Simulation of Atrium Smoke Filling Process by the Zone Model First

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ABSTRACT

The zone model FIRST was applied for studying the smoke filling process in atria. A total number of 972 simulations with different geometry of the atria, the heat release rate of fires and the plume models were performed. Atria classified into three types as cubic, flat and high with volumes varying from 2000 m^3 to 30000 m^3 were considered. Five steady burning fires of peak heat release rate from 1 to 5 MW and four unsteady t^2-fires were used together with four plume models reported in literature.

INTRODUCTION

There are many big atria in the Hong Kong Special Administrative Region (HKSAR) [1, 2] and the number of them is still increasing. The atria are quite different from those in other countries in terms of quantity, volume and geometrical configuration. The atrium is normally of 'open' design and its volume is very large. Therefore, architects, engineers and fire officers are very concerned about the fire safety in the atrium space, particularly when it is located in a shopping mall. Survey on the geometry indicated that atria in the HKSAR can be classified into three main types for the simplicity of modelling the fire environment [1]. Type 1 (Cubic) atria are of cubic shape and they are commonly found in the HKSAR. Type 2 (Flat) atrium has a long transverse dimension compared with the height. Type 3 (High) atrium has a height to length ratio of more than two. Smoke is identified to be a key factor and 'smoke control' system has to be designed carefully.

This paper reports on studying the smoke filling process in those three types of atria with different volumes. The zone model FIRST [3] was used together with different fires and plume models to study the smoke filling process.

THE PLUME EQUATIONS

Four fire plume models in the literature are used:

P1: Area-source Morton-Taylor-Tuner Plume [4, 5];

P2: Point-source Morton-Taylor-Tuner Plume [6];

P3: McCaffrey plume [7];

P4: Zukoski plume [8];

A summary of those expressions has been reported by Chow and Cui [2] and would not be repeated in here. These four plume models (P1 to P4) are used to calculate the mass flow rate m induced by the same fire of heat release rate Q. It was reported earlier in there [2] from studying the vertical profiles of the mass flow ratios that the plume model P4 gave the highest mass flow rate for height lower than 3.5 m, then P1, P3 and P2. For height above 3.5 m, the plume model P1 gave higher mass flow rates. Higher values of mass flow rate into the plume would give a faster smoke filling time, indicating a thicker but 'cooler' smoke layer under the same fire at the same atrium.

GEOMETRY OF ATRIA AND FIRES

With the above four plume models, smoke filling process in an atrium were studied using the zone model FIRST [2]. Three types of atria of volume V of 2,000 m^3, 5,000 m^3, 7,000 m^3, 10,000 m^3, 15,000 m^3, 20,000 m^3, 25,000 m^3, 28,000 m^3 and 30,000 m^3 were considered:

Atrium type 1 (cubic) with length L, width L and height L;
Atrium type 2 (flat) with length 2L, width L and height L;
Atrium type 3 (high) with length L, width L, and height 2L.

At each atrium, there are two doors at the center of the opposite side walls with 5 m wide and 3 m high. A fire of size 3 m by 3 m, height 0.5 m is assumed at the center of the floor. Two groups of heat release rates Q of the fire were assumed. Group 1 fires are those with a steady burning period. The heat release rate increased from 0 to a peak value Q_p in 100 s, remained constant at Q_p up to 2400 s, and then fell linearly to zero up to 2500 s. Five cases with constant steady peak values Q_p of 1, 2, 3, 4 and 5 MW were used and they are labelled as SB1 to SB5. Group 2 fires are unsteady t^2-fires at the beginning stage. When Q increased to 5 MW, the heat release rate was kept at constant until 2400 s, then fell linearly to zero at 2500 s. Four cases labeled as US1 to US4 are considered with the heat release rate given by Q in kW as following, where t is in s:

$$Q = \alpha t^2 \qquad \text{... (1)}$$

US1 is for slow fire, US2 for medium fire, US3 for fast fire and US4 for ultra-fast fire with α being 0.00293 kWs^{-2}, 0.01127 kWs^{-2}, 0.04689 kWs^{-2} and 0.1878 kWs^{-2} respectively.

RESULTS

A total number of 972 (9 × 4 × 3 × 9) simulations with 9 fires (SB1 to SB5 and US1 to US4), 4 plume models (P1 to P4) and 27 atria classified into 3 types (type 1, 2 and 3) each with 9 volumes were performed. Predicted results of interest are the average values of the upper hot layer temperature T_U (in °C), lower layer temperature T_L (in °C), smoke layer interface height h (in m), smoke layer height expressed as a percentage of ceiling height y (in %), maximum upper layer temperature T_{Umax}, minimum smoke layer interface heights h_{min} in m and y_{min} when expressed as a percentage of atrium height, time required to fill 50% of the atrium t_{50}; and time required to fill 80% of the atrium t_{80}. The average values were calculated in the steady burning period which was taken from 1000 s to 2000 s for fires with a steady burning period. For unsteady t^2-fires, average steady burning period as shown from 1420 s to 2300 s for US1 fire; 780 s to 2300 s for US2 fire; 440 s to 2300 s for US3 fire and 280 s to 2300 s for US4 fire. Results are shown in Tables 1 to 5.

DISCUSSION

The detailed information was summarized in the tables. The smoke filling process in atria of same volume but different types would be very different, confirming the earlier reports with smaller number of simulations [e.g. 1]. The smoke filling time is the shortest in type 3 atrium, and being the longest in type 2 atrium as observed from the predicted time to fill up 50% and 80% of atrium space. However, the predicted values of T_U and T_L are similar in the three types of atria of same volume. Therefore, it is not good enough to specify only the atrium volume while providing fire safety because the smoke filling process in atria of different shapes would be different, though the thermal aspects are similar.

For atria of same type, same volume and same plume model, values of T_U, T_L and T_{Umax} increased with the heat release rate for steady burning cases. The values of h and h_{min} were nearly constant for plume models P1 and P2, but a little bit lower for plume model P3 under the same thermal power of fire. The predicted average interface height was the highest while using the plume model P4.

For the cases of using unsteady fires, the values of T_U, T_L, y, h, T_{Umax} and h_{min} were similar with the same plume model because of the same cut-off value of fire.

CONCLUSIONS

Smoke filling process in 27 atria of space volume varying from 2,000 m^3 to 30,000 m^3 and classified into 3 types were studied using the zone model FIRST. Four fire plume models available in the literature were used. Results predicted from those four plume models are discussed. The above results would be useful to determine useful parameter for understanding the atrium smoke filling process and identify the possible fire hazards. Carrying out full scale experiments [9] are required to evaluate with the numerical results [2].

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REFERENCES

[1] W. K. Chow, A comparsion of the use of zone and field models for simulating atrium smoke filling processes. *Fire Safety Journal*, Vol. 25 No. 4 pp.337~353 (1995)

[2] W.K. Chow and E. Cui, Plume equation for studying smoke filling process in atria with a zone model. *Fire and Materials* - accepted to publish (1997).

