FULL-SCALE ANALYSIS ON FIRE CHARACTERISTICS OF A FURNISHED OFFICE ROOM

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ABSTRACT

The full-scale fire test of a furnished office room was performed. The office room was 6m long, 5m wide, and 2.4m high with two openings of 1.8m in height and 0.6m in width. The fire load of the room, including all furniture, was 11,892MJ or approximately 390MJ/m^2. At around 1600 second after the ignition, flashover was observed and the fire rushed out from one of the openings. The flashover occurred at an upper layer temperature of 600^{o}C and a radiation heat flux of 20kW/m^2 detected at the floor center of the room, which were close to the standard criteria adopted by many researchers. The fire test clearly indicated that the major factors leading to flashover were the heat release rate of the fire source and the fire spread to the flammable materials around the fire source.

Keywords: office fire, heat release rate, flashover

INTRODUCTION

For the purpose of establishing a domestic performance based fire code, a large scale fire test facility with a 10MW fire products collector was recently constructed in southern Taiwan. The facility was intended for the assessment of fire characteristics of full-scale furnished compartments. In this experimental study, an office room equipped with typical furniture was burned till flashover and the influencing factors were identified.

A compartment fire, although complicated and varied, can usually be described by four fire stages, namely ignition, spread, fully developed, and decay. At the first ignition stage, the fire source is not affected by the walls of the room and the heat release rate is only controlled by the burning rate of the fire source. Then the heat of burning transfers to the other parts of the room and raises the room temperature through radiation, convection, and conduction. The fire can spread if the heat flux on the nearby pieces of furniture is strong enough to ignite them. There are miscellaneous factors affecting the fire spread at this stage, such as the ignition and burning characteristics of the materials, the geometrical arrangement of the combustibles, the dimensions of the room, the sizes and locations of the openings, etc.

The plume of hot gases from the fire rises to the ceiling and forms a hot ceiling jet which flows under the ceiling. The hot gases then accumulate under the ceiling to form a so-called upper layer. The radiation flux from the upper layer to the combustibles increases with the growth of the thickness and temperature of the upper layer. If the fire continuously proceeds in this direction, eventually all combustibles in the room will be ignited and the whole room will involve in intensive burning. Usually at this time, flames can be observed to come out of the openings of the compartment and this point is identified as “flashover.” After the occurrence of flashover, the fire is fully developed; high temperature and high heat release rate are characteristic. The high intensity burning will continue until all the flammable materials are burned out; then the fire will decay.

The possibility of fire extinguishment or personnel rescue is usually determined by the time from ignition to flashover. In consideration of a fire safety compartment, this time must be long enough for the fire fighting system to operate properly. Peacock et al.[1] analyzed the occurrence of flashover from the results of full-scale fire tests and concluded that the flashover usually happened when the upper layer temperature reached $600^{o}C$ or when the radiation flux to the floor reached $20kW/m^2$. Many researchers have studied the flashover phenomenon.

Babrauskas[2] modeled the flashover by balancing the thermal energy items in the upper layer and derived an equation for the minimum heat release rate necessary to induce flashover. The heat loss was thought to be mainly controlled by the ventilation factor, i.e. the area and height of the compartment opening. McCaffrey et al.[3] presented a correlation based on more than one hundred compartment fire test results. Their correlation related the heat release rate, opening area, wall conduction, and ambient conditions to the temperature of the upper layer. Mowrer and Williamson[4] placed the fire source near the wall or the corner and observed higher upper layer temperatures. The wall and corner effects could speed up the flashover time by 50 to 70 per cent. Modeling of flashover was presented by Jolly and Saito[5] and Holborn et al.[6] and compared well with experimental results. Graham et al.[7] derived an equation for the temperature of the upper layer and the flashover criterion emphasizing the thermal inertia of walls. Based on Graham et al.'s results, Novozhilov[8] studied the suppression of flashover by sprinklers for various degrees of fire intensity. And the role of thermal radiation, openings, and wall conduction on the initiation of flashover was studied in Yuen and Chow[9].

