report specifies the calculation of oxygen and carbon dioxide concentrations in a confined elevator cabin.

Elevator Data

The following data about the elevator are used:

- Most critical case: Fully confined elevator (no gas exchange with elevator shaft due to complete obstruction of elevator cabin ventilation)
- Constant O_2 consumption, considered biological need, is assumed, i.e. increase in breathing frequency counters reduction in oxygen content
- Cabin dimensions : length L, width W and height H
- Capacity of N persons, average weight of m=75 kg
- Increase of temperature is neglected
- Human density is estimated at d=1 g/cm^3
- The concentrations of nitrogen, N_2, and of volatile organic compounds, VOC, remain constant over time, as they are chemically inert in this context

Data on air and oxygen consumption

Air under normal conditions is estimated to have an oxygen content of $c_{O2,0}$=20% and carbon dioxide content of $c_{CO2,0}$=0.03%. Oxygen consumption is labeled s_{O2} with units cm^3 O_2/kg/min (volume of O2 per kg human body mass per minute). Three states are considered: human in relaxed situation, human performing light work and human panicking represented as heavy work.. In a relaxed situation, s_{O2}=3,4 cm^3 O_2/kg/min, in a light work situation, s_{O2}=16 cm^3 O_2/kg/min in a panicking situation s_{O2}=35 cm^3 O_2/kg/min . The respiratory ratio (volume of CO_2 produced per volume of O_2 consumed) is R=0.82 cm^3 CO_2/ cm^3 O_2. The oxygen consumption is assumed to remain constant over time, irrespective of the emotional state of the persons contained in the elevator. As such it is considered a biological, vital need, independent of an emotional state or of the concentration of oxygen in the air. Time is labeled t.

Critical situations arise if:

- O_2 content drops below 13% (death by suffocation)
- CO_2 rises above 4% (unease) (Lethality occurs at 12%!).

Whereas the critical O_2 content seems to be rather unchallenged, some dispersions exist concerning critical CO_2 levels, especially with respect to initial symptoms of poisoning.

Calculations

Elevator cabin volume V_c: $V_c = L\ W\ H$

Total human body volume: $V_h = N\ m\ d$

Volume of air in elevator cabin: $V_{air} = V_c - V_h$

Initial Volume of oxygen in elevator cabin: $V_{O2,0} = V_{air}\ c_{O2,0}$

Volume of oxygen over time $V_{O2(t)} = V_{O2,0} - s_{O2}\ t\ N\ m$

Oxygen concentration over time

$$c_{O2}(t) = \frac{V_{O2}(t)}{V_{air}} = c_{O2,0} - \frac{s_{O2}\ t\ N\ m}{V_{air}} = c_{O2,0} - \frac{s_{O2}\ t\ N\ m}{LWH - Nmd}$$

Initial Volume of carbon dioxide in elevator cabin: $V_{CO2,0} = V_{air}\ c_{CO2,0}$

Volume of carbon dioxide over time $V_{CO2}(t) = V_{CO2,0} + R\ s_{O2}\ t\ N\ m$

Carbon dioxide concentration over time

$$c_{CO2}(t) = \frac{V_{CO2}(t)}{V_{air}} = c_{CO2,0} + R\frac{s_{O2}\ t\ N\ m}{LWH - Nmd}$$

