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EXPERIMENTAL STUDIES ON FIRE RESPONSE OF GLASS FAÇADE SYSTEMS

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ABSTRACT

Behaviour of glass façade systems in a fire was studied experimentally in two parts. Results will be discussed in this paper. In the first part of study, a model box on part of a glass façade system with two panels was built and placed next to a fire room. A 0.2 m pool gasoline fire was set up with smoke and heat directed out to the glass model. Heat transferred from the fire room and smoke movement in the glass façade model were studied. Transient temperatures in the air gap between the two glass panels were measured by a thermocouple tree. To include solar heating effect in tropical areas, surface temperature of the glass panel was heated up to 45ºC.

In the second part, fire response of a single glass panel was studied with another experimental arrangement. Instead of having two glass panels, only one panel was tested. The flame coming out of the fire chamber would act at the panel directly. Locations of cracks and time to cracking were measured.

1. INTRODUCTION

Architectural features with glass panels are used extensively in modern commercial buildings in the Far East [1]. Good outside views and better illumination quality are resulted from this design on building façade. Better utilization of daylighting would reduce the energy use for lighting systems, which occupies up to 50% of the total building energy use in many countries. This will satisfy the design criteria for green and sustainable buildings. Extensive use of glazing might become weak spots in the building envelope from the viewpoint of heat transfer. As reported before on building energy control through the Overall Thermal Transfer Value (OTTV) [2] in countries with hot climate, high solar heat gain would increase the cooling load. There might also be water leakages problems in rainstorms as the wind-induced pressure difference between inside and outside of the building might be very strong, up to 6 kPa in typhoons. Large glass panels might be deflected with amplitudes of several multiples of their thickness under wind action.

New designs such as double-skin façade [3], aluminum-curtain-wall systems and many others are proposed. However, these glass façade designs might bring about fire safety problems [4,5]. Many projects with such designs have difficulties in complying with the fire safety codes [6]. The fire behaviour of such glass façade systems should be studied [7-9]. Two sets of experiments on part of a glass façade system were carried out with results reported in this paper. Analysis and recommendations on proper design will appear in separate articles. All experiments were carried out in a full-scale burning facility developed at a remote site in North Eastern part of China. It is located in a small town Lanxi, Heilongjiang [10].

As many glass façade systems have two pieces of panels, the first set of experiments was focused on this design. A glass model box on part of the façade system was built for carrying out the full-scale burning tests. A fire room was placed adjacent to the model box with flashover onset by a liquid pool fire. Heat release rate of the pool fire was measured by an oxygen consumption calorimeter separately. Heat and smoke were directed out to the model box through an opening. To include solar heating effects in tropical countries, the glass panels were heated up to different temperatures. Fire response of this glass façade was then assessed by studying the smoke movement in the air gap between the two glass panels.

In the second set of experiments, response of a single glass panel to a fire was studied by another model. A single glass panel was installed next to the fire room. Heat and smoke coming out of the room would act at the glass panel. The times required for the cracks to form on the panel and falling down (if any) were recorded. Temperature and heat flux received on the glass surface were measured. From the results, thermal stress distribution over the surface can be estimated.

2. EXPERIMENTS ON A GLASS MODEL BOX

In the first set of experiments, fire response on part of a glass façade system was studied. A model box as shown in Fig. 1a was built. There were two glass panels with an air gap. The model box was of height 3.5 m and cross-section 1 m by 0.2 m as in Fig. 1b.

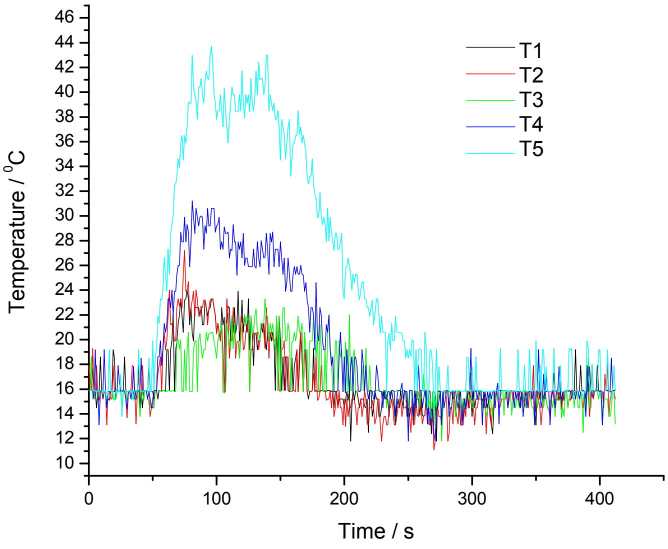
A fire room of length 1.5 m, width 2 m and height 2.1 m as shown in Fig. 1c was built. A pool fire of diameter 0.2 m and 150 ml gasoline as in Fig. 1d was burnt inside. Air was drawn from the rear wall to sustain combustion. The heat release rate of the pool fire was measured separately in an oxygen consumption calorimeter as shown in Fig. 1e. An opening of width 0.1 m and height 0.75 m was designed to direct smoke and heat from the fire room into the glass model box.

The glass panel was kept at different initial temperatures adjusted by thermal radiation from an electrical heater as in Fig. 1a. A total of six sets of tests labeled as D1 to D6 were carried out, with the surface temperature of glass T_s heated up to different values as in Fig. 1. All temperature settings were repeated by three tests.

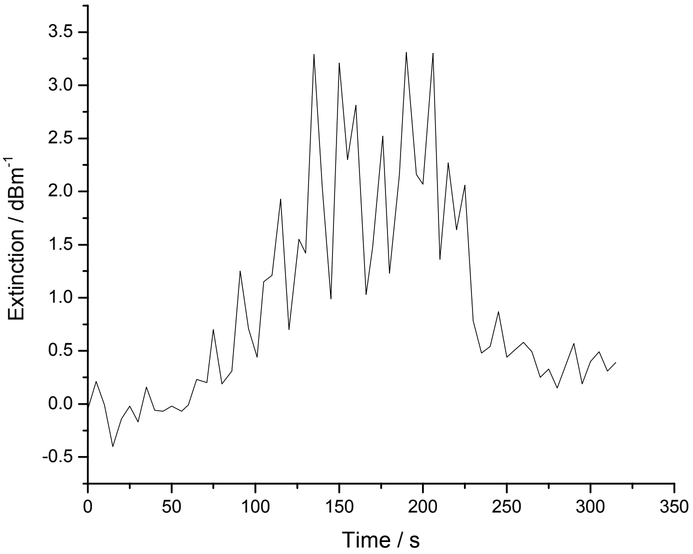
- Test D1 (labeled from D1a to D1c): T_s set at 19°C
- Test D2 (labeled from D2a to D2c): T_s set at 25°C
- Test D3 (labeled from D3a to D3c): T_s set at 30°C
- Test D4 (labeled from D4a to D4c): T_s set at 35°C
- Test D5 (labeled from D5a to D5c): T_s set at 40°C
- Test D6 (labeled from D6a to D6c): T_s set at 45°C

A tree of five thermocouples was placed at the centre of the model box to measure the vertical temperature profile in the gap between the two glass panels. The thermocouples were labeled as T1 to T5 and spaced at 0.7 m intervals as in Fig. 1d. Results on the transient temperatures are shown in Figs. 2a to 19a.

An optical laser system was placed at the middle part of the model box to measure the optical smoke density (given in dBm^{-1}) with results shown in Figs. 2b to 19b.