Flashover is an important stage in the growth of a compartment fire. Although there have been a great amount of research in the past, the applicability of these results has to be verified in order to obtain a localized fire code because of the specific building materials and furniture used in the locality. This study presented an effort by the Architecture and Building Research Institute of Taiwan in assessing the influencing factors for flashover, such as fire load, temperature, heat release, radiation, in a typical Taiwanese office room fire.

EXPERIMENTAL SETUP

A typical office room in Taiwan was chosen as our full-scale fire test model. Figure 1 and Table 1 display the types and arrangement of the instrumentation and furniture in the office room. The office was 6m long, 5m wide, and 2.4m high. The walls were constructed with 0.2m thick ALC (aerated lightweight concrete) plates. The office had one door each at the north-east and the south-east corner. The doors were both half-closed; the bottom half of the south-east door and the upper half of the north-east door were covered. Next to the room at the south was a 10MW fire products collector, with a suction hood of 7.62m×7.62m in size and an exhaust rate of $30m^3/s$, which was capable of analyzing the heat release rate by the oxygen consumption principle.

The furniture in the room included six units of workstation (desk, chair, side panel), and ten wooden cabinets of various height placed near the north and east walls of the room. No additional combustibles, such as paper or computers, were placed in the room; therefore the room represented a new office. The fire load was about $390MJ/m^2$. Pictures of the setup are shown in Figure 2.

The broken-lined circle represented the location of the fire source, which was a 30kW (square, 40cm×40cm) propane gas burner. Since there was no paper or other easily-ignited combustibles near the fire source, the gas burner was left ignited for about 1600 seconds until the fire was fully grown and maintained. The instrumentation of the fire test room included thermocouple trees (TC1~TC7), single thermocouples (T1~T8), radiation flux meters (R1~R5), gas analyzer probes (G1 & G2), air-cooled in-furnace camera system, and differential pressure transducers (BDP_{In} & BDP_{Out}). There was a bi-directional probe at each door opening to measure the rate of the incoming or outgoing gas flow. Their respective numbers and locations are listed in Figure 1. The dashed-line rectangle at the lower right corner of the figure represents the section of the furniture which we burned separately outside the room to evaluate its heat release characteristics.

