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AIR QUALITY IN A CONFERENCE ROOM WITH SMOKING

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În lucrarea de faţă se face analiza aerului dintr-o sală de conferinţe cu un singur compartiment în care se fumează. În acest sens s-a luat în considerare un model cu 3 parametri variabili, şi anume: depunerile, eficienţa filtrului de aer şi factorul de mixare.

Principalele surse de poluare, luate în considerare, sunt ţigările, aerul din exterior şi aerul expirat de oamenii din sală. Poluanţii prezenţi în aerul din interior sunt particulele respirabile, monoxidul de carbon CO şi dioxidul de carbon CO_2. Aceştia sunt aleşi ca poluanţi din următoarele motive:

- particulele respirabile (RP) prezintă un potenţial risc de sănătate, au viteza de depunere măsurabilă şi pot fi îndepărtate cu ajutorul filtrelor de înaltă eficienţă;
- monoxidul de carbon CO prezintă şi el un risc şi e studiat, de obicei, ca index al componenţilor în stare gazoasă din fumul de ţigară;
- dioxidul de carbon CO_2 este luat în considerare datorită importanţei sale referitoare la calitatea aerului din interior.

The main sources of pollution are cigarettes, outdoor air, and people. Such sources can contribute to significant quantities of respirable particles: carbon monoxide, and carbon dioxide to indoor air. These three pollutants are chosen for a variety of reasons. Respirable particles (RP) are a potential health hazard, have a measured deposition velocity, and can be removed by high-efficiency filters. Carbon monoxide is also a potential health hazard and is usually studied as an index of the gas-phase components from cigarette smoke. Carbon dioxide is considered because of its importance in the ASHRAE indoor air quality guidelines. Table 1. gives information about the conference room size, ventilation, and use pattern.

Table 1. Conference Room Ventilation and Source Data

Room size		250 m^3
Ventilation rate	make-up air (q_0)	125 m^3/hr
	Recirculated air (q_1)	520 m^3/hr
Filter efficiency for recirculated air (F_1)		10% for RP 85% for dust
Average number of people in room		10
Average number of smokers in room		4
Average smoking rate per person		4 cigarettes/hr
Periods when room is used		9:00 am – noon 14;00 – 16:00
Location		Timisoara

Table 2 lists characteristics of the three sources being studied. Cigarettes and respiration add pollutants to the conference room during the two periods when it is in use; 9:00 am – 12:00 noon and 14;00 – 16:00. Outdoor air continuously contributes small constant amounts of the three materials.

Table 2. Source Strength Data

Source Type	respirable Particles	Carbon monoxide	Carbon Dioxide
Cigarettes	25,8 mg/cig (410 mg/hr)	37,5 mg/cig (0,6 g/hr)	320 mg/cig (5,1 g/hr)
Outdoor air	0,05 mg/m^3	2,9 mg/m^3	0,79 g/m^3
Respiration	-	-	35g/hr person 350g/hr

Equation (1) is used to predict indoor air quality. The following values are the initial conditions for solving this equation for RP. Note that F_1 is set equal to 0,1. Although the recirculation air filter is 85% efficient for dust, the filter has a low efficiency for the small particles in cigarette smoke. For this problem, t is in hours, and all flow rates must be on the same time basis.

$$Ci = \{\{k[q_0(1-F_0) + q_2]\, Co + S - R\}/[k(q_0+q_1F_1+q_2)]\}\,[1 - e^{-(k/V)(q_0+q_1F_1+q_2)t}] + C_s e^{-(k/V)(q_0+q_1F_1+q_2)t} \quad (1)$$

BASIS FOR SOLVING THE MASS-BALANCE MODEL FOR RESPIRABLE PARTICLES IN A CONFERENCE ROOM

t in hours;
q_2 (infiltration) = 0;
q_3 (exfiltration) = 0; at t = 0 (9;00 a.m.),
Ci = Cs = Co
Co outdoor concentration;
Fo (make-up air filter) = 0;
F_1 (recirculation air filter) = 0,1
R (indoor sink) = 0;
S (source) = 410 mg/hr for 9:00 a.m. – 12:00 noon and 14:00 – 16;00
0 for other times

Solving Ecuation (1) for RP concentration, we obtain

$$Ci = \{[K(q_0)\,Co + S]/[\,k(q_0+q_1F_1)]\}\ [\,1 - e^{-(k/V)(q_0+q_1F_1+q_2)t}] + C_s\, e^{-(k/V)(q_0+q_1F_1+q_2)t} =$$
$$= [(37{,}5C_0+S) / 53{,}10]\ [\,1 - e^{-0{,}21t}] + C_s e^{-0{,}21t} \qquad (2)$$

The approach used throughout this problem for computing indoor concentration for a 24hr period is as follws. Note that the equation has to be reset to t = 0 wenever there is a change in emission rate.