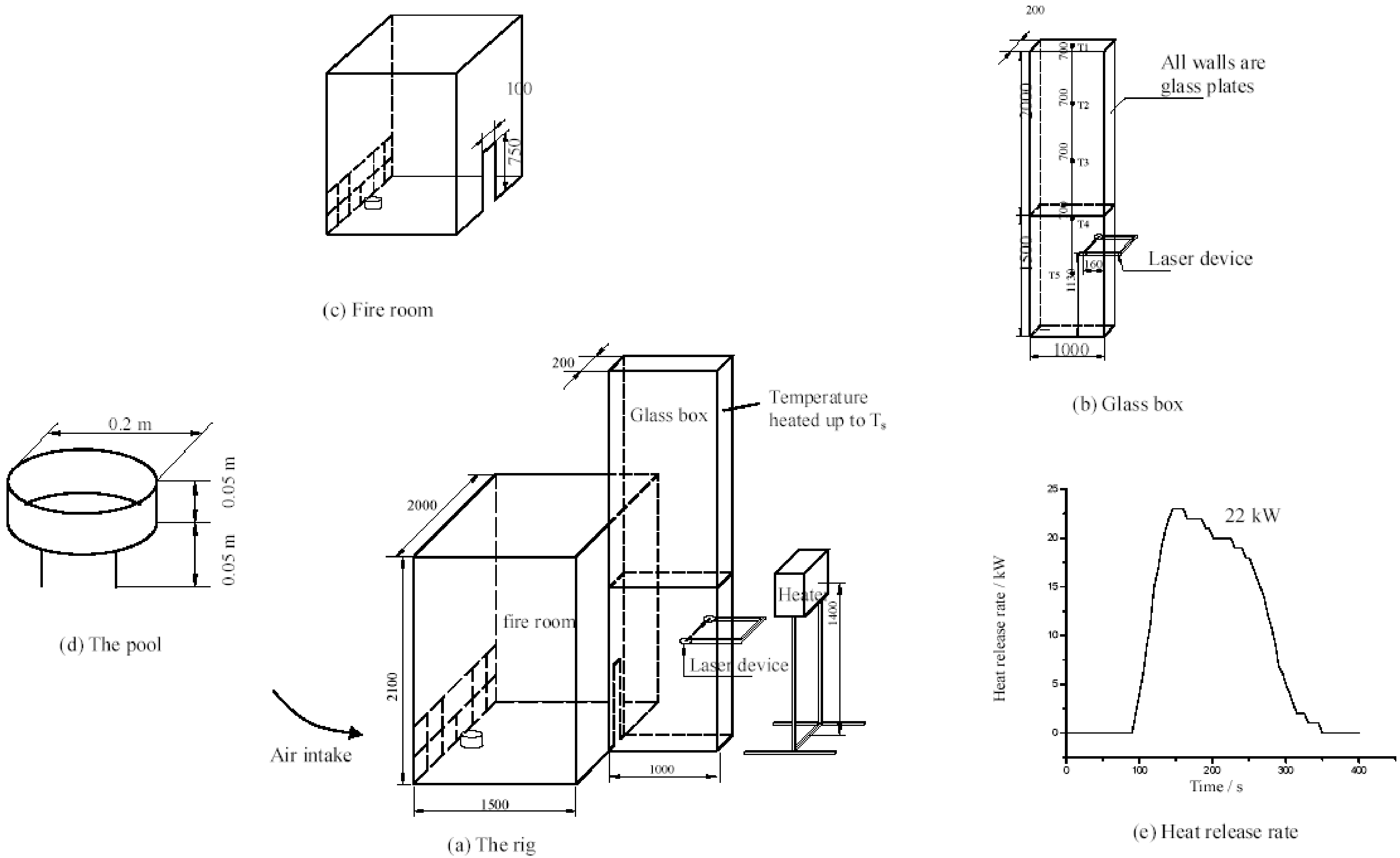


(a) Temperature



(b) Optical density

Fig. 2: Results for Test D1a



(c) Fire room

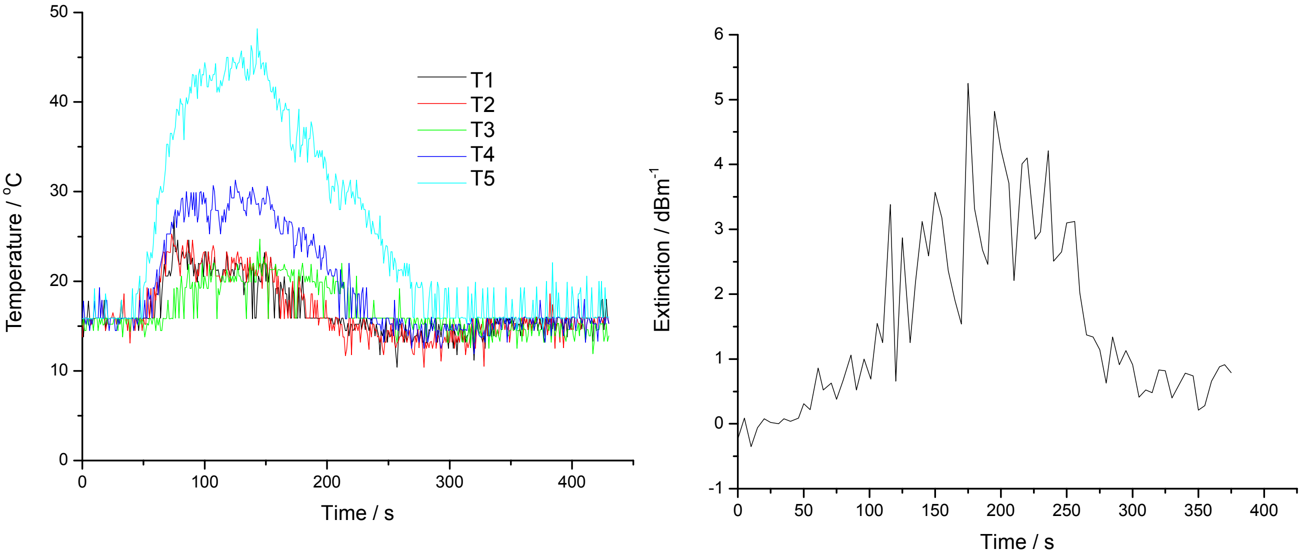
(b) Glass box

(d) The pool

(a) The rig

(e) Heat release rate

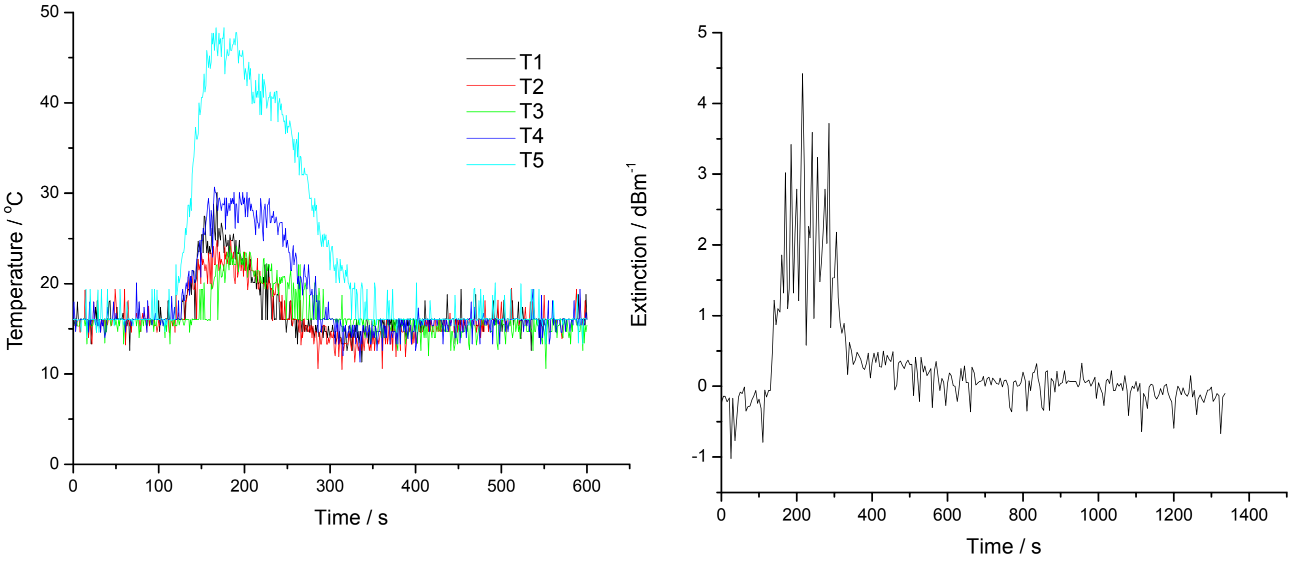
Fig. 1: The experimental set-up



(a) Temperature

(b) Optical density

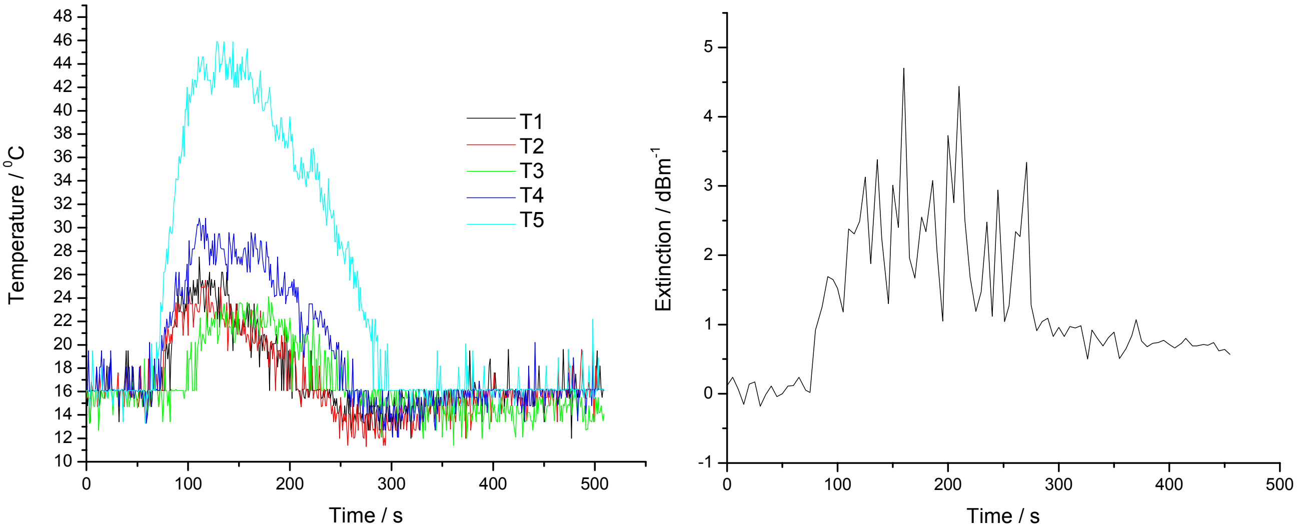
Fig. 3: Results for Test D1b



(a) Temperature

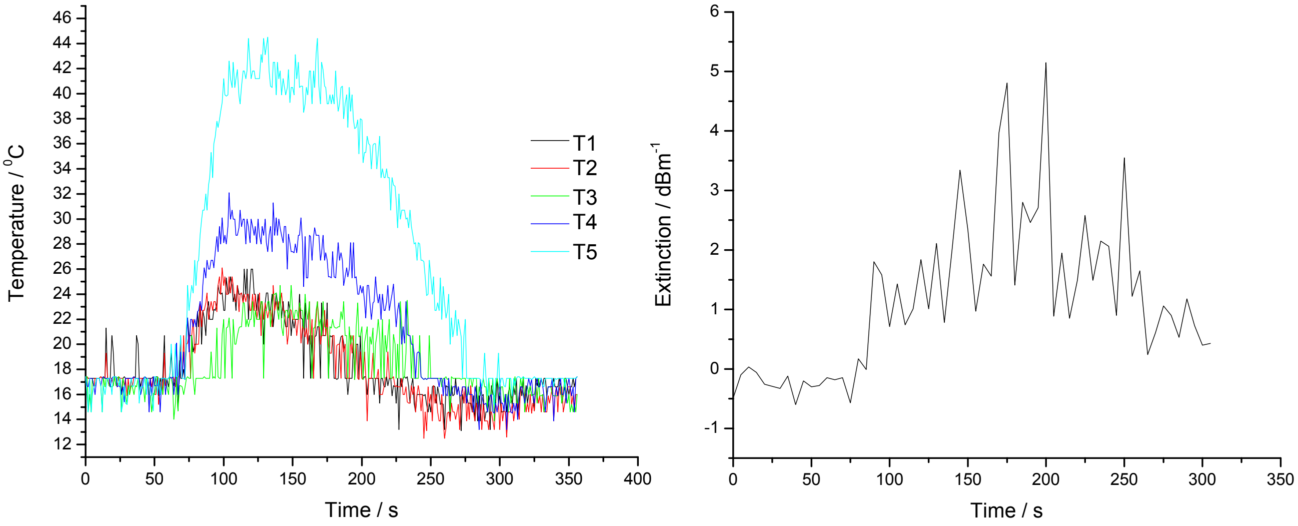
(b) Optical density

Fig. 4: Results for Test D1c



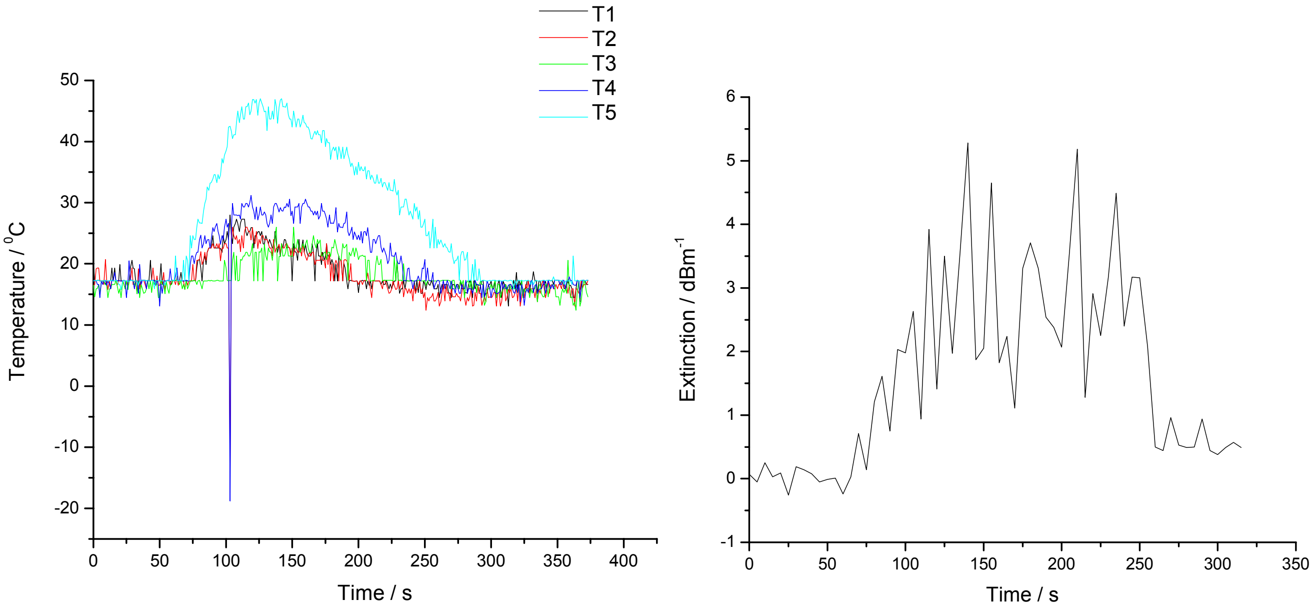
(a) Temperature (b) Optical density