[3] H. Mitler and J. Rockett, User's Guide to FIRST, NBSIR 87-3595, *Center for Fire Research, National Bureau of Standards*, Gaithersburg, MD, U.S.A. (1987)

[4] H. E. Mitler and H. W. Emmons, Documentation for CFC V, the fifth Harvard computer fire code, HFPTR No. 45, *Harvard University and National Bureau of Standards*, Gaithersburg, MD, U.S.A. (1981)

[5] G. Heskestad, Virtual orgins of fire plumes, *Fire Safety Journal* Vol. 5, pp.109~201 (1983)

[6] B. R. Morton, G. I. Turner and J. S. Taylor, Turbulent gravitational convection from maintained and instantaneous source, *Proceedings of Royal Society*, A234, pp.1~23 (1956)

[7] B. J. McCaffrey, Purely buoyant diffusion flames: some experimental results, NBSIR 79-1910, *National Bureau of Standards*, Gaithersburg, MD, U.S.A. (1979)

[8] B. M. Cetegen, E. E. Zukoski and T. Kubota, Entrainment and flame geometry of fire plumes, *PhD Thesis*, *California Institute Technology*, Pasadena, U.S.A. (1982)

[9] W. K. Chow, W. Fan and L. Chen, Full-scale facilities for atrium fire research, *Fire Safety Science - in Chinese*, Vol. 2 No. 2, pp. 60~63 (1993)

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Table 1. Simulation results for volume 2000 m^3 and 5000m^3

Atrium Type			Type 1								Type 2								Type 3							
Volume V/m^3	Fire Type	Plume Model	T_U /°C	T_L /°C	y /%	h /m	T_{UMAX} /°C	h_{MIN} /m	t_{50} /s	t_{80} /s	T_U /°C	T_L /°C	y /%	h /m	T_{UMAX} /°C	h_{MIN} /m	t_{50} /s	t_{80} /s	T_U /°C	T_L /°C	y /%	h /m	T_{UMAX} /°C	h_{MIN} /m	t_{50} /s	t_{80} /s
		P1	66	29	17.3	1.7	68	1.7	78	NF	74	35	13.7	1.7	77	1.7	54	103	FC							
	SB1	P2	92	29	24.9	2.5	99	2.5	139	NF	92	29	19.8	2.5	99	2.5	105	275	86	28	12.4	2.5	93	2.5	61	143
		P3	82	31	21.8	2.5	86	2.2	64	207	82	31	17.3	2.2	87	2.2	46	123	78	30	10.8	2.2	83	2.1	23	64
		P4	78	33	20.0	2.0	81	2.0	74	167	78	32	15.9	2.0	82	2.0	58	123	74	32	9.9	2.0	78	2.0	35	77
		P1	97	32	17.4	1.7	99	1.7	65	NF	114	44	13.9	1.8	119	1.7	45	86	110	41	8.7	1.7	115	1.7	30	59
	SB2	P2	148	32	24.9	2.5	159	2.5	112	NF	149	32	19.8	2.5	162	2.5	87	203	140	31	12.4	2.5	154	2.5	51	114
		P3	123	39	20.7	2.1	130	2.1	55	138	124	38	16.3	2.1	131	2.1	40	100	119	36	10.3	2.1	126	2.0	20	56
		P4	123	39	20.7	2.1	130	2.1	63	136	124	38	16.3	2.1	131	2.1	49	103	118	36	10.2	2.0	126	2.0	30	65
		P1	128	34	17.6	1.8	131	1.7	59	NF	151	54	14.0	1.8	158	1.8	41	76.5	146	50	8.7	1.7	153	1.7	27	53
	SB3	P2	201	37	24.9	2.5	215	2.5	99	NF	201	36	19.7	2.5	217	2.5	77	169	191	34	12.4	2.5	210	2.5	46	100
		P3	159	51	20.0	2.0	167	2.0	51	115	161	48	15.8	2.0	170	2.0	37	89	155	44	9.8	2.0	165	2.0	19	51
		P4	168	47	21.5	2.2	177	2.1	57	122	170	45	17.0	2.1	180	2.1	45	93	163	41	10.6	2.1	175	2.1	27	59
		P1	162	36	17.7	1.8	166	1.7	53	NF	188	66	14.1	1.8	196	1.8	38	70	181	60	8.7	1.7	191	1.7	25	49
	SB4	P2	243	44	24.9	2.5	258	2.5	90	NF	248	42	19.7	2.5	266	2.5	71	148	240	38	12.3	2.5	261	2.4	43	92
		P3	194	66	19.4	1.9	202	1.9	48	103	196	62	15.3	1.9	205	1.9	35	81	189	55	9.5	1.9	200	1.9	18	48
		P4	215	55	22.4	2.2	227	2.2	53	115	218	52	17.7	2.2	231	2.2	42	86	211	45	11.0	2.2	226	2.2	25	55
		P1	194	38	17.6	1.8	199	1.7	51	NF	224	82	14.3	1.8	234	1.8	36	66	217	71	8.8	1.8	228	1.7	24	47
2000	SB5	P2	283	53	25.0	2.5	300	2.5	85	NF	291	50	19.8	2.5	310	2.5	67	135	285	43	12.3	2.5	309	2.4	40	86
		P3	226	87	18.8	1.9	235	1.9	45	95	228	80	14.8	1.9	238	1.9	33	76	221	68	9.1	1.8	233	1.8	17	45
		P4	260	66	23.2	2.3	274	2.3	50	109	266	61	18.3	2.3	281	2.3	39	82	259	51	11.4	2.3	278	2.3	24	52
		P1	186	38	17.7	1.8	194	1.6	175	NF	208	80	14.1	1.8	224	1.8	140	241	FC							
	US1	P2	258	45	24.6	2.5	283	2.4	309	NF	263	44	19.4	2.5	291	2.4	247	487	251	41	12.2	2.4	284	2.4	156	314
		P3	211	84	18.7	1.9	226	1.8	138	385	212	79	14.7	1.9	228	1.9	103	248	203	68	9.1	1.8	220	1.8	56	139
		P4	238	61	23.0	2.3	260	2.3	163	321	241	56	18.1	2.3	265	2.2	136	263	FC							
		P1	187	38	17.6	1.8	198	1.6	142	NF	211	80	14.2	1.8	232	1.7	107	183	FC							
	US2	P2	261	47	24.6	2.5	297	2.3	232	NF	267	45	19.5	2.5	307	2.3	187	353	256	41	12.2	2.4	305	2.3	119	236
		P3	213	84	18.7	1.9	234	1.8	110	280	214	79	14.7	1.9	236	1.8	82	198	205	68	9.1	1.8	231	1.8	45	111