Critical times may be evaluated for oxygen level as

$$t_{crit} = \frac{LWH - Nmd}{s_{O2}\ N\ m}\left(c_{O2,0} - c_{O2,crit}\right)$$

And for carbon dioxide level as

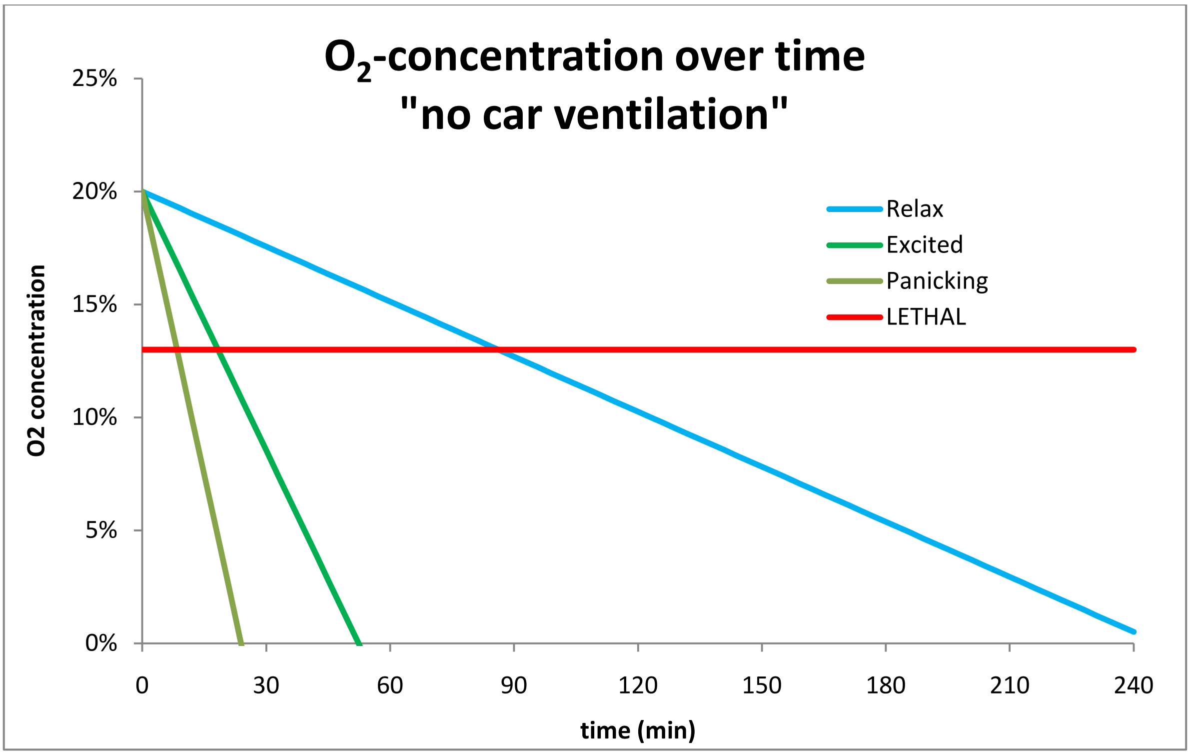
$$t_{crit} = \frac{LWH - Nmd}{R\ s_{O2}\ N\ m}\left(c_{CO2,crit} - c_{CO2,0}\right)$$