Fig. 5: Results for Test D2a



(a) Temperature (b) Optical density

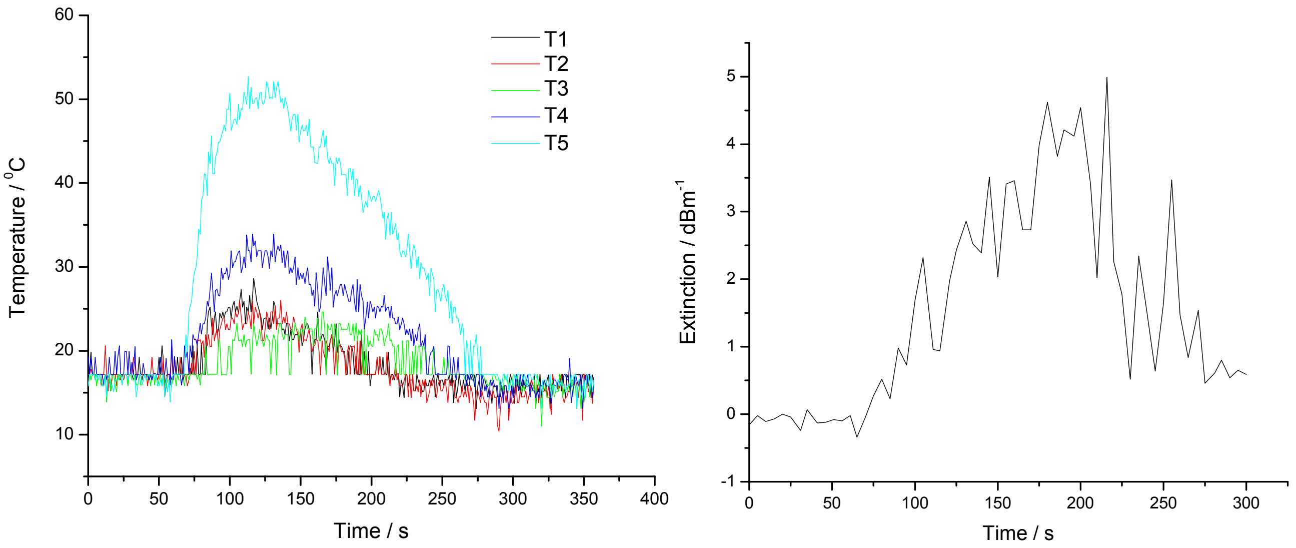
Fig. 6: Results for Test D2b



(a) Temperature

(b) Optical density

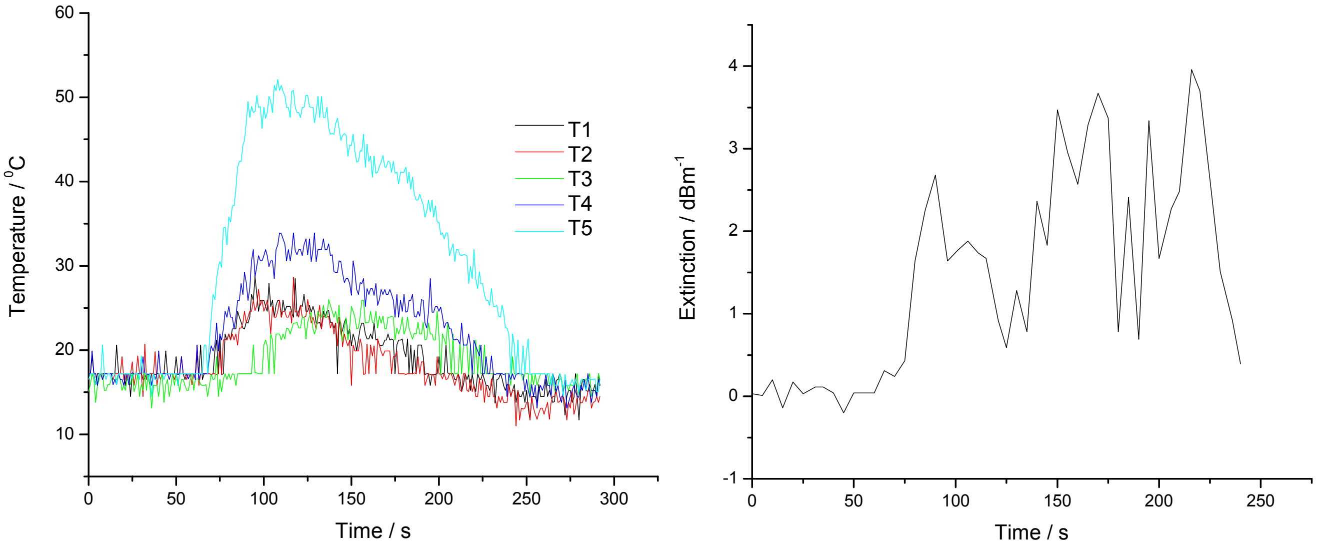
Fig. 7: Results for Test D2c



(a) Temperature

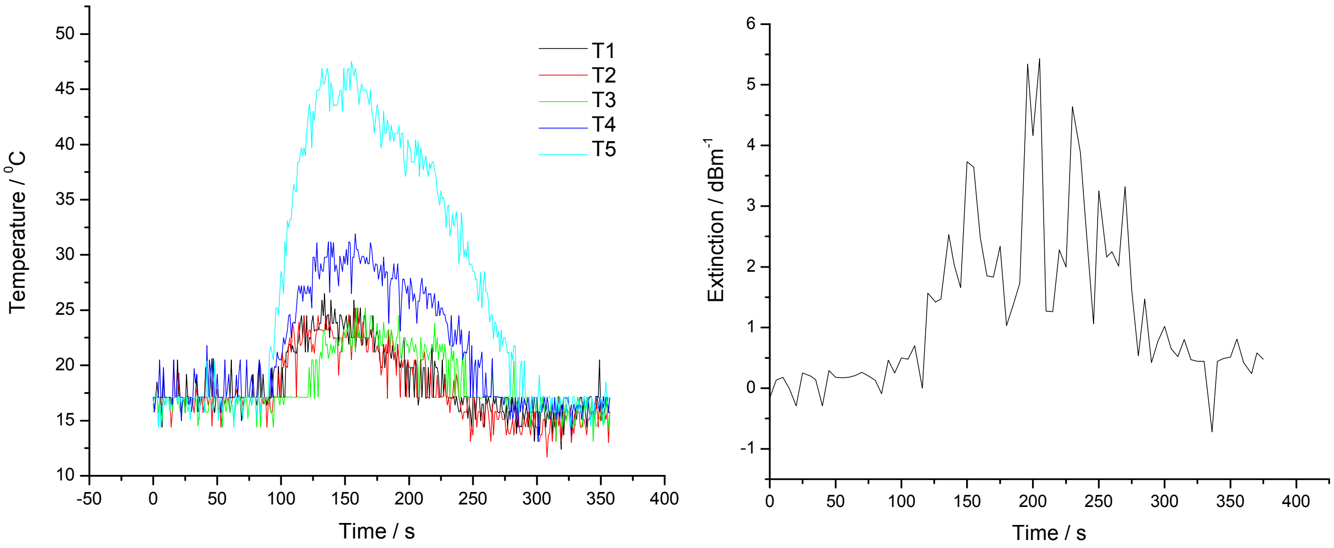
(b) Optical density

Fig. 8: Results for Test D3a



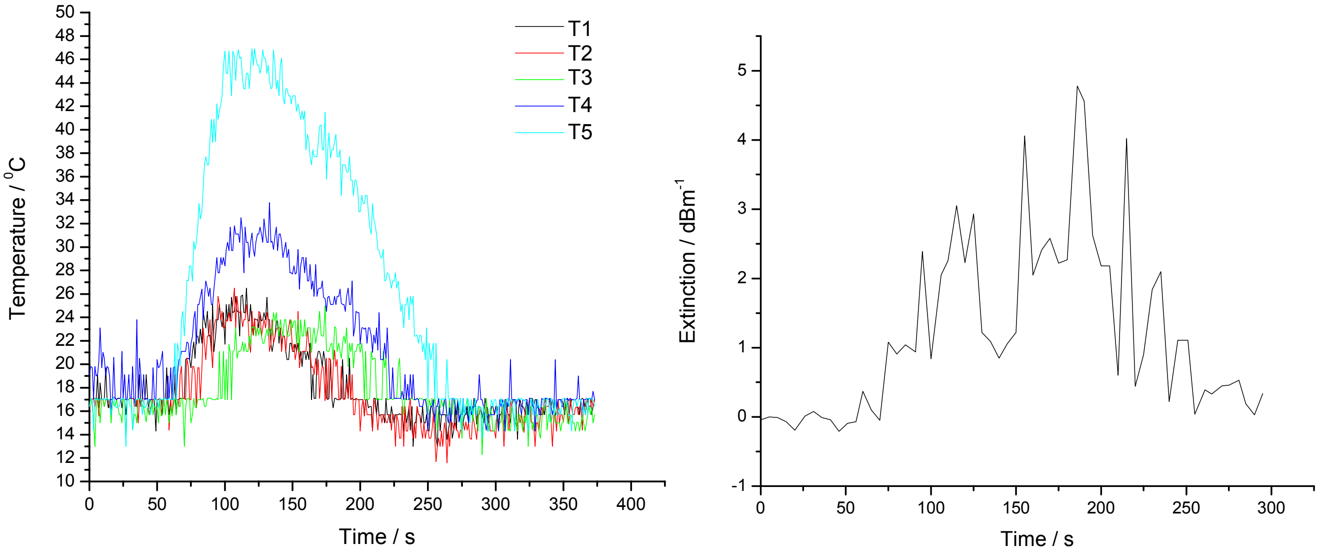
(a) Temperature (b) Optical density

Fig. 9: Results for Test D3b



(a) Temperature (b) Optical density

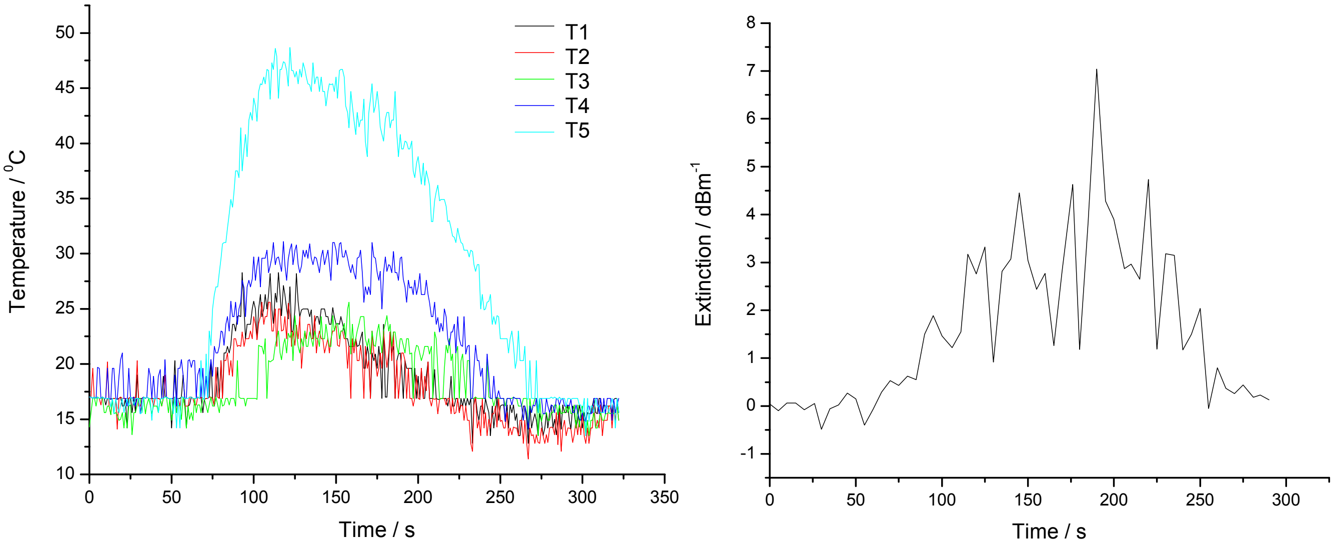
Fig. 10: Results for Test D3c



(a) Temperature

(b) Optical density

