'Bare Cabin' Fires with Operation of Smoke Extraction System

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ABSTRACT

Computer simulations on fires in 'bare cabins' with only the smoke extraction system operating were carried out. Cabins of different sizes and ventilation conditions were considered under a NFPA slow-t^2-fire with cut-off value of 5 MW. The fire zone model FIREWIND was selected as the simulation tool. The time to flashover was simulated with two different times of operation of the smoke extraction system.

KEY WORDS: Zone model, cabin design, flashover.

INTRODUCTION

The concept of 'cabins' for fire protection [1-5] is commonly used in the big halls in the Hong Kong Special Administrative Region (HKSAR, formerly Hong Kong). No doubt, this is a good design which can use the hall spaces effectively without installing big smoke extraction systems. However, a point to be considered in this design concept is the likelihood of flashover in a cabin and its consequences of occurrence, bearing in mind that the sprinkler systems are not so reliable as experienced locally, and the requirements on the sizing of smoke extraction fans are not spelled out clearly in the local design guides [6]. Fires occurred in a cabin where the sprinkler system and smoke extraction system did not work, or 'bare cabin fires' [7-10], had been studied before. In case of the sprinkler system in a cabin does not work, a 'small' cabin might become a big hot object, in particular for shops selling alcohol where spillage fires might happen.

In this paper, the effect of operating only the smoke extraction system in a 'bare cabin fire' without sprinkler operating was studied. A software FIREWIND [11] capable of studying the effect of smoke extraction operation is used [12] for fire simulation. Using a two-layer zone model is reasonable [13,14] to study the likelihood of flashover in a compartment fire.

SIMULATIONS

Different values of the cabin dimension were studied with length L up to 10 m and width W up to 8 m. Different ventilation conditions with opening height H_v up to 2.5 m and width W_v up to the cabin's width were considered. The number of openings varied from 1 to 4, depending on the design conditions and how the cabins are used.

It is important to study the performance of smoke extraction system in a cabin and FIREWIND [11] was used for this purpose. In each cabin, extraction rates of 40, 80, 120 and 180 air changes per hour (ACH) were simulated.

The system was expected to operate at time t_{op} given by one of the following conditions:

- t_{op} at $t_{0.45}$ when the smoke layer thickness is 0.45 m, corresponding to a typical 'downstand' height in the local building fire code [15].
- t_{op} at t_{68} when the smoke layer temperature is heated up to 68°C. This is a common actuation temperature for sprinkler head. Note that a 68°C-rated sprinkler head might not be actuated when the smoke layer temperature reaches 68°C, depending on its response time index. Otherwise, the smoke extraction system might be operated first if both systems are installed.

Nine cases were simulated, each of 40 configurations, 4 air change rates, 2 different operation times $t_{0.45}$ and t_{68}, giving a total of 2880 (9 × 40 × 4 × 2) simulations.

A fire of size 1 m by 1 m was located at the centre. The heat release rate curve following the NFPA slow-t^2-fire [16] with a cut-off value of 5 MW was used.

The initial temperature was taken to be 20°C. Flashover in the enclosure was said to occur when the upper layer gas temperature reached 500°C as listed in the User's Manual of FIREWIND [11].

RESULTS

Typical results of the smoke layer temperature and smoke layer interface height with the extraction system operated at the two operation times in the cabin of length 4 m, width 4 m and height of 5 m; a vertical opening of width 4 m and height 1.5 m, are shown in Figs. 1 and 2. It is observed that small extraction rates would not have any effect on the smoke layer temperature and smoke layer interface height, unless the value was increased to above 40 ACH. In that case, the smoke layer can be kept at a higher position if the extraction rate is sufficiently high.