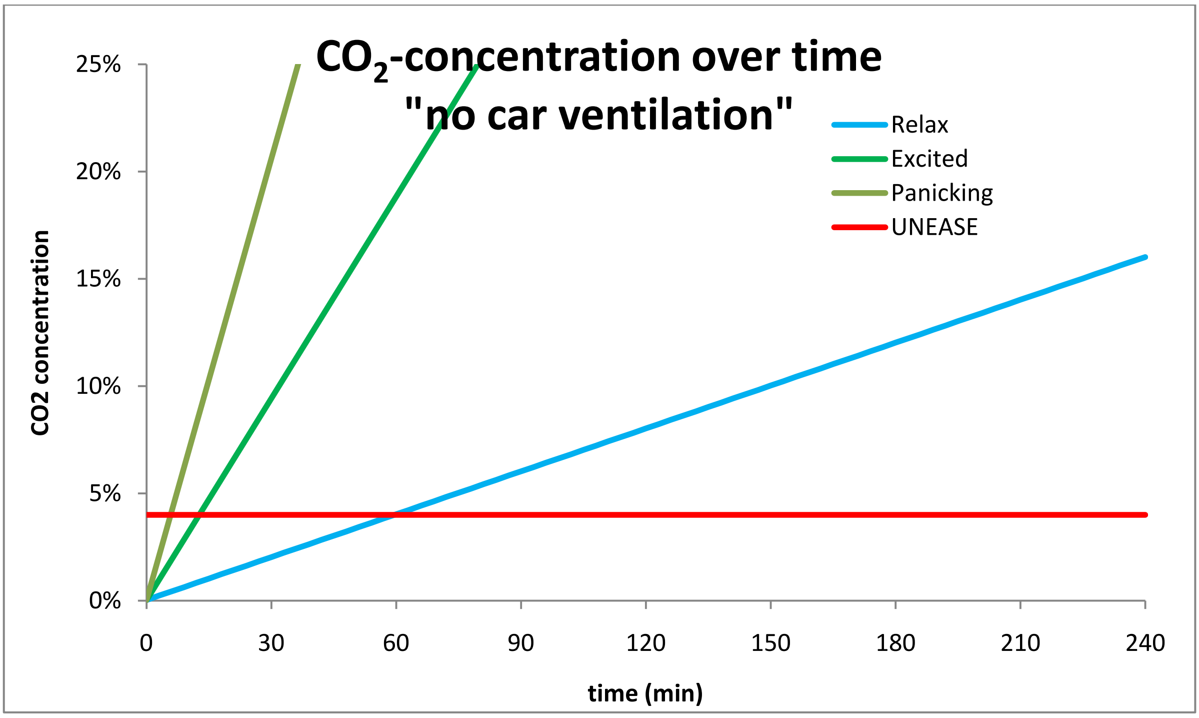
Care has to be taken to use the right units in the equations : all concentration calculations use g (gramm) for mass, therefore the average body mass has to be entered as g for calculating the body volume. Because of the data provided, time has to be entered in minutes, otherwise conversions have to be performed.

It should be noted that because the calculations rely on volumes, the total volume would diminuish because R is not equal 1. This effect is however neglected in the calculations. In fact, the diminuishing total volume would lead to a pressure decrease, which would then lead to a small inflow of fresh air into the cabin in order to maintain a constant atmosperic pressure, thus leading to slightly higher oxygen concentrations over time. It is considered that blocked passengers do not sit down or deposit objects closing the existing natural ventilation openings along the car floor. Thus the actual time to “failure” can derive from the calcualted values but should be considered as conservative.

The number of persons in the cabin has to be chosen in a way that V_{air} is superior to 0, as it is impossible to put more human volume into the cabin as there is cabin volume!

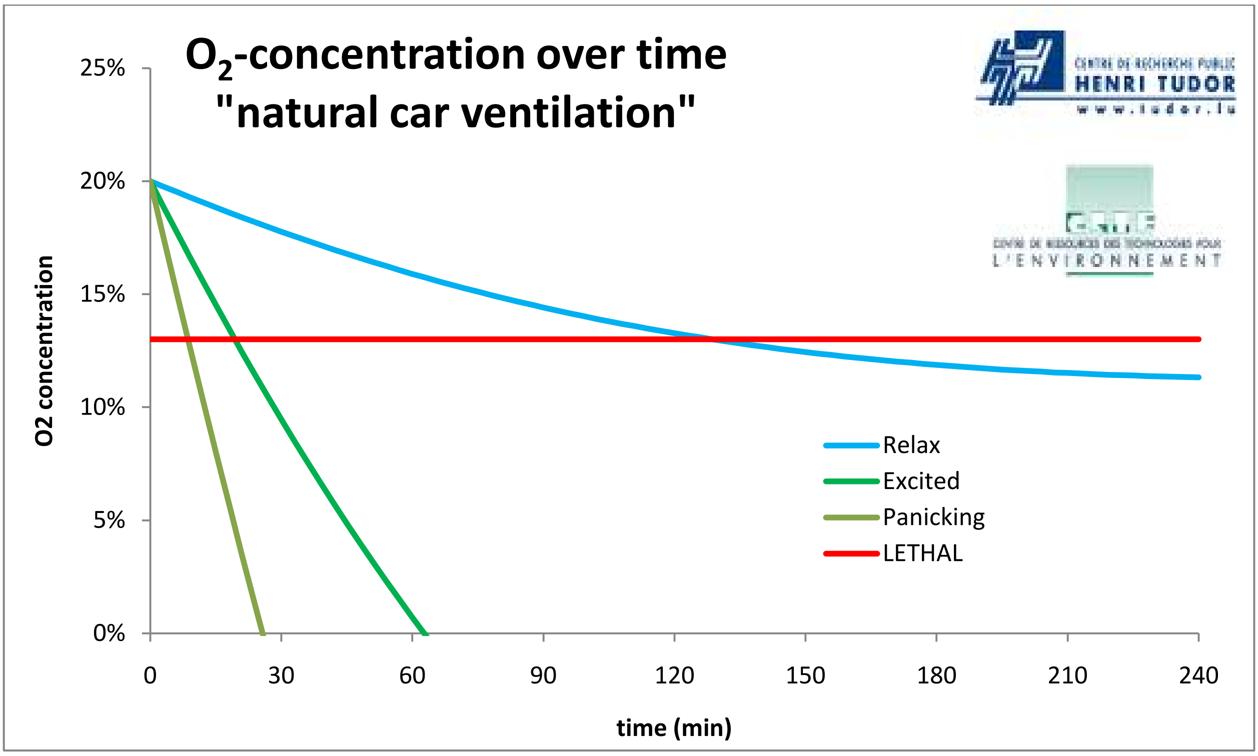
Blocked passengers in an elevator car without ventilation