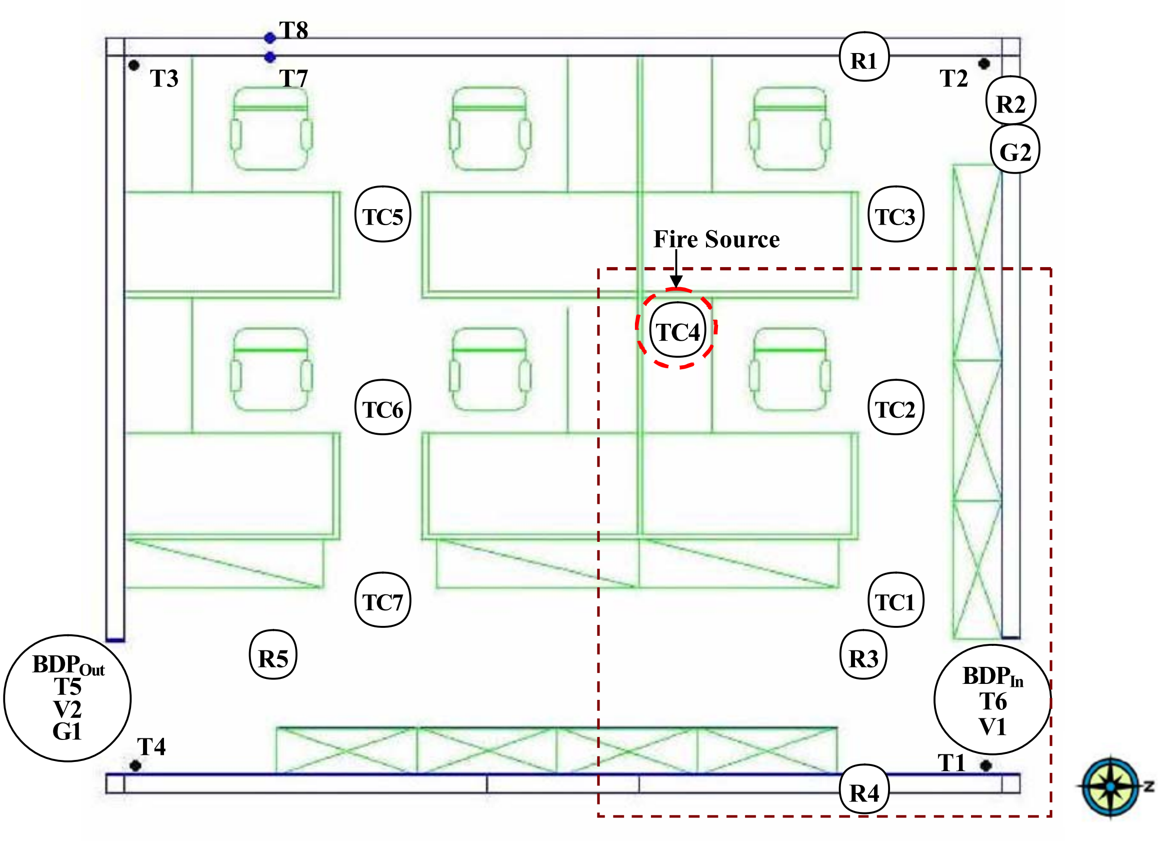

Figure 1 The layout of the office room and the setup of instruments for the full-scale fire test.

Table 1 Locations of the instruments in the office for the full-scale fire test.

Instruments	Indexes	Locations
Thermocouple Trees	TC1~TC7	No.0~No.9 points *
Heat Flux Meters	R1~R5	R_1 & R_4: 150cm height R_2 & R_5: 180cm height R_3: on the ground
Videos	V1&V2	150cm height
Thermocouples	T1~T8	T_1~T_4:10cm below the ceiling T_5: 150cm height T_6: 30cm height T_7 & T_8: 180cm height
Bi-Directional Probes	BDP_{In}& BDP_{Out}	BDP_{In}: 30cm hight BDP_{Out}: 150cm hight
Gas Probes	G1&G2	180cm height

* The length of each thermocouple tree was 250cm and was divided into 10 points numbered No.0 ~ No.9 from the ceiling to the floor. All the points were 30cm apart except that the interval between No.0 and No.1 was 10cm.

Figure 2 Photos of the arrangement of furniture in the office.

RESULTS AND DISCUSSION

The experiment lasted about 4000 seconds; flashover occurred at 1600s and the strongest fire intensity appeared at 3000s. The evolution of the fire in the full-scale test is briefly described in Table 2. Photos corresponding to different states of the fire history described in Table 2 are shown in Figure 3.

Table 2 The evolution of the fire in the full-scale test.

Time (s)	Observations
184	Ignition of the desk
235	Black smoke coming out of the south-east opening
404	Full burning of the workstation near fire source
850	Strong black smoke flowing out of the opening
1260	Fire grew stronger but black smoke reduced, east-side small wooden cabinets started to burn
1440	North-side wooden cabinets started to burn
1492	Fire and black smoke coming out of the north-east opening
1625	Wooden cabinet at the south corner started to burn, fire suddenly grew, flashover occurred
2000	Intense fire keep coming out the openings
3241	Fire began to reduce
3268	No flame coming out of the openings
4000	Experiment finished

(184 sec)

(404 sec)

(1260 sec)

(1492 sec)

(1625 sec)

(3268 sec)

Figure 3 Scenes of the office fire.