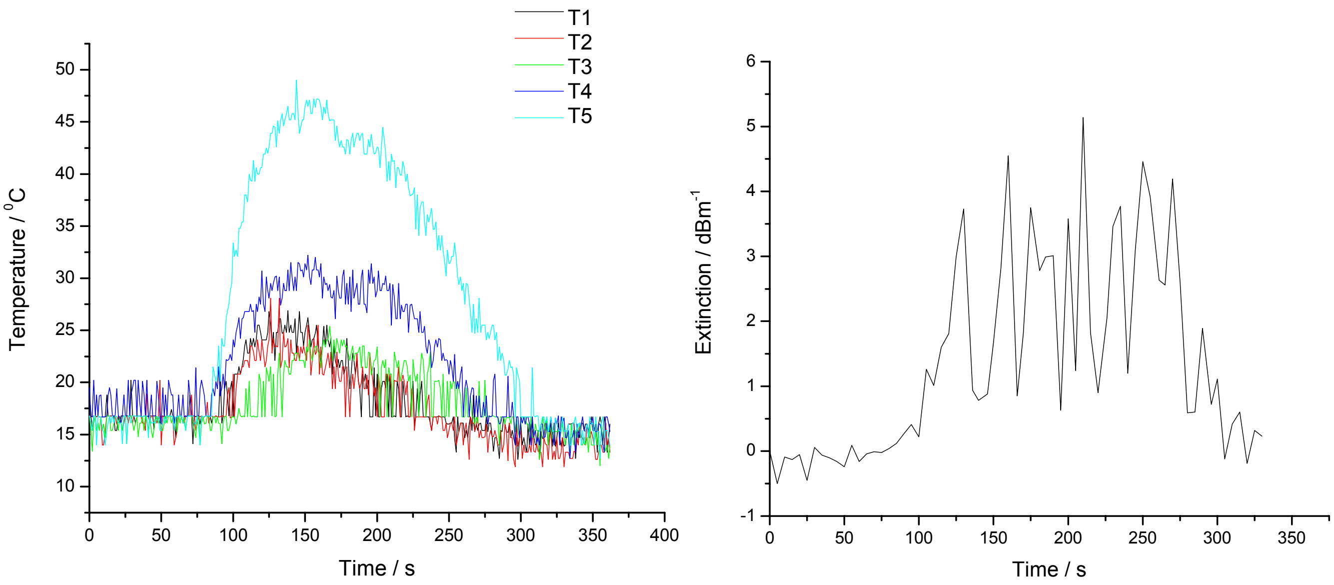
Fig. 11: Results for Test D4a



(a) Temperature

(b) Optical density

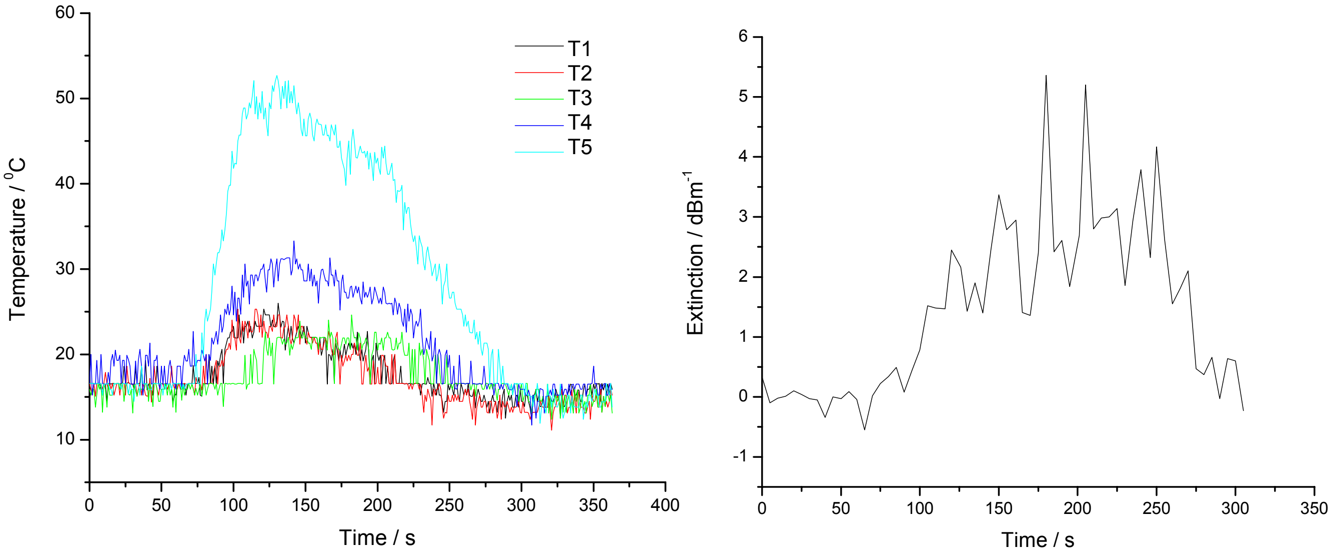
Fig. 12: Results for Test D4b



(a) Temperature

(b) Optical density

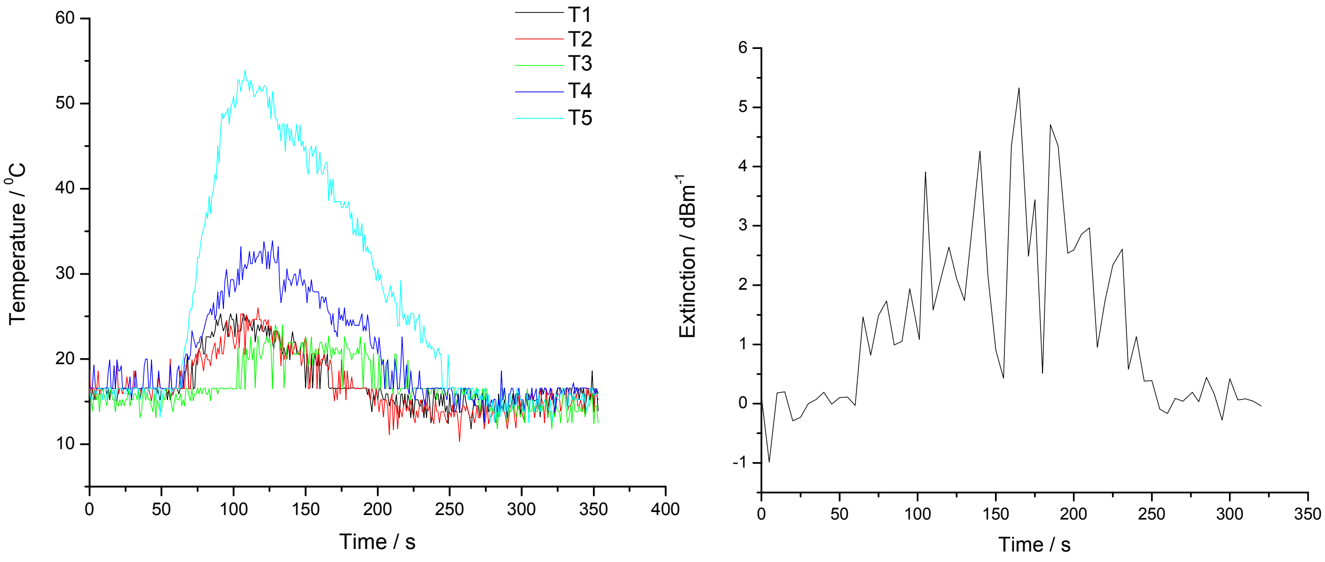
Fig. 13: Results for Test D4c



(a) Temperature

(b) Optical density

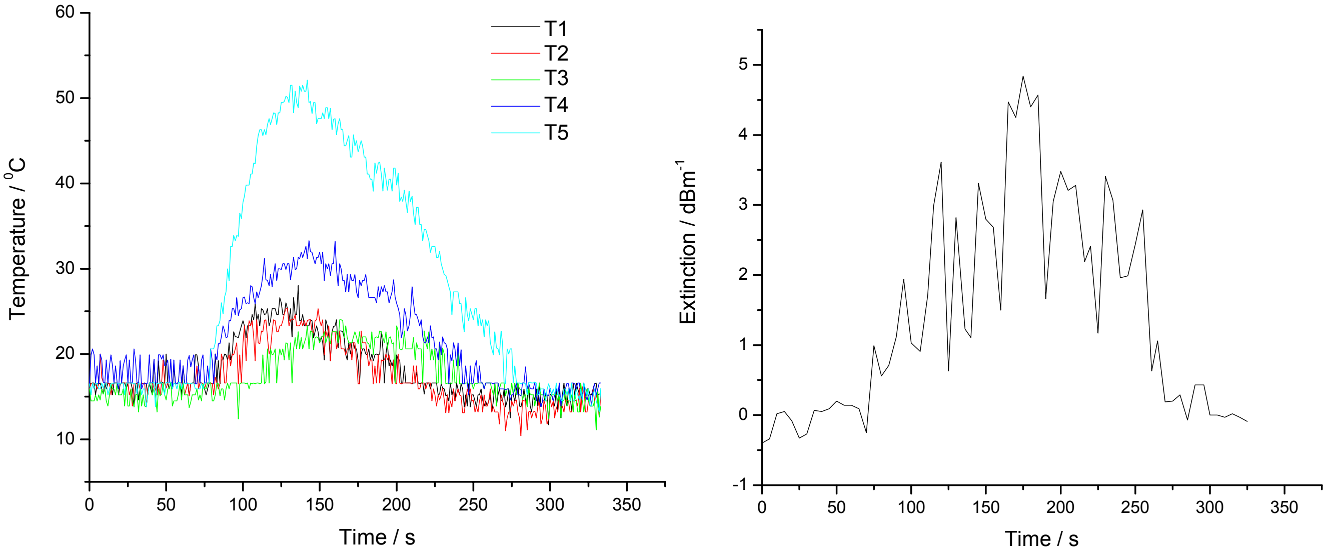
Fig. 14: Results for Test D5a



(a) Temperature

(b) Optical density

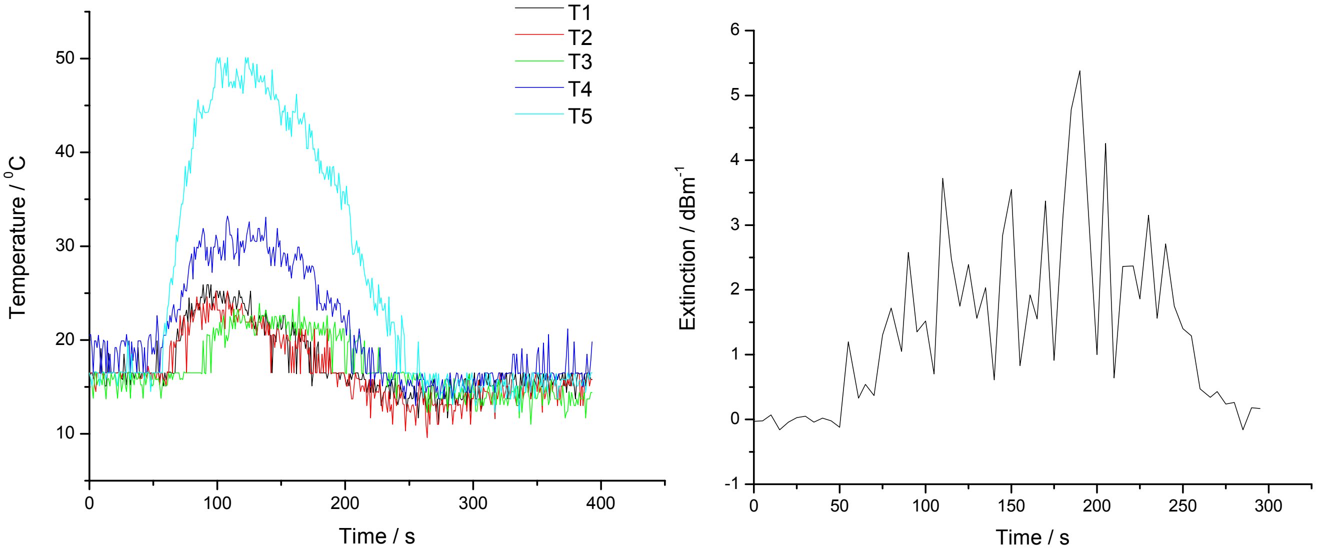
Fig. 15: Results for Test D5b



(a) Temperature

(b) Optical density

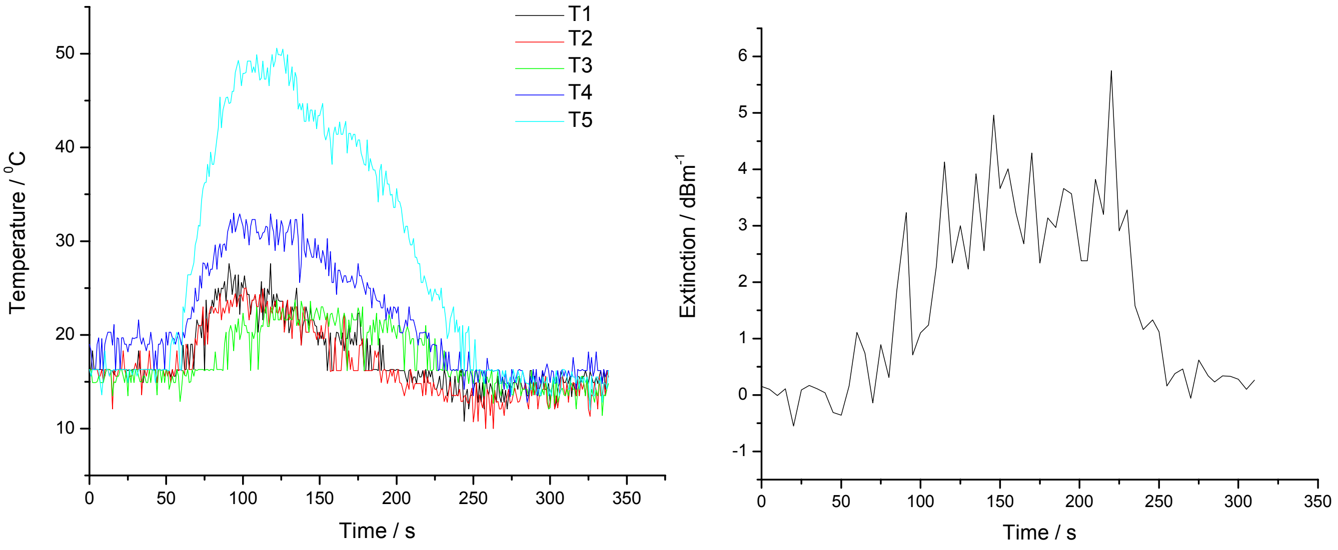
Fig. 16: Results for Test D5c