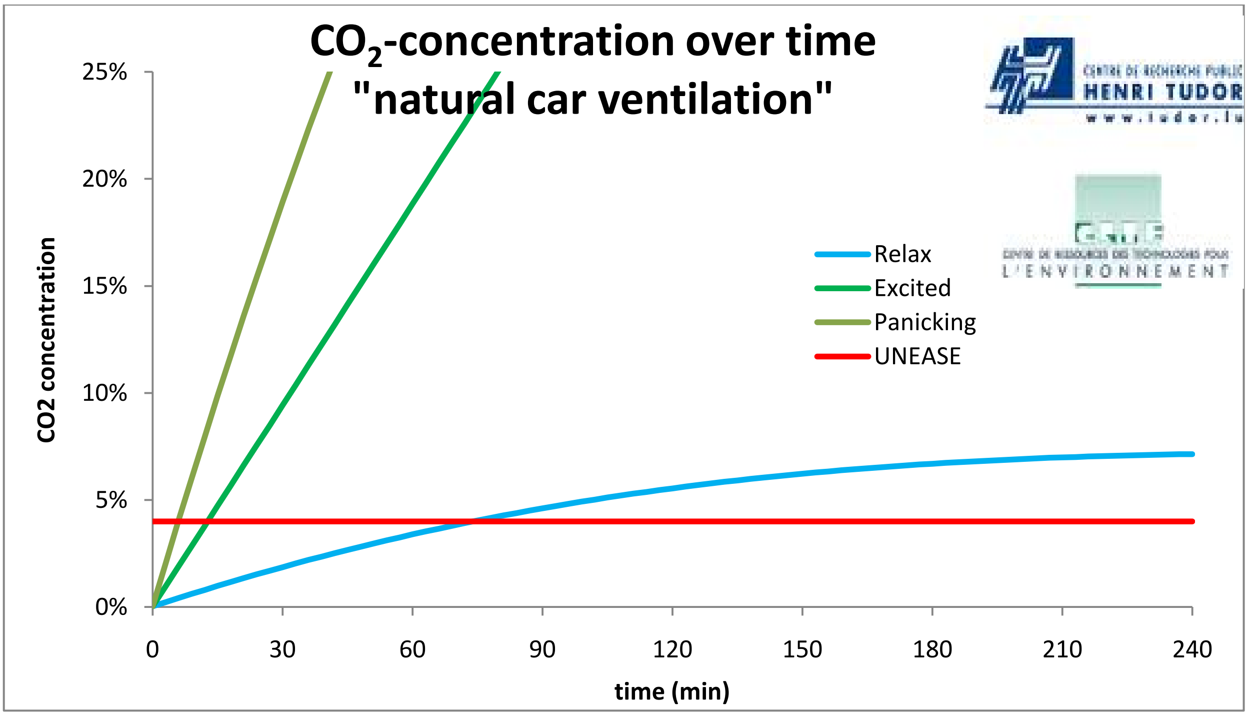




Conclusion: In an elevator car under maximum load without any appropriate natural or forced air ventilation blocked passengers panicking could die by suffocation within less than 15 minutes. In parallel the unease feeling due to CO_2 concentration could already appear within less than 10 minutes. If passengers stay relaxed they might prevent serious health damage for 60 to 90 minutes.

Blocked passengers in an elevator car with natural ventilation





Conclusion: In an elevator car under maximum load with natural air ventilation blocked passengers panicking could die by suffocation within less than 15 minutes. In parallel the unease feeling due to CO_2 concentration could already appear within less than 10 minutes. If passengers stay relaxed and do not sit down and block the ventilation openings while waiting in the car, they might prevent serious health damage for 75 to 130 minutes.