The time to operate the system is important. For earlier operation of the extraction system at $t_{0.45}$ (i.e. 12 s), the smoke layer at the early time, say within 500 s, could be kept at a higher level. However, if the system was operated at a later time at t_{68} (i.e. 166 s), the smoke layer would fall by 1.6 m before the operation of the system. Because of this thick smoke layer, only very high extraction rates can keep the smoke layer at a higher level at the early stage of the fire. For example, 180 ACH would move the smoke up to 3.5 m before 500 s. The

effects of extraction rates less than 40 ACH were not obvious.

Results on time to flashover t_f for the two operating times t_{op} are shown in Table 1.

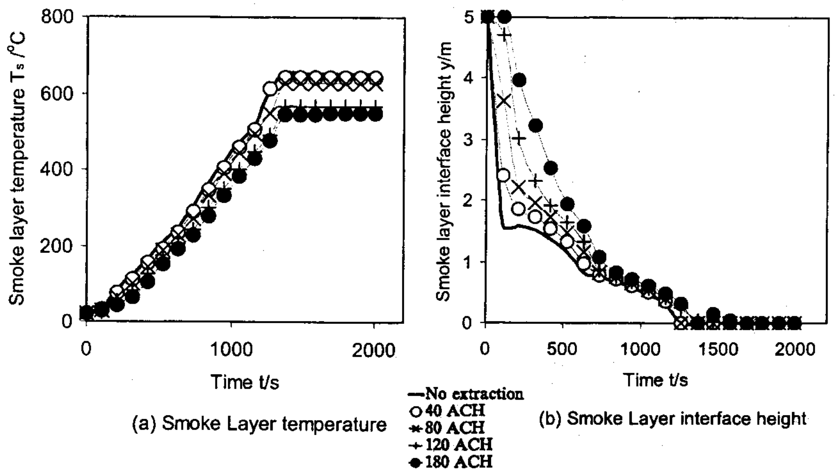

FIGURE 1. Extraction system operated at $t_{0.45}$

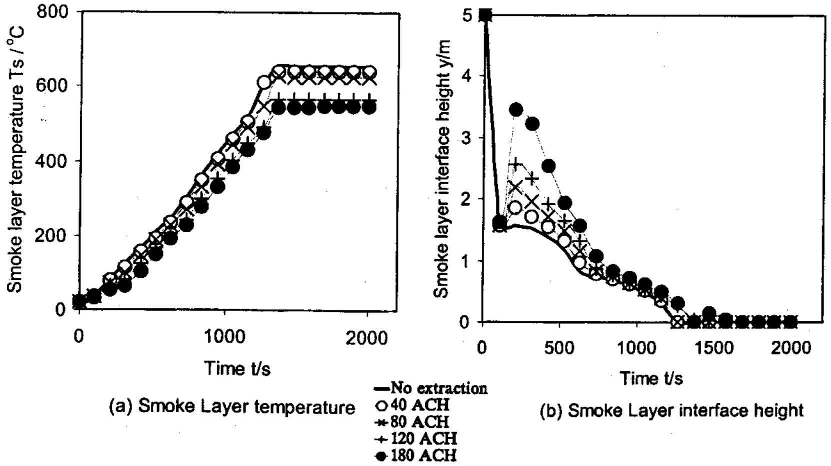

FIGURE 2. Extraction system operated at t_{68}

TABLE 1. Flashover time t_f with smoke extraction system

Slow t^2-Fire
Cut-off value = 5 MW

Cabin		Openings			No Extraction, Height of cabin /m: 2 m		3 m		4 m		5 m	
Length L/m	Width W/m	Number	W_v/m	H_v/m	operated at $t_{0.45}$ t_f/s	operated at t_{68} t_f/s	operated at $t_{0.45}$ t_f/s	operated at t_{68} t_f/s	operated at $t_{0.45}$ t_f/s	operated at t_{68} t_f/s	operated at $t_{0.45}$ t_f/s	operated at t_{68} t_f/s
4	4	4	4x4	1.5	1384	1384	1316	1316	1337	1337	N/F	N/F
6	4		2x(4+6)	1.5	1771	1771	N/F	N/F	N/F	N/F	N/F	N/F
4	4	3	3x4	1.5	1199	1199	1217	1217	1230	1230	1264	1264