Variations of the temperatures of the upper five points (No.0~No.4) of the six thermocouple trees (TC1~TC3, TC4~TC7) inside of the room with respect to time are shown in Figure 4. It is very clear that the temperature field was quite uniform in the upper smoke layer. In the experiment, the office furniture alone was actually very difficult to ignite. The first peak, 200°C, on the temperature curves, at around 500s, was the burning of the workstation near the fire source. While the workstation was burning, the fire still had difficulty spreading to the other workstations. Therefore, the fire intensity reduced while the smoke rate increased; it is evident that the temperatures decreased a little. The intensity of fire and the temperature did not grow until the wooden cabinets on the east side started to burn. The flashover was recorded at 1625s when the strong fire abruptly came out of the openings, and thereafter the temperature increased sharply to over 900°C within a few seconds. Note that the temperature corresponding to the flashover time (1625s) was around 600°C. All the temperatures of the upper layer in the room kept growing in the fully developed period. The temperatures near the openings, TC7 and TC1, were just slightly lower than those in the inner part of the upper smoke layer.

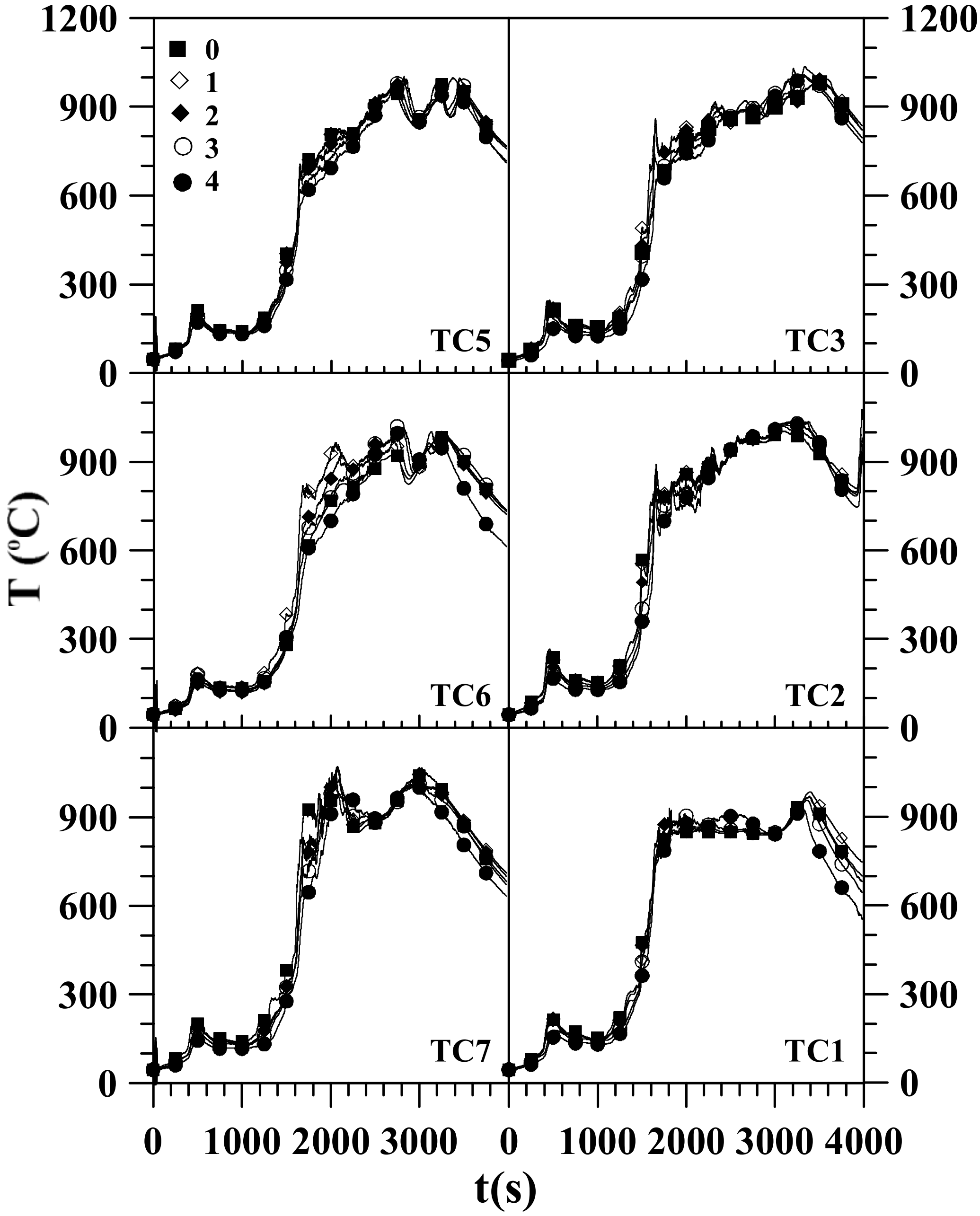

Figure 4 Temperature distribution of the upper region inside the office.

Figure 5 shows the variations of CO and O_2 concentration inside the office room. Before flashover occurred, the concentrations of CO and O_2 were roughly 0.1% and 20% respectively. After flashover, CO concentration suddenly increased to over 0.8% and O_2 concentration dropped to almost zero. There was some oxygen remained at the location of G2 because fresh air came in from the north-east opening.

Figure 6 displays the measurements of radiation heat flux at five locations, R1~R5. Note that all heat flux meters faced horizontally towards the inside of the room except R3, which faced up towards the ceiling. There was almost no radiation flux before the fire grew quite large near 1260s. At the time of flashover, all heat flux meters measured about $20kW/m^2$. After flashover, R5 had the highest value because it was nearest to the flame coming out of the south-east door. R1, R2, and R4 could all reach more than $50kW/m^2$ but R3 did not exceed $20kW/m^2$ before the flashover happened. Due to cooling water problems, all heat flux meters burned down some time after flashover.

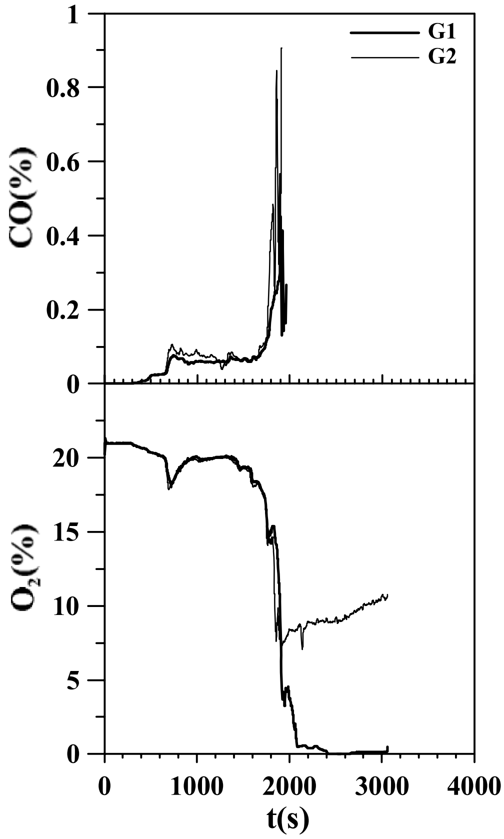

Figure 5 Variations of CO and O_2 concentration inside the office.