	Relax				Excited				Panicking			
t (min)	V_O2	c_O2	V_CO2	c_CO2	V_O2	c_O2	V_CO2	c_CO2	V_O2	c_O2	V_CO2	c_CO2
0	565000	20,0%	848	0,0%	565000	20,0%	848	0,0%	565000	20,0%	848	0,0%
3	558212	19,8%	6413	0,2%	533058	18,9%	27040	1,0%	495127	17,5%	58144	2,1%
6	551524	19,5%	11898	0,4%	501582	17,8%	52851	1,9%	426272	15,1%	114604	4,1%
9	544935	19,3%	17300	0,6%	470579	16,7%	78273	2,8%	358453	12,7%	170216	6,0%
12	538449	19,1%	22619	0,8%	440055	15,6%	103302	3,7%	291683	10,3%	224968	8,0%
15	532066	18,8%	27853	1,0%	410017	14,5%	127934	4,5%	225975	8,0%	278848	9,9%
18	525787	18,6%	33002	1,2%	380469	13,5%	152163	5,4%	161339	5,7%	331850	11,7%
21	519613	18,4%	38064	1,3%	351416	12,4%	175986	6,2%	97786	3,5%	383963	13,6%
24	513546	18,2%	43040	1,5%	322862	11,4%	199401	7,1%	35323	1,3%	435183	15,4%
27	507584	18,0%	47928	1,7%	294809	10,4%	222404	7,9%	-26042	-0,9%	485502	17,2%
30	501730	17,8%	52729	1,9%	267261	9,5%	244994	8,7%	-86304	-3,1%	534917	18,9%
33	495984	17,6%	57441	2,0%	240219	8,5%	267168	9,5%	-145459	-5,1%	583424	20,7%
36	490345	17,4%	62064	2,2%	213685	7,6%	288926	10,2%	-203502	-7,2%	631019	22,3%
39	484815	17,2%	66599	2,4%	187659	6,6%	310267	11,0%	-260433	-9,2%	677702	24,0%
42	479393	17,0%	71045	2,5%	162143	5,7%	331190	11,7%	-316249	-11,2%	723472	25,6%
45	474079	16,8%	75403	2,7%	137137	4,9%	351696	12,4%	-370951	-13,1%	768328	27,2%
48	468873	16,6%	79671	2,8%	112639	4,0%	371784	13,2%	-424540	-15,0%	812270	28,8%
51	463776	16,4%	83852	3,0%	88650	3,1%	391455	13,9%	-477016	-16,9%	855301	30,3%
54	458786	16,2%	87943	3,1%	65167	2,3%	410710	14,5%	-528384	-18,7%	897422	31,8%
57	453903	16,1%	91947	3,3%	42191	1,5%	429551	15,2%	-578645	-20,5%	938636	33,2%
60	449128	15,9%	95863	3,4%	19718	0,7%	447979	15,9%	-627805	-22,2%	978947	34,7%
63	444459	15,7%	99691	3,5%	-2254	-0,1%	465995	16,5%	-675867	-23,9%	1018359	36,0%
66	439896	15,6%	103433	3,7%	-23726	-0,8%	483603	17,1%	-722839	-25,6%	1056875	37,4%
69	435438	15,4%	107088	3,8%	-44703	-1,6%	500804	17,7%	-768725	-27,2%	1094502	38,7%
72	431085	15,3%	110657	3,9%	-65187	-2,3%	517600	18,3%	-813533	-28,8%	1131245	40,0%
75	426837	15,1%	114141	4,0%	-85181	-3,0%	533996	18,9%	-857270	-30,3%	1167109	41,3%
