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PRELIMINARY EXPERIMENTAL RESULTS ON FIRE BEHAVIOUR OF TIMBER PARTITION MATERIALS WITH A ROOM CALORIMETER

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ABSTRACT

Fire behaviour of timber partition materials were assessed in a room calorimeter with size following ISO 9705. Fourteen full-scale burning tests on timber materials used in the local industry with and without paint, wallpaper, fiberglass and fire retardant were carried out. The heat release rate, surface temperature of materials, upper layer gas temperature, floor heat flux and time to flashover were recorded. Flame spreading over the materials was observed.

Results are useful for comparing the flame spreading behaviour of different surfacing and insulating materials with and without fire retardants. It is observed that materials with rapid flame spreading rate might not necessarily give a shorter time to flashover. The performance of fire retardant depends on the substrate and the orientation of the materials.

1. INTRODUCTION

There is not yet a heat release rate database on local construction materials though it is very important in fire hazard assessment in engineering performance-based fire codes or applying fire engineering approach for designing passive building constructions in Hong Kong [e.g. 1-3]. Testing of flame spreading properties of materials still follows the bench scale test British Standard 476 Part 7 [4] without collecting materials data systematically. As surveyed [5], chipboards are commonly used for internal partitioning. Local fire codes [e.g. 6] include requirements on the fire resistance period of structural wall and flame spread over linings and thermal insulations used in ductings, concealed locations and protected means of escape only. No specification is included on the control of those internal partitions. In fact, those wood panels can lead to rapid flame spread in following a NFPA t^2-fire [7]. To understand the contribution of those materials to fire growth, the heat release rate should be measured. It might not be easy to ignite a wood panel. Application of organic materials such as wallpaper and paint might cause more rapid flame spread. However, actual effects are still unknown and are case dependent. Sandwich panel, with two wood panels and some insulation like fiberglass in-between, is a common design in the local industry. The heat transfer in the composite might be different from a bare wood panel. Investigation on this is worthwhile to be carried out. Fire retardant coating might help to reduce the flame spread rate. But that depends on the application, substrate, testing geometry and the fire size. Whether the approved fire retardant coating over different surfaces are good should be demonstrated.

Fourteen full-scale burning tests on timber products, paint, wallpaper, fiberglass backing and fire retardant were carried out. Those are common materials used in the local industry. Tests were done in the PolyU/HEU Assembly Calorimeter [3] developed by The Hong Kong Polytechnic University (PolyU) and the Harbin Engineering University (HEU) in a remote site in Lanxi, Harbin, China. An exhaust hood was built to collect combustion products and smoke generated from burning combustibles. The hood was connected to a fan-duct exhaust system at an extraction rate of 3.5 m^3s^{-1}. A 'duct section' with gas sampling tubes and sensors was installed in the exhaust duct and connected to an instrument station for further data analysis and determination of heat release rate using the oxygen consumption method. A room calorimeter was built according to the standard ISO 9705 [8] adjacent to the hood. The room is 3.6 m long, 2.4 m wide and 2.4 m high with a doorway 0.8 m wide and 2.0 m high as shown in Fig. 1. The walls are 0.24 m thick, constructed with bricks and concrete.

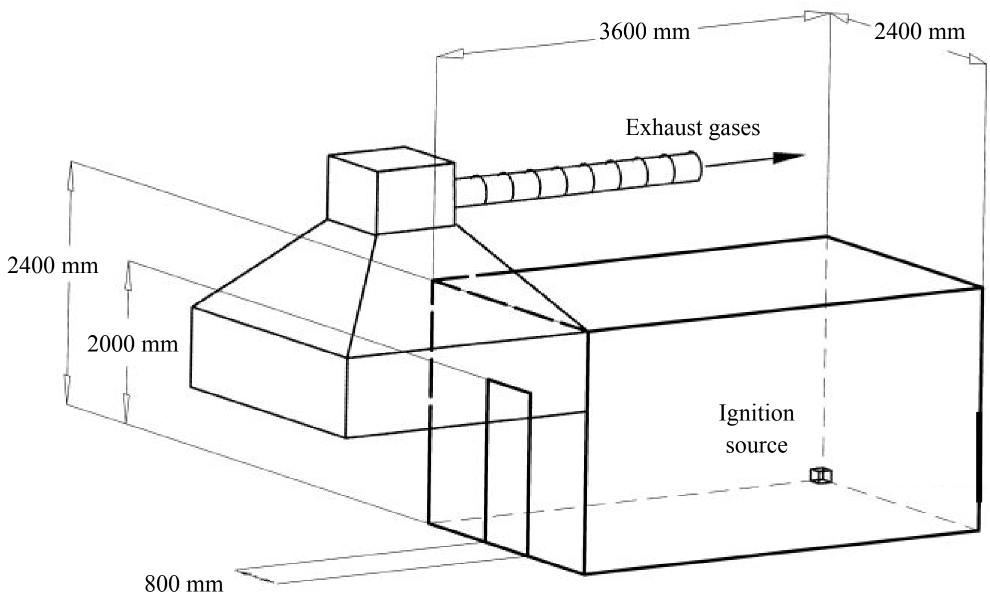


Fig. 1: Configuration of the ISO 9705 full-scale burning test

A heat flux meter is located at the center of the floor, 0.15 m above ground level, for measurement of the floor heat flux. Two Type K stainless steel sheathed thermocouples were mounted 30 mm below the ceiling, at the symmetrical center of the ceiling and above the ignition source for measuring the upper layer gas temperature. The time for flame emerging the doorway is also observed. Those three measurements and observations are useful indications of the time to flashover (TTF).