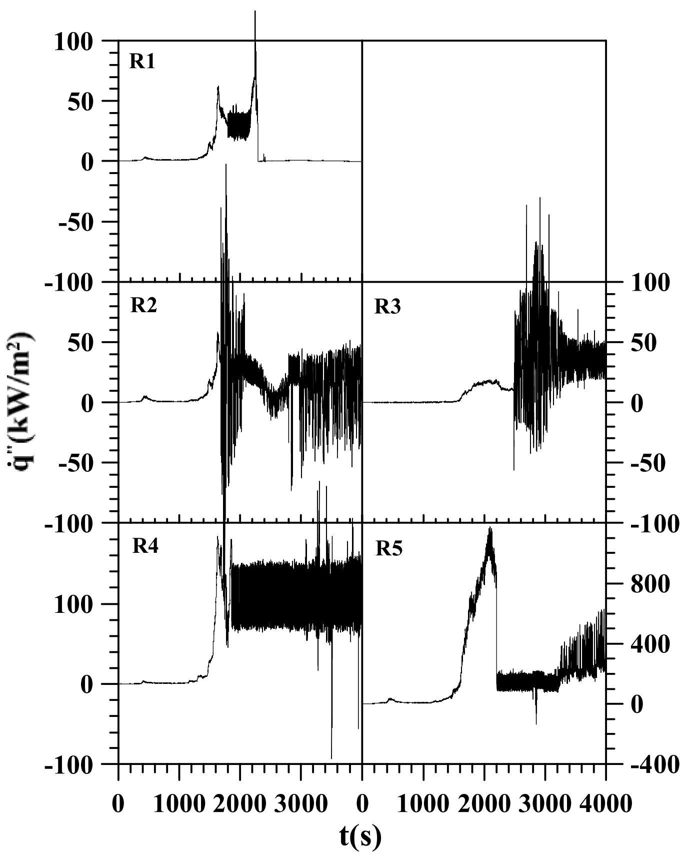

Figure 6 Variations of radiation heat flux for the office fire.

In summary, the flashover of the full-scale office fire was determined to occur at 1600s by observation. At the time of flashover, the temperature of the upper layer was roughly 600°C and the radiation heat flux at the lower layer was around 20kW/m^2.