		P4	242	61	23.0	2.3	272	2.2	133	251	246	56	18.1	2.3	279	2.2	109	204	FC							
		P1	187	38	17.6	1.8	199	1.6	120	NF	211	80	14.1	1.8	236	1.7	79	136	FC							
	US3	P2	262	47	24.6	2.5	302	2.3	170	NF	267	45	19.4	2.5	313	2.3	138	249	258	41	12.2	2.4	314	2.2	88	172
		P3	213	84	18.6	1.9	237	1.7	87	195	214	78	14.7	1.9	240	1.7	64	151	206	68	9.1	1.8	235	1.7	35	87
		P4	242	61	22.9	2.3	277	2.1	112	188	246	56	18.1	2.3	284	2.1	84	154	237	49	11.3	2.3	282	2.1	55	106
		P1	187	38	17.6	1.8	200	1.6	84	NF	211	80	14.1	1.8	237	1.6	59	101	203	70	8.7	1.7	231	1.6	42	75
	US4	P2	262	47	24.6	2.5	305	2.2	124	NF	267	45	19.4	2.5	316	2.2	102	176	258	41	12.2	2.4	317	2.2	66	125
		P3	212	84	18.6	1.9	239	1.6	68	136	214	78	14.6	1.8	241	1.6	51	112	206	68	9.1	1.8	237	1.7	27	68
		P4	242	60	22.9	2.3	279	2.0	77	143	246	56	18.0	2.3	286	2.0	64	116	237	49	11.2	2.2	285	2.1	41	80
		P1	59	37	9.9	1.7	64	1.3	99	177	59	38	12.5	1.7	64	1.4	101	217	FC							
	SB1	P2	64	28	14.1	2.4	72	2.3	152	416	64	28	17.7	2.4	72	2.4	218	586	59	28	9.4	2.5	68	2.4	96	227
		P3	61	32	12.3	2.1	67	1.8	60	171	61	32	15.5	2.1	67	1.9	96	256	57	32	8.2	2.2	64	1.8	50	93
		P4	60	34	11.3	1.9	66	1.6	97	191	60	35	14.3	1.9	66	1.7	113	252	FC							
		P1	90	49	10.3	1.8	100	1.2	72	148	90	50	13	1.8	99	1.3	97	178	FC							
	SB2	P2	98	31	14.2	2.4	114	2.3	140	313	98	31	17.8	2.4	113	2.3	179	433	FC							
		P3	92	44	11.9	2.0	104	1.6	68	160	92	45	15.1	2.1	103	1.7	87	206	88	41	7.9	2.2	99	1.6	33	85
		P4	92	43	12	2.1	104	1.7	90	164	92	45	15.1	2.1	103	1.7	110	217	88	41	8	2.2	99	1.7	58	105
		P1	119	63	10.5	1.8	133	1.2	79	123	119	65	13.3	1.8	132	1.3	86	158	FC							
	SB3	P2	131	35	14.2	2.4	153	2.2	113	261	130	35	17.9	2.4	150	2.3	160	364	FC							
		P3	122	59	11.7	2.0	137	1.5	52	135	121	61	14.8	2.0	136	1.6	73	174	92	31	9.4	2.6	108	2.3	90	171
		P4	123	53	12.5	2.1	141	1.7	76	141	122	55	15.8	2.2	139	1.8	98	200	88	41	7.9	2.3	99	1.6	33	85
		P1	148	79	10.6	1.8	166	1.1	63	112	147	81	13.5	1.8	164	1.2	71	131	88	41	8	2.2	99	1.7	58	105
	SB4	P2	163	41	14.3	2.4	190	2.2	101	231	160	41	18	2.4	185	2.2	132	329	FC							
		P3	150	77	11.4	2.0	169	1.3	55	126	149	80	14.5	2.0	167	1.4	77	152	123	35	9.4	2.6	146	2.3	77	153
		P4	154	63	13.1	2.3	178	1.8	61	131	153	65	16.6	2.3	175	1.9	84	174	116	54	7.8	2.4	131	1.4	35	71
		P1	177	96	10.8	1.9	198	1.1	66	119	176	100	13.8	1.9	196	1.2	75	120	117	49	8.3	2.3	135	1.7	42	94
5000	SB5	P2	193	49	14.4	2.5	225	2.1	107	213	190	49	18.1	2.5	218	2.2	121	281	FC							
		P3	178	96	11.1	1.9	200	1.2	57	114	177	100	14.1	1.9	197	1.3	60	145	FC							
		P4	186	74	13.6	2.3	216	1.8	64	138	183	76	17.2	2.3	212	1.9	88	163	FC							
		P1	157	89	10.5	1.8	179	1.2	204	341	157	91	13.4	1.8	178	1.2	249	406	116	54	7.8	2.1	131	1.4	35	71
	US1	P2	166	40	13.9	2.4	196	2.1	324	628	165	40	17.5	2.4	193	2.1	406	758	117	49	8.3	2.3	135	1.7	42	94
		P3	158	89	10.8	1.9	180	1.6	131	327	157	91	13.7	1.9	179	1.6	187	427	FC							
		P4	161	63	13.3	2.3	189	1.4	207	375	160	65	16.8	2.3	186	1.5	245	442	154	40	9.5	2.6	183	2.2	61	147
		P1	161	90	10.6	1.8	190	1.1	151	263	160	93	13.4	1.8	189	1.1	184	302	143	69	7.6	2.1	162	1.2	36	75
	US2	P2	171	43	14	2.4	213	2.0	240	450	170	43	17.6	2.4	207	2.0	303	543	147	57	8.7	2.4	171	1.7	44	100
		P3	162	90	10.8	1.9	192	1.3	117	252	161	92	13.7	1.9	190	1.3	141	338	FC							
		P4	166	64	13.3	2.3	205	1.5	151	300	164	65	16.7	2.3	201	1.6	198	344	FC							
		P1	162	90	10.5	1.8	195	0.9	129	210	161	92	13.3	1.8	193	1.0	149	220	154	40	9.5	2.6	183	2.2	61	147
	US3	P2	173	44	13.9	2.4	220	2.0	182	320	171	43	17.6	2.4	214	2.2	221	397	143	69	7.6	2.1	162	1.2	36	75
		P3	162	90	10.8	1.8	197	1.0	99	209	161	92	13.6	1.9	195	1.1	111	241	147	57	8.7	2.4	171	1.7	44	100
		P4	167	63	13.2	2.3	212	1.6	127	229	165	65	16.6	2.3	207	1.7	142	268	FC							
		P1	162	90	10.4	1.8	197	1.0	96	159	160	92	13.2	1.8	195	1.1	102	179	184	47	9.5	2.6	219	2.1	64	137
	US4	P2	174	44	14	2.4	223	2.1	148	254	172	44	17.8	2.4	217	2.2	180	324	FC							
		P3	162	89	10.7	1.8	199	1.1	76	156	161	91	13.5	1.8	196	1.2	94	187	177	65	9	2.4	209	1.7	46	84
		P4	167	63	13.1	2.3	215	1.7	95	161	165	65	16.6	2.3	210	1.9	115	207	FC							