(a) Temperature

(b) Optical density

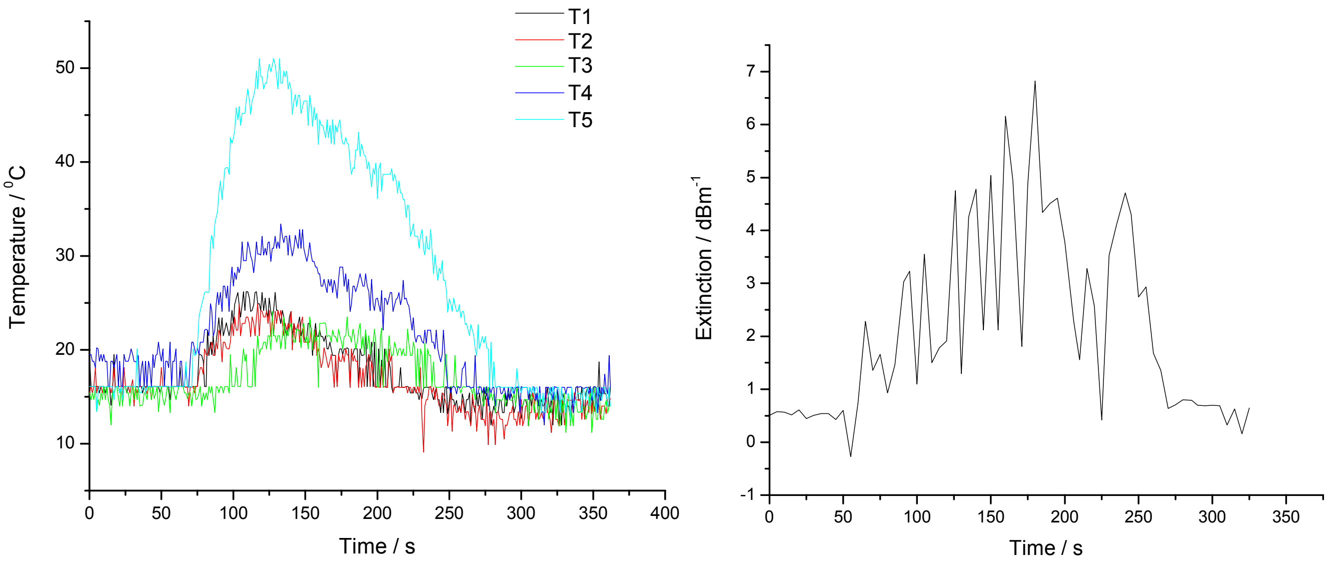
Fig. 17: Results for Test D6a



(a) Temperature

(b) Optical density

Fig. 18: Results for Test D6b



(a) Temperature (b) Optical density

Fig. 19: Results for Test D6c

3. SMOKE SPREADING

In view of the experimental results on smoke spreading, measurement of optical density at height 1.13 m above the floor level, and temperatures at positions T1 to T5 in the air gap, it is observed that heat and smoke spread out rapidly from the fire room to the glass model box. For a small pool fire of 22 kW, smoke temperature at the lowest