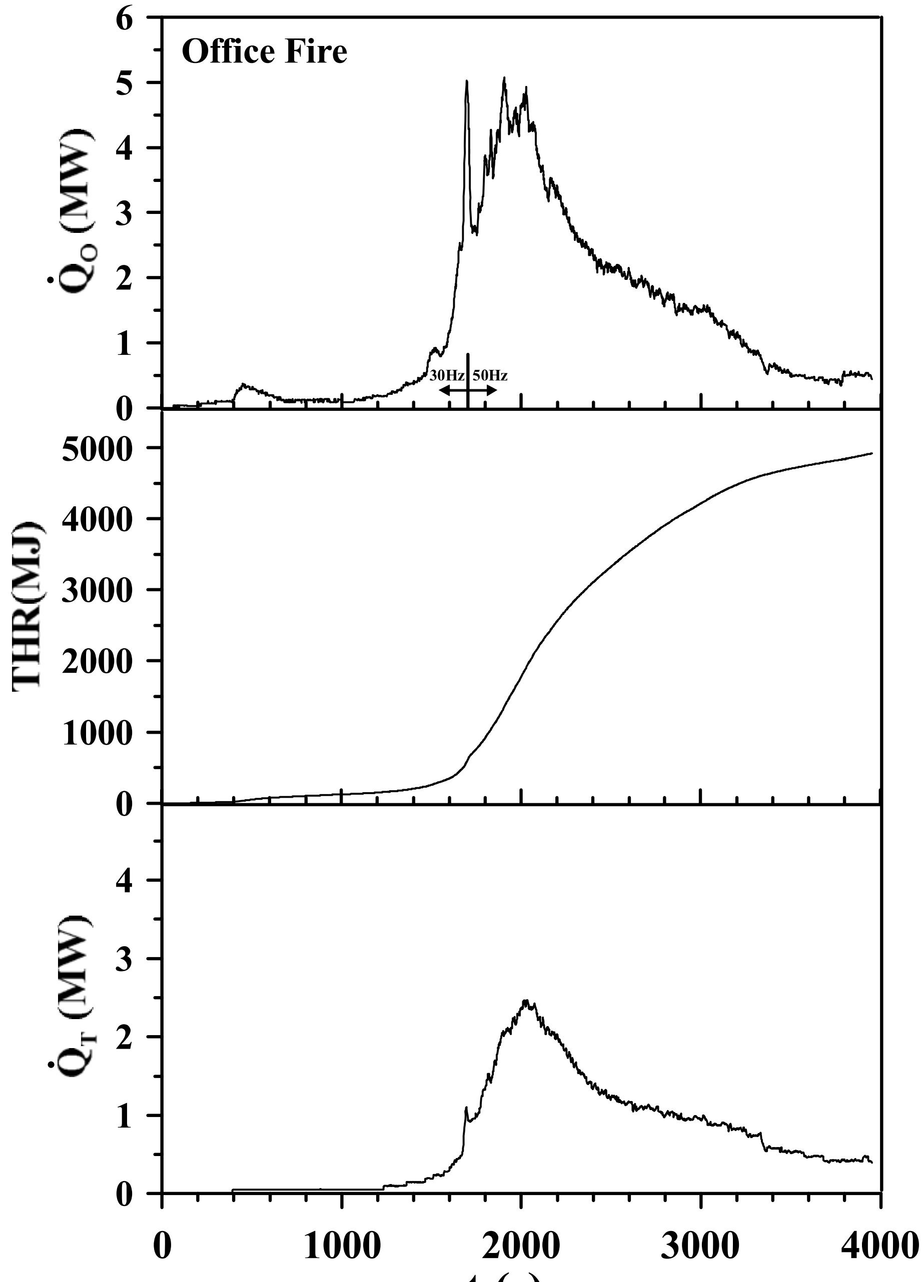

Figure 7 Variations of heat release rates for the office fire.

The instantaneous heat release rates in the fire test are shown in Figure 7. In Figure 7, Q_O and Q_T represent the total heat release rate measured by the oxygen consumption principle and the convective heat release rate measured by the gas temperature rise, respectively. The total heat release (THR) was obtained by the integration of the total heat release rate with respect to the passed time. As stated before, the fire was not intense until the wooden cabinets were ignited at 1260s and the heat release rate was under 0.5MW in this period. After the occurrence of flashover, the total heat release rate quickly increased to over 4MW. Beyond 2000s, the heat release rate started to drop, although the appearance of the fire remained strong until 3241s. Note that at 1650s the suction rate of the hood was raised to accommodate the abruptly increased gas flow coming out of the south-east door. The total heat release (THR) amounted to just 5000MJ in the fire period, because a large portion of the smoke leaked out of the office ceiling without getting into the suction hood. From the convective heat release rate, it can be deduced that the radiation heat release was about 40% of the total heat release.