NF: Unable to fill up 80% of space; FC: Failed to converge.

Table 2. Simulation results for volume 7000 m^3 and 10000m^3

Atrium Type			Type 1								Type 2								Type 3							
Volume V/m^3	Fire Type	Plume Model	T_U /°C	T_L /°C	y /%	h /m	T_{UMAX} /°C	h_{MIN} /m	t_{50} /s	t_{80} /s	T_U /°C	T_L /°C	y /%	h /m	T_{UMAX} /°C	h_{MIN} /m	t_{50} /s	t_{80} /s	T_U /°C	T_L /°C	y /%	h /m	T_{UMAX} /°C	h_{MIN} /m	t_{50} /s	t_{80} /s
		P1	54	37	8.5	1.6	59	1.3	106	205	54	37	10.9	1.7	59	1.3	124	254	FC							
	SB1	P2	56	28	12.2	2.3	63	2.3	172	490	56	28	15.7	2.4	63	2.4	247	688	51	28	7.7	2.4	59	2.3	107	240
		P3	54	32	10.6	2.0	60	1.8	74	191	54	32	13.5	2.1	60	1.9	107	282	FC							
		P4	54	35	9.8	1.9	59	1.6	106	238	54	34	12.5	1.9	59	1.7	137	304	FC							
		P1	81	50	8.9	1.7	91	1.2	81	163	81	50	11.5	1.7	90	1.3	103	205	FC							
	SB2	P2	84	30	12.3	2.4	98	2.2	144	361	84	30	15.7	2.4	97	2.3	195	515	79	31	7.8	2.4	93	2.2	82	210
		P3	81	44	10.4	2.0	93	1.6	63	162	81	45	13.3	2.0	92	1.7	99	234	77	43	6.6	2.0	88	1.4	31	99
		P4	81	44	10.4	2.0	93	1.6	81	198	81	44	13.4	2.0	92	1.7	117	258	77	42	6.6	2.0	88	1.5	53	113
		P1	107	64	9.1	1.8	121	1.1	89	141	106	65	11.8	1.8	119	1.2	93	189	FC							
	SB3	P2	111	34	12.4	2.4	130	2.2	139	316	110	33	15.7	2.4	128	2.3	178	438	104	34	7.9	2.4	124	2.1	90	174
		P3	108	60	10.2	2.0	123	1.4	67	159	107	61	13.1	2.0	122	1.6	86	205	102	56	6.4	2.0	117	1.2	33	85
		P4	108	54	11	2.1	125	1.7	88	177	107	54	14	2.1	123	1.8	106	225	102	51	6.9	2.1	119	1.6	57	103
		P1	132	79	9.3	1.8	150	1.1	74	133	131	80	12	1.8	149	1.2	100	165	FC							
	SB4	P2	137	39	12.4	2.4	162	2.1	129	271	135	38	15.8	2.4	158	2.2	153	390	129	39	7.9	2.4	155	2.0	75	170
		P3	133	78	10	1.9	152	1.3	50	131	132	79	12.9	2.0	151	1.4	70	186	FC							
		P4	133	63	11.5	2.2	157	1.7	73	170	132	63	14.7	2.2	154	1.8	93	202	127	59	7.3	2.2	150	1.6	40	110
		P1	157	95	9.5	1.8	179	1.0	78	122	156	97	12.2	1.9	177	1.2	84	156	FC							
7000	SB5	P2	162	46	12.5	2.4	192	2.1	116	256	160	44	15.9	2.4	187	2.2	144	347	153	46	8	2.4	185	2.0	79	141
		P3	158	95	9.7	1.9	181	1.1	52	140	157	97	12.5	1.9	178	1.3	73	161	FC							
		P4	159	71	11.9	2.3	188	1.8	76	158	156	71	15.2	2.3	185	1.9	97	194	151	66	7.5	2.3	180	1.6	42	94
		P1	FC								138	88	11.8	1.8	158	1.2	279	452	FC.							
	US1	P2	138	38	12	2.3	165	2.0	355	670	137	37	15.3	2.3	162	2.1	447	826	129	40	7.7	2.3	156	2.0	221	460
		P3	138	87	9.4	1.8	160	1.5	160	341	137	87	12	1.8	159	1.5	191	470	FC							
		P4	137	62	11.6	2.2	162	1.4	225	412	136	62	14.8	2.2	160	1.5	276	506	FC							
		P1	FC								FC								120	58	5.3	1.6	84	0.9	122	230
	US2	P2	143	41	12.1	2.3	180	1.9	278	507	142	39	15.4	2.3	176	2.1	333	590	134	41	7.7	2.3	172	1.8	173	346
		P3	FC								141	89	12	1.8	170	1.2	169	368	FC							
		P4	141	61	11.5	2.2	177	1.5	174	327	139	60	14.6	2.2	174	1.6	216	382	134	59	7.3	2.2	169	1.3	112	229
		P1	85	58	6.4	1.2	89	0.9	134	225	141	89	11.6	1.8	174	1.0	151	251	128	68	5	1.5	85	0.8	92	163
	US3	P2	145	41	12.1	2.3	187	2.0	205	367	144	40	15.6	2.4	183	2.2	259	445	137	41	7.7	2.3	180	1.8	136	256
		P3	FC								141	88	11.9	1.8	175	1.1	121	278	129	69	5.1	1.6	88	0.8	52	121
		P4	142	61	11.4	2.2	184	1.6	135	244	141	60	14.6	2.2	180	1.8	166	296	135	59	7.3	2.2	176	1.3	99	161
		P1	142	87	9	1.7	178	1.0	106	161	141	87	11.5	1.8	176	1.1	129	196	122	63	4.5	1.4	88	0.8	74	122
	US4	P2	146	41	12.4	2.4	190	2.1	156	297	144	40	16.1	2.5	185	2.2	183	389	137	41	7.7	2.3	184	1.9	107	180
		P3	143	87	9.2	1.8	179	1.1	70	163	141	87	11.8	1.8	177	1.2	106	206	128	65	4.6	1.4	89	0.8	42	106
		P4	143	61	11.4	2.2	187	1.7	105	181	141	61	14.6	2.2	183	1.9	123	238	136	58	7.2	2.2	179	1.5	79	140
		P1	44	34	6.8	1.5	44	1.3	129	242	49	37	9.3	1.6	53	1.3	142	318	42	36	4.5	1.6	42	1.1	89	151
	SB1	P2	49	28	10.8	2.3	54	2.3	206	562	50	28	13.9	2.4	55	2.3	289	803	45	28	6.7	2.3	50	2.2	115	281
		P3	48	32	9.2	2.0	53	1.8	87	223	48	31	11.5	2.0	53	1.8	116	321	FC							
		P4	48	34	8.5	1.8	53	1.6	112	275	48	33	10.6	1.8	53	1.6	158	364	41	33	5.2	1.8	41	1.5	77	152
		P1	71	49	7.9	1.7	81	1.2	108	209	71	49	9.9	1.7	80	1.3	126	241	FC							
	SB2	P2	72	29	10.8	2.3	83	2.3	163	432	72	29	13.6	2.3	83	2.3	225	617	67	30	6.8	2.3	79	2.2	92	238
		P3	71	44	9.1	2.0	81	1.6	76	199	70	43	11.4	2.0	81	1.7	110	278	68	43	5.7	2.0	78	1.4	48	110
		P4	71	43	9.2	2.0	81	1.6	109	223	70	43	11.5	2.0	81	1.7	121	310	67	43	5.8	2.0	78	1.5	67	137
		P1	94	62	8.1	1.8	107	1.2	97	172	93	63	10.2	1.8	106	1.2	118	212	FC							
	SB3	P2	93	32	10.8	2.3	110	2.2	141	377	93	31	13.6	2.3	108	2.3	192	514	88	34	6.9	2.3	104	2.1	81	207
		P3	93	59	9	2.0	108	1.4	61	178	92	59	11.4	1.9	107	1.5	97	231	FC							
		P4	92	52	9.7	2.1	108	1.7	97	206	91	51	12.2	2.1	107	1.8	113	262	88	51	6.1	2.1	104	1.6	52	129
		P1	FC								114	77	10.5	1.8	131	1.2	105	191	FC							
	SB4	P2	114	36	10.9	2.4	136	2.2	133	338	113	34	13.7	2.3	133	2.2	190	455	108	38	6.9	2.4	129	2.0	86	185
		P3	116	75	8.9	1.9	134	1.3	64	150	115	76	11.2	1.9	133	1.4	82	214	FC							
		P4	113	59	10.1	2.2	135	1.8	83	181	112	58	12.7	2.2	133	1.8	120	243	108	59	6.4	2.2	· 129	1.6	55	116
		P1	FC								135	91	10.6	1.8	156	1.1	91	185	FC							
10000	SB5	P2	134	41	11	2.4	160	2.1	121	307	133	39	13.7	2.4	157	2.2	162	418	127	44	6.9	2.4	154	1.9	71	178
		P3	FC								136	91	10.9	1.9	157	1.3	86	192	FC							
		P4	134	65	10.5	2.3	161	1.8	87	172	131	63	13.2	2.3	158	1.9	105	237	128	66	6.6	2.3	154	1.6	57	102
		P1	FC								FC								104	66	5	1.7	84	1.0	184	326
	US1	P2	114	36	10.4	2.2	137	2.0	399	759	114	34	13.1	2.2	135	2.0	483	901	107	38	6.6	2.3	129	1.9	259	495
		P3	FC								118	82	10.3	1.8	138	1.3	213	506	94	68	5.2	1.8	85	1.4	95	212
		P4	115	58	10.1	2.2	137	1.4	259	480	114	56	12.7	2.2	135	1.5	303	562	FC							
		P1	81	66	6.6	1.4	84	0.9	209	349	82	60	7.6	1.3	86	1.0	234	395	90	64	4.8	1.6	83	0.9	146	241
	US2	P2	118	37	10.5	2.3	150	2.0	291	554	118	36	13.3	2.3	147	2.1	380	667	111	40	6.6	2.3	143	1.7	197	374
		P3	83	65	6.5	1.4	88	1.0	137	304	83	58	7.4	1.3	90	1.1	174	394	80	67	4.9	1.7	84	1.0	73	174
		P4	118	56	10	2.2	150	1.5	195	367	117	53	12.5	2.1	147	1.6	231	433	112	58	6.4	2.2	144	1.3	140	245
		P1	77	56	5.7	1.2	88	0.9	157	255	78	48	7	1.2	90	1.1	171	296	92	68	4.3	1.5	84	0.7	120	182
	US3	P2	120	38	10.8	2.3	156	2.1	225	401	119	36	14	2.4	153	2.2	275	517	113	40	6.6	2.3	149	1.9	143	271
		P3	79	56	5.8	1.3	89	1.0	103	231	121	81	10.1	1.7	154	1.1	150	291	100	70	4.3	1.5	85	0.7	67	149
		P4	119	56	10	2.1	157	1.7	140	274	118	54	12.5	2.1	153	1.8	187	339	114	58	6.3	2.2	150	1.4	110	183
		P1	76	49	5.7	1.2	90	1.0	113	197	121	81	9.9	1.7	155	1.1	133	225	98	62	3.9	1.4	86	0.8	85	146
	US4	P2	121	38	11.4	2.5	159	2.1	160	348	120	37	14.9	2.5	155	2.2	202	441	114	40	6.8	2.3	152	1.9	117	218
		P3	76	48	5.9	1.3	91	1.1	83	185	121	80	10.2	1.8	156	1.2	117	238	99	64	4	1.4	86	0.8	58	117
		P4	120	56	10	2.2	160	1.8	114	215	118	54	12.7	2.2	156	1.9	149	261	114	57	6.3	2.1	153	1.5	72	145