6	4		4+6+4	1.5	1328	1328	1357	1357	N/F	N/F	N/F	N/F
4	4	2	2x4	1.5	1103	1103	1121	1121	1129	1129	1161	1161
6	4		4+6	1.5	1237	1237	1258	1258	1280	1280	1322	1322
4	4	1	4	1.5	952	952	966	966	975	975	997	997
6	4		4	1.5	1044	1044	1060	1060	1070	1070	1103	1103
8	4		4	1.5	1130	1130	1146	1146	1162	1162	1196	1196
10	4		4	1.5	1206	1206	1222	1222	1245	1245	1283	1283
6	6		6	1.5	1245	1245	1266	1266	1294	1294	1333	1333
4	4	1	2	2.5	-	-	1067	1067	1074	1074	1117	1117
6	4		2	2.5	-	-	1149	1149	1169	1169	1185	1185
8	4		2	2.5	-	-	1216	1216	1222	1222	1254	1254
10	4		2	2.5	-	-	1294	1294	1310	1310	1321	1321
6	6		2	2.5	-	-	1248	1248	1280	1280	1298	1298
8	6		2	2.5	-	-	1360	1360	1364	1364	1362	1362
4	4	2	2	2.5	-	-	1346	1346	N/F	N/F	N/F	N/F
4	4	1	2	2	-	-	951	951	957	957	970	970
6	4		2	2	-	-	1039	1039	1053	1053	1075	1075
8	4		2	2	-	-	1114	1114	1118	1118	1135	1135
10	4		2	2	-	-	1186	1186	1203	1203	1211	1211
6	6		2	2	-	-	1149	1149	1174	1174	1190	1190
8	6		2	2	-	-	1248	1248	1251	1251	1251	1251
10	6		2	2	-	-	1359	1359	1361	1361	1360	1360
4	4	1	1.5	2	-	-	880	880	884	884	889	889
6	4		1.5	2	-	-	970	970	977	977	990	990
8	4		1.5	2	-	-	1043	1043	1045	1045	1045	1045
10	4		1.5	2	-	-	1119	1119	1125	1125	1131	1131
6	6		1.5	2	-	-	1080	1080	1082	1082	1107	1107
8	6		1.5	2	-	-	1184	1184	1186	1186	1210	1210
10	6		1.5	2	-	-	1283	1283	1285	1285	1285	1285
8	8		1.5	2	-	-	1321	1321	1321	1321	1342	1342
4	4	2	2	2.5	-	-	1146	1146	1155	1155	1187	1187
6	4		2	2.5	-	-	1225	1225	1242	1242	1277	1277
8	4		2	2.5	-	-	1309	1309	1338	1338	N/F	N/F