Calculational Approach

1. Solve Equation (2) for concentr. at 10:00, 11:00 a.m., and noon (t = 1, 2, and 3hr), Cs = Co.
2. From noon to 14:00, set Cs = Ci at noon and assume S = 0 (t = 1 and 2).
3. From 14;00 to 16:00, set Cs to Ci at 14:00 and solve for con.at 15:00 and 16:00 (t = 1 and 2).
4. From 16:00 on, set Cs to Ci at 16:00 and assume S = 0 (t = 2, 6, 12, and 16).

The solution of Equation (2) for RP is the following:

Time	t (hr)	Cs (mg/m^3)	S (mg/hr)	Ci (mg/m^3)
9;00	0	0,05	-	0,05
10:00	1	0,05	410	1,51
11:00	2	0,05	410	2,69
12;00	3	0,05	410	3,65
13:00	1	3,65	0	2,97
14:00	2	3,65	0	2,41
15:00	1	2,41	410	3,42
16:00	2	2,41	410	4,24
18:00	2	4,24	0	2,80
22:00	6	4,24	0	1,23
4;00 a.m.	12	4,24	0	0,37
8:00	16	4,24	0	0.18

CO and CO_2 Concentrations in the Conference Room

The procedure for solving Equation (1) for CO and CO_2 is the same as for RP except for the follwing changes:
F_1 = 0 (removal of CO and CO_2 at ambient levels is not practical)
Co (CO) = 2,9 mg/m^3
Co (CO_2) = 0,79 g/m^3
S (CO) = 0,6 g/hr for 9:00 a.m. – 12:00 noon and 14:00 – 16:00
S (CO_2) = 355 g/hr 0 at other times
Solving equation (1) for CO and CO_2 concentration we obtain

$$Ci = [(37{,}5Co + S)/ 37{,}5]\ (1-e^{-0.15t}) + C_s e^{-0.15t} \qquad (3)$$

For CO, we obtain

Time	t (hr)	Cs (mg/m^3)	S (mg/hr)	Ci(mg/m^3)	Ci(ppm)
9:00 a.m.	0	2,9	-	2,90	2,53
10:00	1	2,9	600	5.13	4,48
11:00	2	2,9	600	7,05	6,16
12:00	3	2,9	600	8,70	7,60
13:00	1	8,70	0	7,89	6,89
14:00	2	8,70	0	7,20	6,29
15:00	1	7,20	600	8,83	7,71
16:00	2	7,20	600	10,23	8,93
18:00	2	10,23	0	8,33	7,27
22:00	6	10,23	0	5,88	5,13
4:00 a.m.	12	10,23	0	4,11	3,59
8:00	16	10:23	0	3,56	3,11

For CO_2, we obtain

Time	t (hr)	Cs (mg/m^3)	S (mg/hr)	Ci(mg/m^3)	Ci(ppm)
9:00 a.m.	0	0,79	-	0,79	0,04
10:00	1	0,79	355,1	2,11	0,12
11:00	2	0,79	355,1	3,24	0,18
12:00	3	0,79	355,1	4,22	0,23
13:00	1	4,22	0	3,74	0,21
14:00	2	4,22	0	3,33	0,19
15:00	1	3,33	355,1	4,30	0,24
16:00	2	3,33	355,1	5,13	0,29
18:00	2	5,13	0	4,00	0,22
22:00	6	5,13	0	2,55	0,14
4:00 a.m.	12	5,13	0	1,51	0,08
8:00	16	5,13	0	1,18	0,07

Table 3 is a summary of peak and average concentrations of CO, CO_2, and RP.

Table 3. Summary of Predicted Concentrations

Pollutant	Peak Concentration	9:00a.m. – 16:00 Average Concentration	24-hr Average Concentration
RP	4,24 mg/m^3	2,62mg/m^3	1,43mg/m^3
CO	0,93 ppm	6,32 ppm	
CO_2	0,29%	0,19%	

COMPARISION WITH ASHRAE STANDARD

Based on the pollutant mass balance model, indoor concentration of RP exceed the ASHRAE recommend indoor value (250$\mu g/m^3$ for 24 hr). All calculations to this point assume the sink value, R, is zero. This may not be a good assumption for all pollutants. Deposition of particles less than 1-µm diameter, the size range of tobacco smoke particles, has been estimated at 0,05hr^{-1} (Dockery and Spengler, 1981), Given a deposition rate, K, the sink term can be expressed as

$$R = KM = \text{(deposition rate)(mass)} \quad (4)$$

And $$R = KVC_i = \text{(deposition rate)(room volume)(concentration)} \quad (5)$$

Substituting E = KV and Equation (5) into Equation Pollutant mass balance

$\{V(dC_i/dt) = kq_0C_0(1 – F_0) + kq_1C_i(1-F_1) +kq_2C_0 – k(q_0+q_1+q_2)C_i = S – R\}$, leads to

$$C_i = C_s e^{\alpha t/V} + (\beta/\alpha) (e^{\alpha t/V} -1) \quad (6)$$

Where $\alpha = kq_1F_1 - kq_0 - kq_2 - KV$

$\beta = kq_2C_0 + kq_0(1 - F_0)C_0 + S$

Solving Equation (6) for RP concentrations with K = 0,05hr^{-1}and all other assumptions and conditions as before, α = -65,60 and β = 1,88 + S:

Time	t (hr)	Cs (mg/m^3)	S (mg/hr)	Ci (mg/m^3)
9;00	0	0,05	-	0,05
10:00	1	0,05	410	1,49
11:00	2	0,05	410	2,59
12;00	3	0,05	410	3,44
13:00	1	3,44	0	2,65
14:00	2	3,44	0	2,05
15:00	1	2,05	410	3,03
16:00	2	2,05	410	3,78
18:00	2	3,78	0	2,25
22:00	6	3,78	0	0,81
4;00 a.m.	12	3,78	0	0,19
8:00	16	3,78	0	0.09

The nonzero value of R results in lower predicted concentrations. The peak concentration at 4:00a.m. is 0,5 mg/m^3 lower; and by the next morning the concentration has dropped by 50%. The 9;00a.m. – 16:00 p.m. average concentration is still 2,39 mg/m^3, and the 24-hr average is 1,17 mg/m^3 – almost 5 times the recommended standard.

ASHRAE (1980) recommends a minimum of 5 cfm/person make up air (q_0) for each person in a room for CO_2 control. q_0 for the conference room is 75 cfm, 25 cfm above this recommendation. Predicted CO_2 concentrations are below the ASHRAE recommended value and consequently the ASHRAE recommended ventilation rate are appropriate. For ten persons in conference room, this corresponds to 350cfm of outdoor or equivalent air. The outdoor air supply is only 75 cfm. Because of the low-efficiency filter in the recirculation air stream (F_1 = 0,1 for RP), the recirculated air does not meet criteria for ventilation air. ASHRAE recommendeds that Ecuation (7) be used to relate F_1, q_0, and q_1:

$$q_1 = (q_R - q_0)/F_1 \tag{7}$$

where q_R is the recommended ventilation rate (from table) and q_0 is the actual ventilation rate of outdoor air. Given recommended q_R of 350 cfm (600m^3/hr), $q_0$of 75 cfm (125 m^3/hr) and q_1 of 310 cfm (520 m^3/hr), a recirculation air filter efficiency (F_1) of 0,9 will meet ASHRAE ventilation standards. Substituting these values into Equation (1) and solving for the RP concentration, where α = -190,40 and β = 1,88 + S, we obtain

Time	t (hr)	Cs (mg/m^3)	S (mg/hr)	Ci (mg/m^3)
9;00	0	0,05	-	0,05
10:00	1	0,05	410	1,18
11:00	2	0,05	410	1,70
12;00	3	0,05	410	1,95
13:00	1	1,95	0	0,91
14:00	2	1,95	0	0,43
15:00	1	0,43	410	1,36
16:00	2	0,43	410	1,79
18:00	2	1,79	0	0,40
22:00	6	1,79	0	0,03
4;00 a.m.	12	1,79	0	0,01
8:00	16	1,79	0	0.01

Using the ASHRAE recommended value for F_1, the predicted 9;00a.m. – 16:00p.m. average RP concentration is reduced to 1,17 mg/m^3, more than 50% below the previous value. However, the predicted 24-hr average concentration is 0,43 mg/m^3, which is still 67% above the ASHRAE indoor recommendation.

The predicted CO concentrations (8,93ppm peak and 6,32 ppm average) are for conditions that do not meet ASHRAE ventilation standards where smoking is allowed. Unlike particles, control devices for CO or CO_2 are less practical. The best way to meet the ASHRAE ventilation standard for CO or CO_2 is to use outside air only [q_0 = 600m^3 /hr(350cfm) and q_1 = 0]. Resolving Equation (1) for RP, CO, and CO_2 with q_0 = 600m^3/hr, q_1 = 0, F_1 = 0 and K_{CO} = 0, we obtain

Time	t (hr)	RP (mg/m^3)	CO (ppm)	CO_2 (%)
9;00	0	0,05	2,53	0,04
10:00	1	1,19	4,03	0,10
11:00	2	1,72	4,75	0,13
12;00	3	1,97	5,11	0,14
13:00	1	0,94	3,79	0,09
14:00	2	0,46	3,14	0,07
15:00	1	1,38	4,32	0,11
16:00	2	1,81	4,90	0,13
18:00	2	0,42	3,09	0,07
22:00	6	0,06	2,57	0,05
4;00 a.m.	12	0,05	2,53	0,04
8:00	16	0,05	2,53	0.04

Ventilation that meets the ASHRAE standards results in a predicted 9:00a.m. – 16:00p.m. average Co concentration of 4,07 ppm, a reduction of 2,25 ppm from the previous conditions. This concentration is below the outdoor air standard.

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