FC: Failed to converge

Table 3. Simulation results for volume 15000 m^3 and 20000m^3

Atrium Type			Type 1								Type 2								Type 3							
Volume V/m^3	Fire Type	Plume Model	T_U /°C	T_L /°C	y /%	h /m	T_{UMAX} /°C	h_{MIN} /m	t_{50} /s	t_{80} /s	T_U /°C	T_L /°C	y /%	h /m	T_{UMAX} /°C	h_{MIN} /m	t_{50} /s	t_{80} /s	T_U /°C	T_L /°C	y /%	h /m	T_{UMAX} /°C	h_{MIN} /m	t_{50} /s	t_{80} /s
15000	SB1	P1	41	35	5.9	1.5	42	1.2	147	302	42	34	7.2	1.4	43	1.3	171	398	40	36	3.9	1.5	40	1.1	95	198
		P2	43	28	9.8	2.4	47	2.3	231	687	44	28	13.7	2.7	47	2.3	338	974	42	28	5.8	2.3	37	2.3	139	348
		P3	42	30	7.5	1.9	46	1.8	97	269	43	29	9.5	1.9	46	1.8	123	388	38	32	4.9	1.9	39	1.6	59	122
		P4	42	33	6.9	1.7	46	1.5	134	337	43	31	8.6	1.7	47	1.6	171	441	39	34	4.5	1.8	40	1.4	87	185
	SB2	P1	54	43	6.1	1.5	54	1.2	129	242	55	42	7.3	1.4	56	1.2	142	318	50	46	4.2	1.6	50	1.1	89	152
		P2	60	29	9.2	2.3	69	2.2	195	521	61	28	11.9	2.3	69	2.3	264	745	56	29	5.7	2.3	65	2.1	119	276
		P3	60	42	7.6	1.9	70	1.6	88	230	60	40	9.4	1.8	69	1.6	118	313	FC							
		P4	60	41	7.6	1.9	70	1.6	114	277	60	39	9.5	1.9	69	1.7	160	363	FC							
	SB3	P1	FC								FC								FC							
		P2	77	30	9.1	2.3	90	2.2	177	458	77	29	11.6	2.3	89	2.2	237	639	72	32	5.8	2.2	86	2.1	109	230
		P3	79	57	7.6	1.9	92	1.4	73	191	77	54	9.4	1.9	91	1.5	106	288	FC							
		P4	77	48	8.1	2.0	92	1.7	104	245	76	45	10.1	2.0	90	1.7	134	323	74	51	5.2	2.0	88	1.5	64	150
	SB4	P1	FC								FC								FC							
		P2	93	33	9.1	2.3	111	2.1	151	407	93	31	11.5	2.3	109	2.2	218	552	88	36	5.8	2.2	106	2.0	96	212
		P3	FC								96	70	9.4	1.8	113	1.3	92	253	FC							
		P4	93	53	8.5	2.1	112	1.7	90	224	92	50	10.6	2.1	110	1.8	122	308	90	57	5.5	2.1	108	1.6	68	139
	SB5	P1	FC								FC								FC							
		P2	109	36	9.2	2.3	130	2.1	141	362	108	34	11.5	2.3	128	2.2	193	504	106	41	5.7	2.1	125	1.9	80	208
		P3	FC								FC								FC							
		P4	109	57	8.8	2.2	133	1.8	95	217	107	53	11	2.2	130	1.9	129	286	105	62	5.6	2.2	128	1.6	51	125
	US1	P1	75	68	6.3	1.5	77	1.0	291	514	75	64	7.4	1.4	77	1.0	356	607	81	58	4.7	1.9	84	0.9	218	379
		P2	92	33	8.6	2.1	111	1.9	435	832	92	31	10.9	2.1	110	2.0	548	1005	93	36	5.5	2.2	104	1.8	272	559
		P3	78	68	6.2	1.5	81	1.1	190	428	79	64	7.1	1.4	82	1.1	231	553	92	56	4.8	1.9	115	1.2	106	230
		P4	93	51	8.4	2.1	112	1.4	287	535	92	47	10.4	2.0	110	1.5	343	642	FC							
	US2	P1	73	62	5.4	1.3	81	0.8	240	397	73	55	6.2	1.2	82	0.9	278	453	76	58	4.4	1.7	82	0.8	166	285
		P2	96	34	8.9	2.2	122	2.0	338	629	96	32	11.7	2.3	120	2.1	418	742	90	38	5.5	2.2	116	1.7	215	411
		P3	74	62	5.3	1.3	83	0.9	144	332	74	53	6.3	1.2	84	1.0	197	431	79	59	4.7	1.8	87	0.8	85	196
		P4	96	50	8.3	2.0	123	1.5	210	418	95	46	10.4	2.0	121	1.7	261	491	94	56	5.3	2.1	119	1.3	145	274
	US3	P1	70	53	5	1.2	84	1.0	175	296	71	47	6.4	1.3	85	1.1	205	342	71	57	3.7	1.5	82	0.7	125	214
		P2	97	34	9.8	2.4	127	2.1	240	477	97	33	13.1	2.6	125	2.1	303	603	92	37	5.7	2.2	121	1.9	167	319
		P3	71	53	5.1	1.3	85	1.0	113	266	72	46	6.8	1.3	87	1.1	156	337	73	50	3.9	1.5	83	0.7	61	155
		P4	97	49	8.4	2.1	129	1.7	162	316	96	46	10.7	2.1	126	1.8	204	389	93	55	5.3	2.1	125	1.4	119	219
	US4	P1	69	49	5.5	1.4	85	1.0	136	224	70	43	7.4	1.5	86	1.1	154	280	70	42	3.5	1.4	83	0.8	94	166
		P2	98	35	10.6	2.6	129	2.1	181	403	98	33	14.3	2.8	127	2.2	233	546	95	38	6	2.4	124	1.9	125	248
		P3	70	48	5.6	1.4	87	1.1	95	202	71	42	8	1.6	89	1.2	126	279	70	54	3.6	1.4	83	0.8	53	126
		P4	98	50	8.6	2.1	131	1.8	120	259	97	46	11.2	2.2	128	1.8	151	330	94	44	5.3	2.1	127	1.5	83	167
20000	SB1	P1	38	34	5.1	1.4	40	1.2	167	369	39	33	6.3	1.35	41	1.25	204	468	38	35	3.4	1.5	39	1.1	105	230
		P2	39	28	10.2	2.8	42	2.3	262	771	40	27	15.1	3.24	43	2.31	376	1022	39	28	5.3	2.3	36	2.2	146	385
		P3	39	29	6.5	1.8	42	1.7	110	282	39	28	8.4	1.82	42	1.78	131	425	37	31	4.3	1.8	38	1.6	55	131
		P4	38	31	5.9	1.6	40	1.5	159	389	39	30	7.5	1.62	42	1.56	209	512	37	33	3.9	1.7	38	1.4	99	202
	SB2	P1	50	43	5.4	1.5	52	1.2	134	280	51	41	6.5	1.39	53	1.22	161	363	48	36	4	1.7	49	1.0	80	189
		P2	53	28	8.5	2.3	61	2.2	213	606	54	28	11.8	2.54	61	2.26	291	854	50	29	5.1	2.2	58	2.1	129	302
		P3	53	39	6.5	1.8	62	1.5	81	246	53	36	8.1	1.73	62	1.6	129	356	47	45	4.7	2.0	53	1.4	41	128
		P4	53	38	6.6	1.8	62	1.6	122	318	53	36	8.1	1.75	61	1.63	162	428	FC							
	SB3	P1	61	52	5.7	1.5	62	1.1	127	255	62	50	6.7	1.44	64	1.18	159	329	58	46	4.1	1.8	60	1.0	88	168
		P2	67	29	8.1	2.2	79	2.2	198	512	67	29	10.7	2.31	78	2.22	268	724	66	31	5.1	2.2	75	2.0	120	280
		P3	62	47	6	1.6	64	1.4	87	230	68	50	8.1	1.74	81	1.46	118	314	59	47	4.6	2.0	62	1.2	43	117
		P4	67	44	7.1	1.9	81	1.7	113	271	67	40	8.8	1.89	79	1.72	158	374	65	49	4.6	2.0	78	1.5	78	153
	SB4	P1	72	61	5.9	1.6	72	1.1	115	238	72	59	6.9	1.5	73	1.14	150	299	70	46	4.2	1.8	70	0.9	73	141
		P2	81	31	8.1	2.2	96	2.1	173	468	80	30	10.3	2.22	95	2.18	231	646	79	34	5.1	2.2	92	2.0	107	244
		P3	73	60	6.1	1.7	74	1.2	71	206	73	55	7.1	1.53	76	1.31	104	300	74	47	5	2.1	76	1.0	45	103
		P4	81	48	7.4	2.0	98	1.7	100	252	80	43	9.2	1.99	96	1.79	148	343	78	45	4.8	2.1	95	1.6	62	144
	SB5	P1	82	70	6.1	1.6	82	1.0	101	214	82	68	7.2	1.55	83	1.11	138	261	81	47	4.3	1.9	81	0.8	77	149
		P2	94	33	8	2.2	112	2.1	164	427	93	31	10.2	2.19	111	2.14	228	585	92	38	5.1	2.2	108	1.9	92	222
		P3	83	71	6.2	1.7	83	1.1	74	197	83	67	7.1	1.53	85	1.19	108	260	83	53	4.8	2.1	84	0.8	47	108
		P4	94	50	7.7	2.1	115	1.8	106	247	92	45	9.6	2.06	112	1.84	135	324	91	45	5	2.1	112	1.6	65	131
	US1	P1	70	66	5.5	1.5	75	0.9	320	579	70	62	6.3	1.36	75	0.93	400	662	75	47	4.3	1.8	87	0.8	238	401
		P2	81	31	7.5	2.0	95	1.9	461	903	80	30	9.7	2.09	95	2.01	585	1041	80	35	4.8	2.1	90	1.7	310	595
		P3	72	66	5.4	1.5	77	0.9	197	457	72	61	6	1.3	78	0.98	254	592	81	49	4.1	1.8	96	1.0	119	253
		P4	80	45	7.2	1.9	97	1.4	302	585	79	40	8.8	1.91	95	1.53	372	719	FC							
	US2	P1	68	58	4.7	1.3	78	0.8	256	435	68	51	5.6	1.2	79	0.97	290	504	80	39	3.9	1.7	98	0.7	171	316
		P2	83	32	8.3	2.2	105	2.0	351	677	83	30	11.3	2.43	104	2.1	445	827	81	36	4.9	2.1	100	1.8	239	458
		P3	69	58	4.6	1.3	79	0.9	154	368	69	50	5.7	1.23	80	1.02	203	478	71	37	4	1.7	89	0.7	100	202
		P4	83	44	7.2	2.0	107	1.6	232	459	82	40	9.1	1.96	104	1.71	297	542	80	38	4.6	2.0	104	1.3	153	310
	US3	P1	66	51	4.7	1.3	80	1.0	198	326	66	46	6.3	1.36	81	1.06	224	373	70	38	3.6	1.6	81	0.8	133	233
		P2	84	32	9.5	2.6	109	2.1	261	523	84	31	13.1	2.83	108	2.13	339	684	82	36	5.2	2.3	105	1.9	175	334
		P3	67	51	4.8	1.3	81	1.0	124	286	67	45	6.6	1.43	83	1.12	165	369	78	37	3.8	1.7	103	0.7	77	164
		P4	84	44	7.5	2.0	112	1.7	188	347	83	41	9.7	2.09	109	1.8	227	426	81	41	4.6	2.0	109	1.5	130	221
	US4	P1	65	49	5.5	1.5	81	1.0	143	254	66	44	7.7	1.65	82	1.09	178	301	67	37	3.5	1.5	81	0.8	105	190
		P2	84	32	10.5	2.9	111	2.1	204	469	85	31	14.4	3.1	110	2.14	268	627	81	36	5.7	2.5	107	1.9	136	263
		P3	66	48	5.6	1.5	82	1.0	108	224	66	42	8	1.72	84	1.17	137	308	70	39	3.8	1.6	84	0.8	50	137
		P4	84	45	7.9	2.2	114	1.7	149	290	84	41	10.5	2.25	111	1.83	177	367	81	41	4.7	2.0	111	1.5	97	173