78	422691	15,0%	117541	4,2%	-104689	-3,7%	549993	19,5%	-899945	-31,9%	1202102	42,6%
81	418648	14,8%	120856	4,3%	-123716	-4,4%	565594	20,0%	-941565	-33,3%	1236231	43,8%
84	414706	14,7%	124088	4,4%	-142264	-5,0%	580804	20,6%	-982141	-34,8%	1269503	44,9%
87	410865	14,5%	127238	4,5%	-160340	-5,7%	595626	21,1%	-1021680	-36,2%	1301925	46,1%
90	407124	14,4%	130306	4,6%	-177946	-6,3%	610063	21,6%	-1060194	-37,5%	1333507	47,2%
93	403481	14,3%	133293	4,7%	-195088	-6,9%	624120	22,1%	-1097693	-38,9%	1364256	48,3%
96	399936	14,2%	136200	4,8%	-211771	-7,5%	637800	22,6%	-1134187	-40,1%	1394181	49,4%
99	396487	14,0%	139028	4,9%	-228000	-8,1%	651108	23,0%	-1169688	-41,4%	1423292	50,4%
102	393134	13,9%	141777	5,0%	-243780	-8,6%	664047	23,5%	-1204207	-42,6%	1451597	51,4%
105	389875	13,8%	144450	5,1%	-259117	-9,2%	676623	24,0%	-1237756	-43,8%	1479107	52,4%
108	386709	13,7%	147046	5,2%	-274016	-9,7%	688840	24,4%	-1270347	-45,0%	1505832	53,3%
111	383635	13,6%	149567	5,3%	-288482	-10,2%	700702	24,8%	-1301991	-46,1%	1531780	54,2%
114	380652	13,5%	152013	5,4%	-302521	-10,7%	712215	25,2%	-1332703	-47,2%	1556964	55,1%
117	377758	13,4%	154386	5,5%	-316140	-11,2%	723382	25,6%	-1362493	-48,2%	1581392	56,0%
120	374952	13,3%	156687	5,5%	-329344	-11,7%	734209	26,0%	-1391377	-49,3%	1605076	56,8%
123	372233	13,2%	158916	5,6%	-342138	-12,1%	744701	26,4%	-1419365	-50,2%	1628027	57,6%
126	369600	13,1%	161076	5,7%	-354530	-12,5%	754862	26,7%	-1446473	-51,2%	1650255	58,4%
129	367051	13,0%	163166	5,8%	-366526	-13,0%	764699	27,1%	-1472712	-52,1%	1671772	59,2%
132	364585	12,9%	165188	5,8%	-378130	-13,4%	774214	27,4%	-1498098	-53,0%	1692588	59,9%

Simulations based on regular elevator car volumes

Paragraph 8.2. EN 81:		
car load kg	Car area m2	Car volume m3
300	0,9	1,8
375	1,1	2,2
400	1,17	2,34
450	1,3	2,6
525	1,45	2,9
600	1,6	3,2
630	1,66	3,32
675	1,75	3,5
750	1,9	3,8
800	2	4
825	2,05	4,1
900	2,2	4,4
975	2,35	4,7
1000	2,4	4,8
1050	2,5	5
1125	2,65	5,3
1200	2,8	5,6
1250	2,9	5,8
1275	2,95	5,9
1350	3,1	6,2
1425	3,25	6,5
1500	3,4	6,8
1600	3,56	7,12
2000	3,4	6,8
2500	5	10