Cabin		Openings			40 ACH, Height of cabin /m: 2 m		3 m		4 m		5 m	
Length L/m	Width W/m	Number	W_v/m	H_v/m	operated at $t_{0.45}$ t_f/s	operated at t_{68} t_f/s	operated at $t_{0.45}$ t_f/s	operated at t_{68} t_f/s	operated at $t_{0.45}$ t_f/s	operated at t_{68} t_f/s	operated at $t_{0.45}$ t_f/s	operated at t_{68} t_f/s
4	4	4	4x4	1.5	1281	1281	1297	1297	1331	1331	N/F	N/F
6	4		2x(4+6)	1.5	N/F	N/F	N/F	N/F	N/F	N/F	N/F	N/F
4	4	3	3x4	1.5	1205	1205	1228	1228	1245	1245	1288	1288
6	4		4+6+4	1.5	1340	1340	N/F	N/F	N/F	N/F	N/F	N/F
4	4	2	2x4	1.5	1111	1111	1133	1133	1146	1146	1183	1183
6	4		4+6	1.5	1247	1247	1278	1278	1309	1309	1356	1356
4	4	1	4	1.5	962	962	982	982	996	996	1025	1025
6	4		4	1.5	1059	1059	1082	1082	1101	1101	1140	1140
8	4		4	1.5	1147	1147	1172	1172	1199	1199	1241	1241
10	4		4	1.5	1226	1226	1252	1252	1295	1295	1347	1347
6	6		6	1.5	1262	1262	1298	1298	1338	1338	N/F	N/F
4	4	1	2	2.5	-	-	1082	1082	1105	1105	1145	1145
6	4		2	2.5	-	-	1170	1170	1188	1188	1204	1204
8	4		2	2.5	-	-	1241	1241	1282	1282	1304	1304
10	4		2	2.5	-	-	1326	1326	1345	1345	1454	1454
6	6		2	2.5	-	-	1289	1289	1318	1318	1330	1330
8	6		2	2.5	-	-	N/F	N/F	N/F	N/F	N/F	N/F
4	4	2	2	2.5	-	-	1362	1362	N/F	N/F	N/F	N/F
4	4	1	2	2	-	-	966	966	977	977	1020	1020
6	4		2	2	-	-	1061	1061	1078	1078	1097	1097
8	4		2	2	-	-	1142	1142	1176	1176	1197	1197
10	4		2	2	-	-	1219	1219	1235	1235	1293	1293
6	6		2	2	-	-	1184	1184	1205	1205	1222	1222
8	6		2	2	-	-	1292	1292	1327	1327	1344	1344
10	6		2	2	-	-	N/F	N/F	N/F	N/F	N/F	N/F
4	4	1	1.5	2	-	-	897	897	906	906	952	952
6	4		1.5	2	-	-	994	994	1005	1005	1020	1020
8	4		1.5	2	-	-	1075	1075	1100	1100	1117	1117
10	4		1.5	2	-	-	1154	1154	1168	1168	1209	1209
6	6		1.5	2	-	-	1118	1118	1132	1132	1145	1145
8	6		1.5	2	-	-	1227	1227	1245	1245	1257	1257
10	6		1.5	2	-	-	1345	1345	1365	1365	N/F	N/F
8	8		1.5	2	-	-	N/F	N/F	N/F	N/F	N/F	N/F
4	4	2	2	2.5	-	-	1362	1362	N/F	N/F	N/F	N/F
6	4		2	2.5	-	-	N/F	N/F	N/F	N/F	N/F	N/F
8	4		2	2.5	-	-	N/F	N/F	N/F	N/F	N/F	N/F