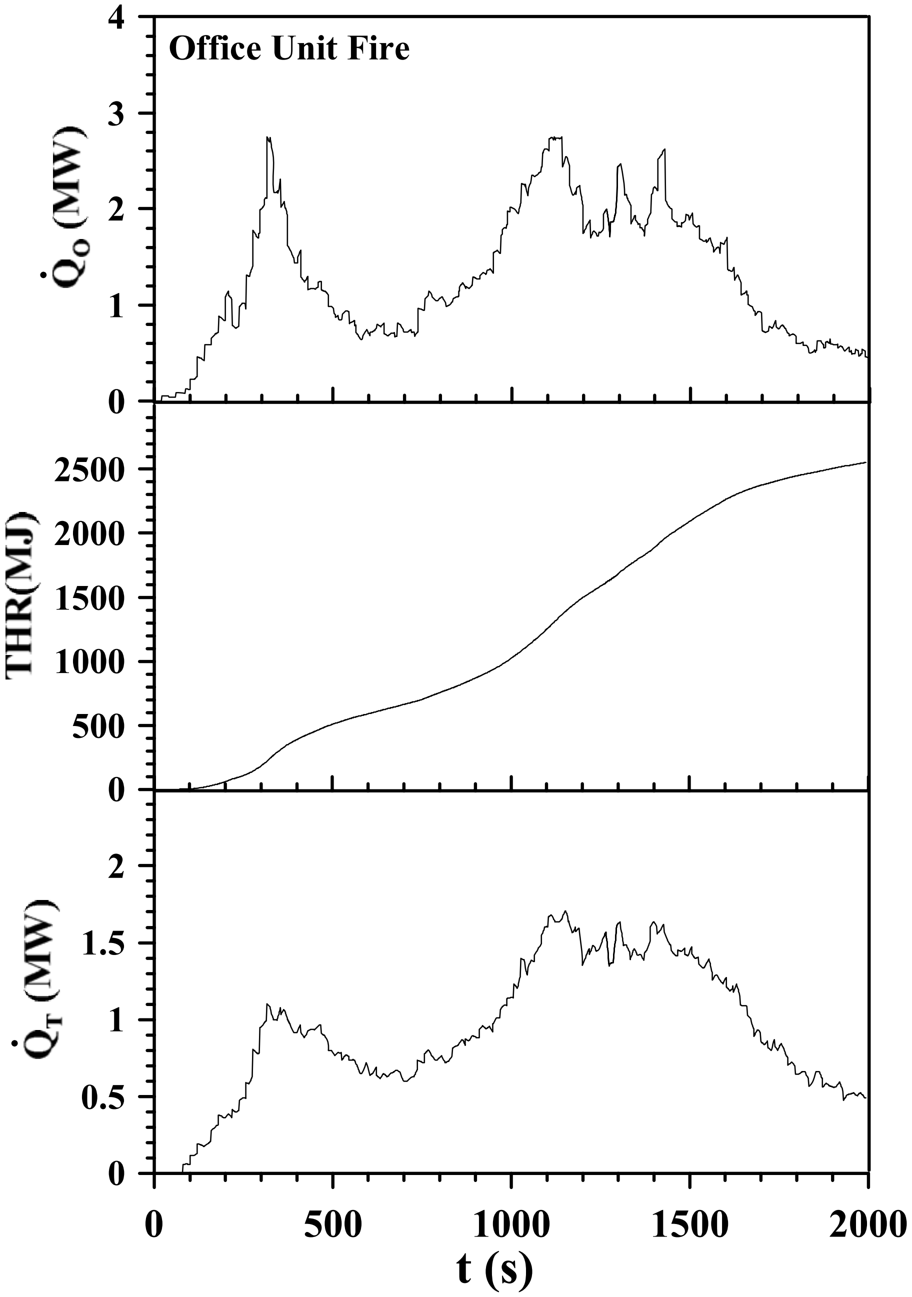

Figure 8 Variations of heat release rates for burning a single set of office furniture.

After the full-scale office fire test, one set of the workstation (dashed-line region at the lower right corner of Figure 1) was burned freely under the 10MW fire products collector to measure its heat release characteristics. The instantaneous heat release rates of free burning a single set of the workstation are shown in Figure 8. As shown in Figure 8, there were several peaks of heat release rate corresponding to flame spreading to different pieces of furniture. The highest heat release rate was about 2.5MW and the total heat release was about 2500MJ. In comparisons of Figure 7 and 8, it is noted that under the free burning condition, there was distinct pattern for flame spreading from one piece of furniture to another; while under the confined condition, such as the office room, the distinct flame spreading was restricted by the lack of oxygen supply and the rapid accumulation of smoke. However, the office fire had an intense burning when the flashover occurred. As we mentioned earlier that the total heat release of the office fire (5000MJ) was much less than that of six sets of workstation under free burning, because of smoke leakage leading to insufficient suction and incomplete burned out in the office fire.

CONCLUSIONS

The fire characteristics inside of a furnished office room were experimentally investigated. The dimensions of the room were 6m x 5m x 2.4m high, with two 0.6m x 1.8m high doors in two opposite walls. The office room was furnished by six units of workstation and ten wood cabinets, and amounted to a fire load density of 390MJ/m^2. In the experiment, the total heat release rate of the room fire was measured by a 10MW fire products collector based on the oxygen consumption principle. Additional measurements taken in the room were radiant heat flux at different levels and temperatures distributions. The fire process was carefully observed and recorded. A propane burner with the heat release rate of 30kW was taken as the ignition source. The full-scale fire test of a furnished office room with a fire load of about 390MJ/m^2 had indicated that the flashover occurred at an upper layer temperature of 600? and a radiation heat flux of roughly 20kW/m^2 detected either at the floor center of the room or at a height of 150cm.

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