FC: Failed to converge

Table 4. Simulation results for volume 25000 m³ and 28000m³

Atrium Type			Type 1								Type 2								Type 3							
Volume V/m³	Fire Type	Plume Model	T_U /°C	T_L /°C	y /%	h /m	T_{UMAX} /°C	h_{MIN} /m	t_{50} /s	t_{80} /s	T_U /°C	T_L /°C	y /%	h /m	T_{UMAX} /°C	h_{MIN} /m	t_{50} /s	t_{80} /s	T_U /°C	T_L /°C	y /%	h /m	T_{UMAX} /°C	h_{MIN} /m	t_{50} /s	t_{80} /s
		P1	36	32	4.4	1.3	38	1.2	189	402	37	31	5.6	1.3	39	1.2	220	525	36	34	3.1	1.4	38	1.1	116	244
	SB1	P2	37	27	11.1	3.3	39	2.3	298	869	38	27	16.8	3.9	40	2.4	420	1233	37	28	5.1	2.4	35	2.2	154	427
		P3	FC								37	28	7.9	1.8	39	1.8	142	469	35	30	3.8	1.8	36	1.6	52	141
		P4	36	30	5.3	1.5	38	1.5	165	427	37	29	7.1	1.6	39	1.5	229	571	36	32	3.5	1.6	37	1.4	93	222
		P1	47	42	4.9	1.4	50	1.1	140	323	48	39	5.9	1.4	51	1.2	182	413	46	36	3.8	1.8	49	1.0	92	209
	SB2	P2	49	28	8.5	2.5	56	2.2	233	660	50	28	12.5	2.9	56	2.3	322	958	47	29	4.6	2.2	52	2.1	140	332
		P3	49	37	5.7	1.7	57	1.5	96	267	49	33	7.2	1.7	56	1.6	121	385	45	34	4.3	2.0	53	1.4	58	120
		P4	49	36	5.8	1.7	57	1.6	131	344	49	33	7.3	1.7	56	1.6	186	479	44	32	4.2	2.0	51	1.5	86	181
		P1	57	50	5.1	1.5	60	1.1	135	283	58	47	5.9	1.4	61	1.2	162	366	FC							
	SB3	P2	61	29	7.7	2.2	71	2.2	200	575	61	28	10.7	2.5	71	2.2	282	800	59	30	4.6	2.1	67	2.0	112	293
		P3	58	45	5.4	1.6	61	1.3	82	232	61	45	7	1.6	73	1.4	111	346	FC							
		P4	61	40	6.3	1.8	73	1.7	124	301	60	36	7.8	1.8	71	1.7	164	411	54	41	3.9	1.8	57	1.5	73	179
		P1	67	59	5.3	1.5	69	1.1	124	268	67	56	6.1	1.4	70	1.1	155	320	FC							
	SB4	P2	72	30	7.4	2.2	86	2.1	198	516	72	29	9.9	2.3	85	2.2	268	711	68	33	4.6	2.1	82	2.0	120	260
		P3	68	58	5.5	1.6	71	1.2	87	229	68	52	6.3	1.5	72	1.3	117	313	70	44	4.6	2.1	79	1.0	43	116
		P4	72	43	6.6	1.9	88	1.7	112	285	67	56	6.1	1.4	70	1.1	155	320	70	42	4.3	2.0	86	1.6	78	151
		P1	76	68	5.4	1.6	78	1.0	111	247	76	65	6.3	1.5	79	1.1	144	305	76	46	4.1	1.9	80	0.8	71	155
25000	SB5	P2	83	31	7.3	2.1	100	2.1	190	479	83	30	9.5	2.2	99	2.1	247	656	84	36	4.6	2.1	96	1.9	105	260
		P3	77	68	5.5	1.6	79	1.1	90	201	77	64	6.2	1.4	81	1.2	102	294	83	42	4.1	1.9	101	0.8	45	101
		P4	84	45	6.9	2.0	102	1.7	117	261	83	40	8.5	2.0	100	1.8	144	366	81	45	4.5	2.1	101	1.6	61	159
		P1	67	64	4.9	1.4	72	0.8	355	613	66	59	5.5	1.3	72	0.9	428	727	67	37	3.7	1.7	85	0.8	241	449
	US1	P2	71	30	6.8	2.0	85	1.9	493	967	72	29	9.3	2.2	85	2.0	629	1160	70	33	4.2	2.0	80	1.7	312	639
		P3	68	64	4.7	1.4	74	0.8	207	471	67	57	5.4	1.3	75	0.9	280	637	69	39	4	1.9	75	0.9	113	279
		P4	71	41	6.3	1.8	86	1.4	322	623	71	36	7.8	1.8	85	1.5	406	766	FC							
		P1	64	55	4.3	1.2	75	0.9	277	460	64	49	5.3	1.2	76	1.0	327	542	64	35	3.3	1.6	72	0.7	198	331
	US2	P2	74	30	8.1	2.4	93	2.0	390	713	74	29	11.5	2.7	92	2.1	478	899	70	34	4.4	2.1	89	1.8	245	470
		P3	65	55	4.3	1.3	76	0.9	165	387	65	48	5.4	1.3	77	1.0	212	490	66	36	3.5	1.6	73	0.6	95	211
		P4	74	40	6.5	1.9	95	1.6	256	487	74	37	8.3	1.9	93	1.7	317	582	72	37	4.1	1.9	94	1.3	163	330
		P1	63	50	4.7	1.4	77	1.0	203	359	63	45	6.4	1.5	78	1.1	246	418	73	39	3.4	1.6	96	0.8	144	255
	US3	P2	75	31	9.6	2.8	97	2.0	284	576	75	29	13.5	3.1	96	2.1	358	754	71	34	5	2.3	93	1.9	184	353
		P3	63	50	4.7	1.4	78	1.0	138	290	64	44	6.6	1.5	79	1.1	176	384	65	36	3.4	1.6	81	0.7	73	175
		P4	75	41	7	2.0	99	1.7	196	361	74	37	9.3	2.2	97	1.8	232	469	73	38	4.2	1.9	98	1.5	122	246
		P1	62	48	5.6	1.6	78	1.0	152	287	62	43	7.9	1.8	78	1.1	184	345	65	38	3.4	1.6	82	0.8	117	195
	US4	P2	75	31	10.7	3.1	99	2.1	230	501	76	30	14.9	3.5	98	2.1	287	698	71	34	5.6	2.6	95	1.9	148	280