Cabin		Openings			80 ACH, Height of cabin /m: 2 m		3 m		4 m		5 m	
Length L/m	Width W/m	Number	W_v/m	H_v/m	operated at $t_{0.45}$ t_f/s	operated at t_{68} t_f/s	operated at $t_{0.45}$ t_f/s	operated at t_{68} t_f/s	operated at $t_{0.45}$ t_f/s	operated at t_{68} t_f/s	operated at $t_{0.45}$ t_f/s	operated at t_{68} t_f/s
4	4	4	4x4	1.5	1309	1309	1304	1304	1349	1349	N/F	N/F
6	4		2x(4+6)	1.5	N/F	N/F	N/F	N/F	N/F	N/F	N/F	N/F
4	4	3	3x4	1.5	1213	1213	1239	1239	1260	1260	1311	1311
6	4		4+6+4	1.5	1352	1352	N/F	N/F	N/F	N/F	N/F	N/F
4	4	2	2x4	1.5	1120	1120	1146	1146	1164	1164	1206	1206
6	4		4+6	1.5	1258	1258	1299	1299	1337	1337	N/F	N/F
4	4	1	4	1.5	973	973	998	998	1017	1017	1052	1052
6	4		4	1.5	1074	1074	1104	1104	1131	1131	1179	1179
8	4		4	1.5	1165	1165	1199	1199	1236	1236	1293	1293
10	4		4	1.5	1246	1246	1290	1290	1349	1349	N/F	N/F
6	6		6	1.5	1284	1284	1331	1331	N/F	N/F	N/F	N/F
4	4	1	2	2.5	-	-	1101	1101	1128	1128	1169	1169
6	4		2	2.5	-	-	1190	1190	1210	1210	1273	1273
8	4		2	2.5	-	-	1280	1280	1321	1321	1335	1335
10	4		2	2.5	-	-	1365	1365	N/F	N/F	N/F	N/F
6	6		2	2.5	-	-	1322	1322	1350	1350	N/F	N/F
8	6		2	2.5	-	-	N/F	N/F	N/F	N/F	N/F	N/F
4	4	2	2	2.5	-	-	N/F	N/F	N/F	N/F	N/F	N/F
4	4	1	2	2	-	-	983	983	1008	1008	1048	1048
6	4		2	2	-	-	1084	1084	1103	1103	1166	1166
8	4		2	2	-	-	1176	1176	1203	1203	1339	1339
10	4		2	2	-	-	1252	1252	1308	1308	1332	1332
6	6		2	2	-	-	1214	1214	1237	1237	1302	1302
8	6		2	2	-	-	1346	1346	N/F	N/F	N/F	N/F
10	6		2	2	-	-	N/F	N/F	N/F	N/F	N/F	N/F
4	4	1	1.5	2	-	-	914	914	942	942	970	970
6	4		1.5	2	-	-	1017	1017	1035	1035	1086	1086
8	4		1.5	2	-	-	1111	1111	1134	1134	1177	1177
10	4		1.5	2	-	-	1191	1191	1226	1226	1248	1248
6	6		1.5	2	-	-	1151	1151	1173	1173	1219	1219
8	6		1.5	2	-	-	1269	1269	1307	1307	1352	1352
10	6		1.5	2	-	-	N/F	N/F	N/F	N/F	N/F	N/F
8	8		1.5	2	-	-	N/F	N/F	N/F	N/F	N/F	N/F
4	4	2	2	2.5	-	-	N/F	N/F	N/F	N/F	N/F	N/F
6	4		2	2.5	-	-	N/F	N/F	N/F	N/F	N/F	N/F
8	4		2	2.5	-	-	N/F	N/F	N/F	N/F	N/F	N/F

* N/F: No flashover.