position T5 was from 40ºC to 50ºC. The temperature recorded at the highest position T1 was up to 30ºC, for ambient temperature at about 15ºC.

One interesting point to note is that it took a longer time for the temperature at higher positions such as T1 to T2 to reach a steady value when the surface temperature of glass was heated up to high temperatures, as comparing test D6 with D1.

4. CRACKING OF A SINGLE GLASS PANEL

In addition to testing the whole glass model box, cracking of a single piece of glass panel was also studied. Another experimental arrangement with a single glass panel placed next to the fire room as in Fig. 20a was constructed. The opening of the fire room was 0.8 m wide and 1.5 m tall.

A tree of nine thermocouples was stuck to the glass surface. The thermocouples where labeled as B1 to B9 and placed at 0.2 m intervals as in Fig. 20b.

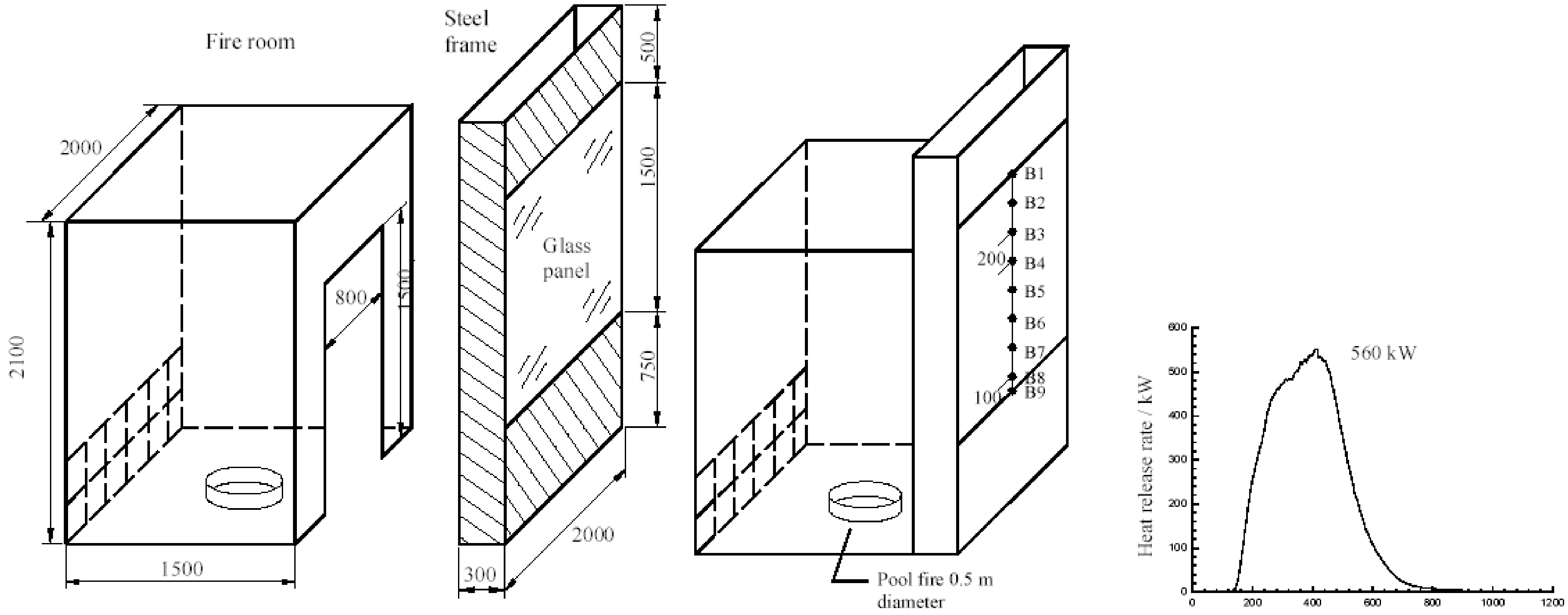
In this set of tests, a bigger pool fire of diameter 0.5 m was set up by burning 5000 ml gasoline. The heat release rate was measured in an oxygen consumption calorimeter separately with results shown in Fig. 20c.

Two tests were carried out and labeled as S1 and S2. Surface temperatures were measured for B1 to B9 as shown in Fig. 21.