		P3	63	48	5.5	1.6	79	1.0	103	248	63	42	8	1.9	80	1.2	130	321	73	36	3.5	1.6	97	0.8	67	150
		P4	75	41	7.6	2.2	101	1.7	140	304	75	38	10.1	2.4	99	1.8	186	410	73	38	4.4	2.0	100	1.5	91	181
		P1	35	31	4.1	1.3	37	1.2	200	436	36	30	5.4	1.3	38	1.2	247	570	36	34	2.9	1.4	37	1.1	111	270
	SB1	P2	36	27	11.8	3.6	38	2.3	304	903	37	27	17.7	4.3	39	2.5	440	1306	37	28	5.1	2.5	35	2.2	168	446
		P3	35	27	6.1	1.9	35	1.8	100	326	36	28	7.8	1.9	38	1.7	157	490	35	30	3.6	1.7	36	1.6	50	156
		P4	35	29	5.1	1.5	36	1.5	178	444	36	28	7	1.7	38	1.5	239	618	35	32	3.2	1.6	36	1.4	109	231
		P1	46	41	4.6	1.4	49	1.1	152	342	47	38	5.6	1.4	50	1.2	191	445	45	35	3.6	1.7	48	1.0	108	218
	SB2	P2	47	28	8.7	2.6	53	2.2	242	704	48	28	13.1	3.2	53	2.2	346	1006	46	28	4.5	2.2	50	2.1	135	355
		P3	46	35	5.3	1.6	50	1.5	93	276	47	32	6.8	1.6	54	1.6	136	409	44	33	4.1	2.0	53	1.4	56	136
		P4	47	34	5.5	1.7	54	1.6	145	365	47	32	6.9	1.7	53	1.6	198	492	43	34	3.9	1.9	52	1.5	83	192
		P1	56	49	4.8	1.5	59	1.1	148	305	56	46	5.6	1.4	60	1.2	173	382	54	35	3.8	1.8	59	1.0	97	181
	SB3	P2	58	29	7.6	2.3	67	2.2	211	604	58	28	11	2.7	67	2.2	309	855	57	30	4.4	2.1	64	2.0	128	319
		P3	56	45	5.2	1.6	60	1.3	100	242	57	41	6.4	1.5	63	1.4	127	351	56	34	4.4	2.1	61	1.1	60	126
		P4	58	38	5.9	1.8	69	1.6	139	325	57	34	7.4	1.8	68	1.7	177	447	54	42	4	1.9	59	1.5	71	171
		P1	65	58	4.9	1.5	68	1.0	138	272	65	54	5.7	1.4	69	1.1	167	359	64	37	3.8	1.9	69	0.9	83	176
	SB4	P2	68	29	7.1	2.2	81	2.1	209	547	69	29	9.9	2.4	80	2.2	276	770	68	32	4.3	2.1	77	2.0	116	287
		P3	65	57	5.1	1.6	69	1.2	84	239	65	50	6	1.4	71	1.3	113	339	67	36	4.4	2.1	74	0.9	42	113
		P4	68	41	6.2	1.9	83	1.7	127	310	68	36	7.8	1.9	81	1.8	169	401	66	34	4.1	2.0	75	1.6	75	164
		P1	74	67	5.1	1.5	76	1.0	126	252	73	63	5.9	1.4	77	1.1	156	325	73	41	3.9	1.9	81	0.8	87	166
28000	SB5	P2	79	31	7	2.1	94	2.1	182	493	79	29	9.3	2.2	93	2.1	255	698	78	35	4.4	2.1	91	1.9	102	267
		P3	74	67	5.1	1.6	77	1.0	87	212	74	61	5.8	1.4	79	1.2	118	320	73	39	4.1	2.0	88	0.8	43	118
		P4	79	42	6.5	2.0	97	1.7	113	287	78	38	8.1	1.9	94	1.8	157	386	77	38	4.2	2.0	95	1.6	79	153
		P1	65	62	4.6	1.4	71	0.8	361	648	64	57	5.1	1.2	71	0.9	432	757	64	37	3.5	1.7	71	0.8	252	451
	US1	P2	67	29	6.6	2.0	80	1.9	517	996	68	29	9.3	2.2	80	2.0	631	1203	68	33	4	1.9	76	1.7	323	659
		P3	65	60	4.2	1.3	71	0.8	201	497	65	55	5	1.2	73	0.9	273	659	67	36	3.4	1.6	104	0.8	110	271
		P4	67	39	5.8	1.8	82	1.4	331	641	67	34	7.3	1.8	80	1.6	412	798	FC							
		P1	63	54	4.1	1.2	73	0.9	286	481	62	48	5.1	1.2	74	1.0	334	560	67	37	3.3	1.6	107	0.7	191	359
	US2	P2	70	30	8.1	2.5	88	2.0	398	748	70	29	11.7	2.8	87	2.1	484	922	68	33	4.3	2.1	84	1.8	258	496
		P3	63	54	4.1	1.3	74	0.9	161	396	63	47	5.3	1.3	75	1.0	226	516	FC							
		P4	70	38	6.1	1.9	90	1.6	268	510	70	35	8	1.9	88	1.7	327	620	68	39	3.9	1.9	89	1.3	178	339
		P1	61	49	4.7	1.4	75	1.0	215	364	61	44	6.5	1.6	76	1.1	257	438	62	36	3.1	1.5	74	0.8	158	265
	US3	P2	71	30	9.8	3.0	92	2.0	296	610	72	29	13.9	3.3	91	2.1	367	796	68	33	5	2.4	88	1.9	199	361
		P3	62	49	4.6	1.4	76	1.0	134	302	62	44	6.6	1.6	77	1.1	171	391	62	36	3.2	1.5	74	0.7	71	170
		P4	71	39	6.8	2.1	94	1.7	190	387	71	35	9.1	2.2	92	1.8	244	488	66	34	4	1.9	93	1.5	139	258
		P1	61	47	5.7	1.7	76	1.0	166	292	61	43	8	1.9	77	1.1	196	365	67	67	3.4	1.6	95	0.8	113	207
	US4	P2	71	30	10.9	3.3	94	2.1	222	535	72	29	15.2	3.7	92	2.1	295	740	68	33	5.6	2.7	90	1.9	144	308
		P3	61	47	5.5	1.7	77	1.0	100	259	62	42	7.9	1.9	78	1.1	146	347	62	39	3.3	1.6	88	0.8	65	146
		P4	71	39	7.4	2.3	96	1.7	156	330	71	36	10	2.4	93	1.8	199	429	67	37	4.2	2.0	94	1.5	108	194