TABLE 1 (Cont'd). Flashover time t_f with smoke extraction system

Slow t^2-Fire
Cut-off value = 5 MW

Cabin		Openings			120 ACH, Height of cabin /m: 2 m		3 m		4 m		5 m	
Length L/m	Width W/m	Number	W_v/m	H_v/m	operated at $t_{0.45}$ t_f/s	operated at t_{68} t_f/s	operated at $t_{0.45}$ t_f/s	operated at t_{68} t_f/s	operated at $t_{0.45}$ t_f/s	operated at t_{68} t_f/s	operated at $t_{0.45}$ t_f/s	operated at t_{68} t_f/s
4	4	4	4x4	1.5	1382	1382	1334	1316	1366	1366	N/F	N/F
6	4		2x(4+6)	1.5	N/F	N/F	N/F	N/F	N/F	N/F	N/F	N/F
4	4	3	3x4	1.5	1219	1219	1249	1217	1279	1279	1335	1335
6	4		4+6+4	1.5	1364	1364	N/F	1357	N/F	N/F	N/F	N/F
4	4	2	2x4	1.5	1129	1129	1159	1121	1182	1182	1228	1228
6	4		4+6	1.5	1271	1271	1320	1258	1365	1365	N/F	N/F
4	4	1	4	1.5	984	984	1014	966	1037	1037	1082	1082
6	4		4	1.5	1088	1088	1126	1060	1161	1161	1216	1216
8	4		4	1.5	1183	1183	1225	1146	1276	1276	1349	1349
10	4		4	1.5	1268	1268	1330	1222	N/F	N/F	N/F	N/F
6	6		6	1.5	1306	1306	1363	1266	N/F	N/F	N/F	N/F
4	4	1	2	2.5	-	-	1117	1067	1149	1149	1273	1273
6	4		2	2.5	-	-	1210	1149	1262	1262	1297	1297
8	4		2	2.5	-	-	1309	1216	1345	1345	N/F	N/F
10	4		2	2.5	-	-	N/F	1294	N/F	N/F	N/F	N/F
6	6		2	2.5	-	-	1356	1248	N/F	N/F	N/F	N/F
8	6		2	2.5	-	-	N/F	1360	N/F	N/F	N/F	N/F
4	4	2	2	2.5	-	-	N/F	1346	N/F	N/F	N/F	N/F
4	4	1	2	2	-	-	1003	951	1030	1030	1067	1067
6	4		2	2	-	-	1107	1039	1156	1156	1189	1189
8	4		2	2	-	-	1203	1114	1240	1240	1304	1304
10	4		2	2	-	-	1300	1186	1345	1345	N/F	N/F
6	6		2	2	-	-	1245	1149	1306	1306	1339	1339
8	6		2	2	-	-	N/F	1248	N/F	N/F	N/F	N/F
10	6		2	2	-	-	N/F	1359	N/F	N/F	N/F	N/F
4	4	1	1.5	2	-	-	940	880	964	964	990	990
6	4		1.5	2	-	-	1041	970	1083	1083	1113	1113
8	4		1.5	2	-	-	1141	1043	1185	1185	1223	1223
10	4		1.5	2	-	-	1230	1119	1268	1268	1337	1337
6	6		1.5	2	-	-	1185	1080	1229	1229	1259	1259
8	6		1.5	2	-	-	1325	1184	N/F	N/F	N/F	N/F
10	6		1.5	2	-	-	N/F	1283	N/F	N/F	N/F	N/F
8	8		1.5	2	-	-	N/F	1321	N/F	N/F	N/F	N/F
4	4	2	2	2.5	-	-	N/F	1146	N/F	N/F	N/F	N/F
6	4		2	2.5	-	-	N/F	1225	N/F	N/F	N/F	N/F
8	4		2	2.5	-	-	N/F	1309	N/F	N/F	N/F	N/F