For test S1, a small crack was found at 52 s. A bigger crack was observed at 3 min 27 s (207 s). The glass fell down in 3 min 27 s. The whole experiment lasted for 7 min 25 s. The glass surface temperature was up to 550ºC in view of Fig. 21a.

For test S2, cracks were found at 35 s, 45 s, and 1 min 12 s (72 s) respectively. A large crack was found at 2 min 4 s. The whole piece of glass panel fell down at 2 min 29 s. The whole experiment was completed at 7 min 11 s. The glass temperature was up to 500ºC in view of Fig. 21b.

Surface temperatures measured by thermocouples B1 to B9 at the times when cracking occurred, i.e. 52 s and 207 s for test S1; and 35 s, 45 s, 72 s and 124 s for test S2, are shown in Table 1. Such results are useful for modeling the breaking of glass panels [11-14].



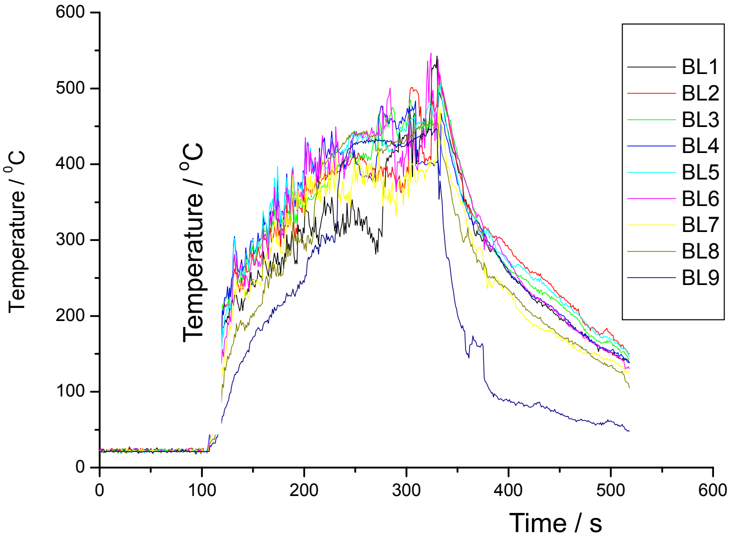
All in mm

(a) The rig

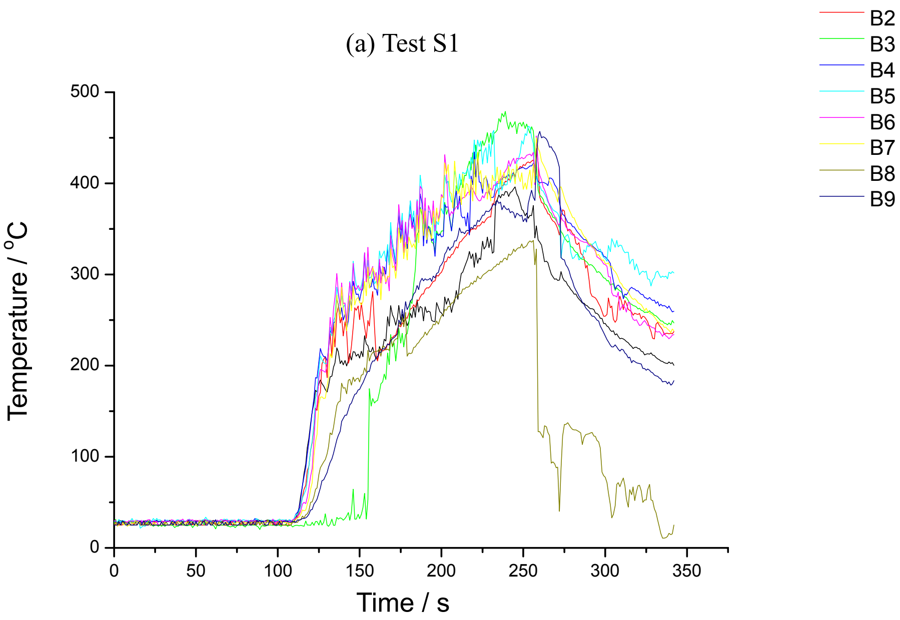
(b) Location of 9 thermocouples

(c) Heat release rate of pool fire

Fig. 20: The rig for studying cracking in a glass panel



(a) Test S1



(b) Test S2

Fig. 21: Glass Surface Temperature Measured

Table 1: Surface temperature (^{o}C)

Thermocouples	Test S1		Test S2			
	52 s	207 s	35 s	45 s	72 s	124 s
B1	21	305	28	30	30	171
B2	21	357	25	30	30	151
B3	21	353	25	25	25	29
B4	21	408	30	31	30	186
B5	21	405	30	31	30	170
B6	20	388	31	31	29	157
B7	21	358	28	28	25	124
B8	19	294	28	28	25	66
B9	19	278	28	25	25	53

5. CONCLUSION

The potential fire safety problems in the extensive use of glass façades in new architectural features should be watched more carefully, especially in green and sustainable buildings [15]. There are not yet detailed specifications on the type and configuration of glass façades in the existing building fire codes for design considerations. Appropriate regulations should be worked out with systematic experimental studies supported by full-scale burning tests. As reported in above, two sets of preliminary experiments on glass systems were carried out. Heat transfer and smoke movement in a model box on part of a glass system were studied. The glass panel was heated up to different surface temperatures. In the second set, fire response of a single panel was studied.

ACKNOWLEDGMENTS

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REFERENCES

1. W.Y. Hung and W.K. Chow, “Fire safety in new architectural design associated with the extensive use of glass”, Proceedings of the International Symposium on Fire Science and Fire-protecting Engineering (2003 ISFSFE), 12-15 October, Beijing, China, pp. 389-396 (2003).
2. Philip C.H. Yu and W.K. Chow, “Sizing of air-conditioning plant for commercial buildings in Hong Kong”, Applied Energy, Vol. 66, No. 2, pp. 91-103 (2000).
3. J. Jones, T. Messadi and S.S. Li, “Experimental study of the cooling season performance of ventilation double-glass envelope cavities”, International Building Physics Conference, Tools for design and engineering of buildings, 18-21 September, Eindhoven, The Netherlands, pp. 357-365 (2000).
4. J.J. Lentini, “Behavior of glass at elevated temperatures”, Journal of Forensic Sciences, JFSCA, Vol. 37, No. 5, pp. 1358-1362 (1992).
5. W. Kelvin, “Glazing against fire”, Glass Science and Technology, Vol. 66, No. 6-7, pp. 185-190 (1993).
6. W.K. Chow, “Fire safety in green or sustainable buildings: Application of the fire engineering approach in Hong Kong”, Architectural Science Review, Vol. 46, No. 3, pp. 297-303 (2003).
7. W.K. Chow, W.Y. Hung, G.W. Zou, H. Dong and Y. Gao, “Preliminary experimental study of double-skinned facade”, International Journal on Engineering Performance-Based Fire Codes, Vol. 6, No. 3, pp. 155-167 (2004).
8. W.K. Chow, W.Y. Hung, Y. Gao, G. Zou and H. Dong, “Experimental study on smoke movement in double-skinned façade”, Construction and Building Materials – Accepted to publish (2005).
9. W.K. Chow and W.Y. Hung, “Effect of cavity depth on fire spreading of double-skin facade”, Building and Environment – Accepted to publish (2005).
10. W.K. Chow, International Journal on Engineering Performance-Based Fire Codes - Special Issue, Vol. 6, No. 3 (2004)
11. J. Virgone, P. Depecker and G. Krauss, “Computer simulation of glass temperatures in fire conditions”, Building and Environment, Vol. 32, No. 1, pp. 13-23 (1997).
12. L. Tian and C. Pu, “Studying on thermal breakage mechanism of double-pane glass”, Fire Safety Science, Vol. 10, No. 2, pp. 67-71 (2001).
13. T.J. Shields, G.W. Silcock and S.K.S. Hassani, “The behavior of double glazing in an enclosure fire”, Journal of Applied Fire Science, Vol. 7, No. 3, pp. 267-286 (1997-98).
14. P.E. Sincaglia and J.R. Barnett, “Development of a glass window fracture model for zone-type computer fire codes”, Journal of Fire Protection Engineering, Vol. 8, No. 3, pp. 101-118 (1997).
15. Chow, W.K. and C.L. Chow, “Green influences”, Fire Prevention & Fire Engineers Journal, September, pp. 34-35 (2003).