FC: Failed to converge.

Table 5. Simulation results for volume 30000m^3

Atrium Type			Type 1								Type 2								Type 3							
Volume V/m^3	Fire Type	Plume Model	T_U /°C	T_L /°C	y /%	h /m	T_{UMAX} /°C	h_{MIN} /m	t_{50} /s	t_{80} /s	T_U /°C	T_L /°C	y /%	h /m	T_{UMAX} /°C	h_{MIN} /m	t_{50} /s	t_{80} /s	T_U /°C	T_L /°C	y /%	h /m	T_{UMAX} /°C	h_{MIN} /m	t_{50} /s	t_{80} /s
	SB1	P1	35	31	4	1.2	37	1.2	193	459	36	30	5.4	1.3	38	1.2	259	587	35	34	2.7	1.4	37	1.1	127	261
		P2	35	27	12.2	3.8	37	2.3	315	935	37	27	18.4	4.5	38	2.6	447	1344	35	28	5.2	2.6	34	2.2	164	453
		P3	35	28	5.8	1.8	35	1.7	118	338	36	28	7.8	1.9	37	1.7	154	497	35	30	3.4	1.7	35	1.6	69	153
		P4	35	29	5	1.6	36	1.5	173	469	36	28	7.1	1.8	38	1.5	232	637	35	31	3.1	1.5	36	1.4	107	244
	SB2	P1	45	40	4.5	1.4	48	1.1	167	369	46	37	5.4	1.3	49	1.2	204	467	45	37	3.5	1.7	48	1.0	106	210
		P2	46	28	8.9	2.8	52	2.2	255	722	47	28	13.5	3.3	52	2.3	356	1032	45	28	4.4	2.2	48	2.1	132	365
		P3	45	34	5.2	1.6	49	1.5	91	289	46	31	6.6	1.6	52	1.6	134	418	43	32	3.9	1.9	52	1.4	56	133
		P4	45	33	5.3	1.6	50	1.5	142	373	46	31	6.8	1.7	52	1.6	193	515	42	33	3.8	1.9	50	1.5	82	206
	SB3	P1	55	49	4.6	1.4	58	1.1	144	313	55	45	5.4	1.3	59	1.2	187	407	53	36	3.7	1.8	58	1.0	95	195
		P2	56	28	7.6	2.4	65	2.2	225	624	57	28	11.2	2.8	65	2.2	320	886	53	29	4.2	2.1	62	2.0	125	330
		P3	55	45	5	1.6	59	1.3	98	256	55	39	6.2	1.5	61	1.4	124	361	53	34	4.3	2.1	76	1.1	59	124
		P4	56	37	5.7	1.8	67	1.6	135	334	56	33	7.2	1.8	66	1.7	172	452	53	35	3.8	1.9	61	1.5	89	186
	SB4	P1	63	57	4.7	1.5	67	1.0	135	282	63	53	5.5	1.4	67	1.1	161	364	64	33	3.8	1.9	70	0.9	81	170
		P2	66	29	7	2.2	78	2.1	204	570	66	29	10	2.5	78	2.2	288	784	64	31	4.2	2.1	75	2.0	113	299
		P3	64	56	4.9	1.5	68	1.2	83	234	64	49	5.8	1.4	69	1.3	111	350	64	33	4.2	2.1	70	0.9	41	111
		P4	66	39	6	1.9	80	1.7	124	300	66	35	7.5	1.9	79	1.8	164	428	62	34	3.9	1.9	69	1.5	74	179
	SB5	P1	72	66	4.9	1.5	75	1.0	122	262	72	61	5.6	1.4	76	1.1	151	332	70	43	3.7	1.8	80	0.8	85	161
30000		P2	76	30	6.8	2.1	91	2.1	197	517	76	29	9.3	2.3	90	2.1	268	714	72	34	4.2	2.1	88	1.9	119	280
		P3	73	66	4.9	1.5	76	1.0	86	227	72	60	5.5	1.4	77	1.2	116	311	72	44	4	2.0	77	0.8	43	115
		P4	76	41	6.2	1.9	93	1.7	110	298	75	36	7.8	1.9	91	1.8	153	393	72	45	4.1	2.0	92	1.6	77	168
	US1	P1	63	61	4.4	1.4	70	0.8	373	652	63	55	5	1.2	70	0.9	442	779	65	33	3.4	1.7	87	0.7	266	461
		P2	65	29	6.5	2.0	77	1.9	528	1014	66	29	9.4	2.3	77	2.0	659	1240	61	32	3.8	1.9	73	1.7	337	667
		P3	63	60	4.1	1.3	70	0.8	218	509	64	54	4.9	1.2	72	0.9	288	668	69	33	3.2	1.6	98	0.8	128	286
		P4	65	38	5.6	1.7	79	1.4	344	668	65	33	7.1	1.7	77	1.6	424	801	FC							
	US2	P1	61	53	4	1.2	72	0.9	300	510	61	47	5.1	1.3	73	1.0	346	586	FC							
		P2	68	30	8.2	2.5	85	2.0	391	752	68	29	11.9	2.9	84	2.1	495	958	64	33	4.2	2.1	81	1.8	253	507
		P3	62	53	4	1.3	73	0.9	178	409	62	47	5.2	1.3	74	1.0	222	527	FC							
		P4	68	37	6	1.9	87	1.6	263	519	67	34	7.8	1.9	85	1.7	321	626	64	45	3.7	1.8	80	1.3	175	333
	US3	P1	60	49	4.7	1.5	74	1.0	210	375	60	44	6.5	1.6	75	1.1	251	445	61	39	3	1.5	74	0.8	155	279
		P2	69	30	9.9	3.1	89	2.0	291	613	69	29	14.1	3.5	88	2.1	380	812	65	33	4.9	2.4	85	1.9	195	373
		P3	61	49	4.6	1.4	75	1.0	132	316	61	43	6.6	1.6	76	1.1	188	402	62	40	3.1	1.5	74	0.7	90	187
		P4	68	38	6.7	2.1	90	1.7	206	398	68	35	9.1	2.2	88	1.8	259	495	65	40	3.9	1.9	90	1.5	136	253
	US4	P1	60	47	5.7	1.8	75	1.0	162	303	60	43	8	2.0	75	1.1	192	372	61	38	3.3	1.6	76	0.8	111	202
		P2	69	30	11.1	3.4	90	2.1	237	558	70	29	15.5	3.8	89	2.1	308	756	65	33	5.6	2.8	87	1.9	141	301
		P3	60	47	5.5	1.7	76	1.0	119	254	61	42	7.9	2.0	77	1.1	144	359	61	37	3.3	1.6	76	0.8	64	143
		P4	69	38	7.4	2.3	92	1.7	153	321	69	35	10	2.5	90	1.8	195	436	64	36	4.1	2.0	91	1.5	106	190

FC: Failed to converge.