Cabin		Openings			180 ACH, Height of cabin /m: 2 m		3 m		4 m		5 m	
Length L/m	Width W/m	Number	W_v/m	H_v/m	operated at $t_{0.45}$ t_f/s	operated at t_{68} t_f/s	operated at $t_{0.45}$ t_f/s	operated at t_{68} t_f/s	operated at $t_{0.45}$ t_f/s	operated at t_{68} t_f/s	operated at $t_{0.45}$ t_f/s	operated at t_{68} t_f/s
4	4	4	4x4	1.5	1311	1311	1350	1350	N/F	N/F	N/F	N/F
6	4		2x(4+6)	1.5	N/F	N/F	N/F	N/F	N/F	N/F	N/F	N/F
4	4	3	3x4	1.5	1230	1230	1267	1267	1309	1309	1371	1371
6	4		4+6+4	1.5	N/F	N/F	N/F	N/F	N/F	N/F	N/F	N/F
4	4	2	2x4	1.5	1141	1141	1178	1178	1210	1210	1261	1261
6	4		4+6	1.5	1292	1292	1351	1351	N/F	N/F	N/F	N/F
4	4	1	4	1.5	1000	1000	1038	1038	1071	1071	1125	1125
6	4		4	1.5	1111	1111	1155	1155	1208	1208	1275	1275
8	4		4	1.5	1209	1209	1267	1267	1347	1347	N/F	N/F
10	4		4	1.5	1309	1309	N/F	N/F	N/F	N/F	N/F	N/F
6	6		6	1.5	1339	1339	N/F	N/F	N/F	N/F	N/F	N/F
4	4	1	2	2.5	-	-	1140	1140	1173	1173	1297	1297
6	4		2	2.5	-	-	1246	1246	1300	1300	1524	1524
8	4		2	2.5	-	-	1356	1356	N/F	N/F	N/F	N/F
10	4		2	2.5	-	-	N/F	N/F	N/F	N/F	N/F	N/F
6	6		2	2.5	-	-	N/F	N/F	N/F	N/F	N/F	N/F
8	6		2	2.5	-	-	N/F	N/F	N/F	N/F	N/F	N/F
4	4	2	2	2.5	-	-	N/F	N/F	N/F	N/F	N/F	N/F
4	4	1	2	2	-	-	1028	1028	1060	1060	1129	1129
6	4		2	2	-	-	1147	1147	1191	1191	1271	1271
8	4		2	2	-	-	1244	1244	1315	1315	1664	1664
10	4		2	2	-	-	1360	1360	N/F	N/F	N/F	N/F
6	6		2	2	-	-	1306	1306	1464	1464	N/F	N/F
8	6		2	2	-	-	N/F	N/F	N/F	N/F	N/F	N/F
10	6		2	2	-	-	N/F	N/F	N/F	N/F	N/F	N/F
4	4	1	1.5	2	-	-	965	965	995	995	1063	1063
6	4		1.5	2	-	-	1085	1085	1125	1125	1194	1194
8	4		1.5	2	-	-	1188	1188	1240	1240	1321	1321
10	4		1.5	2	-	-	1291	1291	1364	1364	N/F	N/F
6	6		1.5	2	-	-	1238	1238	1318	1318	1360	1360
8	6		1.5	2	-	-	N/F	N/F	N/F	N/F	N/F	N/F
10	6		1.5	2	-	-	N/F	N/F	N/F	N/F	N/F	N/F
8	8		1.5	2	-	-	N/F	N/F	N/F	N/F	N/F	N/F
4	4	2	2	2.5	-	-	N/F	N/F	N/F	N/F	N/F	N/F
6	4		2	2.5	-	-	N/F	N/F	N/F	N/F	N/F	N/F
8	4		2	2.5	-	-	N/F	N/F	N/F	N/F	N/F	N/F

* N/F: No flashover.

For bare cabins without operating the extraction fan, values of t_f are the same for the two different values of t_{op}. For operating rates of 40 ACH and 80 ACH, the results predicted are also the same. Values of t_f are larger when the smoke extraction system was operated earlier at $t_{0.45}$ for the extraction rate of 120 ACH. But when the extraction rate was 180 ACH, values of t_f are the same for the two values of t_{op} and independent of those values.

CONCLUSION

The time to flashover in 'bare cabins' with only the smoke extraction system operating under a NFPA slow-t^2-fire in cabins of different sizes was studied. The two-layer zone model FIREWIND [11] was used.

Detailed experiments on bare cabin fires have just been started recently in the PolyU/USTC Atrium, a full-scale burning facility built as a 20-year collaboration project between The Hong Kong Polytechnic University (PolyU) and the University of Science and Technology of China (USTC) [17]. The following will be studied as fire protection systems including fire detection system, sprinkler system and smoke extraction system should be provided in each cabin:

- performance of the systems integrated;
- whether the sprinkler system or smoke extraction system should be operated first;
- the time for detecting a fire, operating the sprinkler to discharge water, turning on the smoke extraction system and the time for people staying inside to escape;
- whether the cabin should be enclosed completely in case of a fire;
- the impact of exposure of occupants to the steam generated by the sprinkler water.

The results are useful for the Authority to inspect new projects of this kind, especially for those who are not so experienced in using fire models while implementing engineering performance-based fire codes [18].

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