2. MATERIALS TESTED

Timber materials commonly used in the local industry were tested. These include 8 mm chipboard for internal partitioning and surface alignment. It was tested in different combinations to allow comparison between the effects of those finishing and insulating materials. Other chipboards of different thickness were tested with fire retardant. A common fire retardant paste coating for wood in China was used. It is composed of potassium silicate, mica powder and quartz sand.

These materials were fixed on the ceiling and three walls, excluding the wall with the doorway based on their end-use conditions. The total specimen size is 31.68 m^2. Four groups of tests were carried out including four types of chipboard with different thickness (M1, M2, M3 and M4), paint, wallpaper, fiberglass and fire retardant coating as follows:

- Group 1: 8 mm chipboard (M1)
  - M1: Bare chipboard only
  - M1a: M1 with fire retardant coating
  - M1b: M1 with fiberglass backing
  - M1c: Painted M1
  - M1d: Painted M1 with fire retardant coating
  - M1e: M1 with wallpaper
  - M1f: M1 with wallpaper and fire retardant coating
- Group 2: 2.5 mm chipboard (M2)
  - M2: Bare chipboard only
  - M2a: M2 with fire retardant coating
- Group 3: 4.5 mm chipboard (M3)
  - M3: Bare chipboard only
  - M3a: M3 with fire retardant coating
  - M3b: M3 with fiberglass backing
- Group 4: 11 mm chipboard (M4)
  - M4: Bare chipboard only
  - M4a: M4 with fire retardant coating

Thermocouples were fixed on the left sidewall and ceiling materials as shown in Figs. 4a and 4b for measurement of surface temperature.

3. IGNITION SOURCE

According to ISO 9705 [8], both primary ignition sources and secondary ignition sources can be used such that they are appropriate to the designed scenario. A typical example of primary ignition sources is the standard propane gas burner of side length 0.17 m and heat output of 100 kW for 600 s and 300 kW for a further 600 s if no flashover occurred. Examples of secondary ignition sources are furniture and waste paper basket. In this set of full-scale experiments, it is attempted to use a paper basket as the ignition source to simulate an accidental fire. Different configurations were tested:

Trial 1: Paper basket
3 kg of paper strips were put in a basket of diameter 0.35 m. When the paper on the top was ignited, it burned quickly to ashes as shown in Fig. 2a. However, the paper in the lower part was not involved in burning due to insufficient air entrainment. The reproducibility in heat output was poor. Even when the paper strips were freely burnt on the floor, the fire size was not too big as shown in Fig. 2b. The paper strips should be turned for more oxygen supply to sustain burning.

(a) Burning of paper basket

(b) Free burning of paper strips

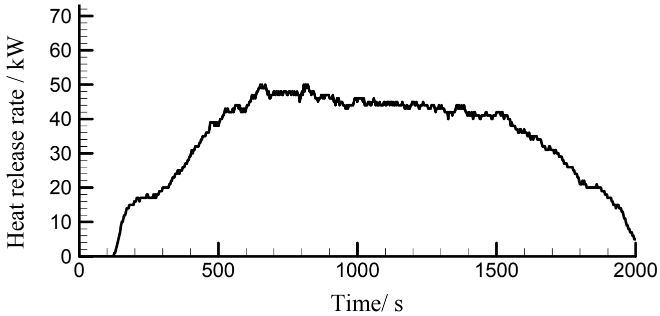
Fig. 2: Ignition source

Trial 2: Paper basket and gasoline
Gasoline was added into the 350 mm diameter basket with paper strips. A more steady heat output was obtained. However, the contribution to the heat release rate was dominated by burning of gasoline.

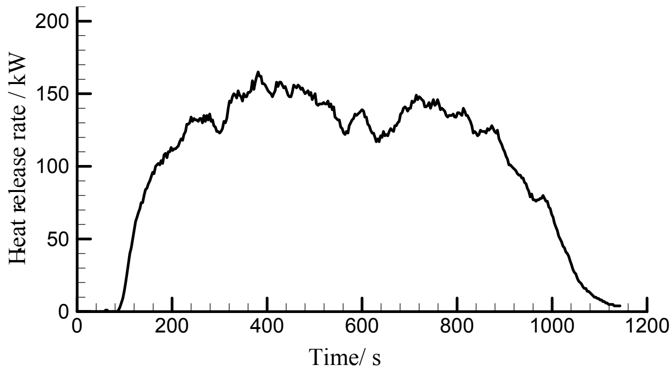
Trial 3: Gasoline
Square containers were used to produce a pool fire. The ignition sources were burnt in the left-rear wall corner. 2000 ml gasoline were used in a 0.26 m × 0.26 m by 0.26 m high container. A steady heat output of around 45 kW was given out for 1000 s which is over 50 % of the total burning time as shown in Fig. 3a. In another 0.35 m × 0.35 m by 0.25 m high container, 3500 ml gasoline was used. The heat output was over 120 kW for over 60 % (around 700 s) of the total burning time (around 1000 s) as shown in Fig. 3b.

Compared to the paper basket in Trial 1, the heat output in using liquid fuel is steadier. Liquid fires can be more reproducible under the same exposure conditions and this allows the same initial conditions for tests and ensures comparisons between different materials. However, the variation due to radiation feedback during the testing of materials is unknown and this should be further monitored by measuring the mass loss rate of the fuel. In this paper, it is assumed that the heat output from the ignition source is the same at the early stage of the fire growth.

The container of side length 0.26 m was used as the ignition source to simulate a small accidental fire in the full scale burning tests.



(a) 0.26 m × 0.26 m by 0.26 m high container with 2000 ml gasoline



(b) 0.35 m × 0.35 m by 0.25 m high container with 3500 ml gasoline

Fig. 3: Heat release rate curves of ignition sources

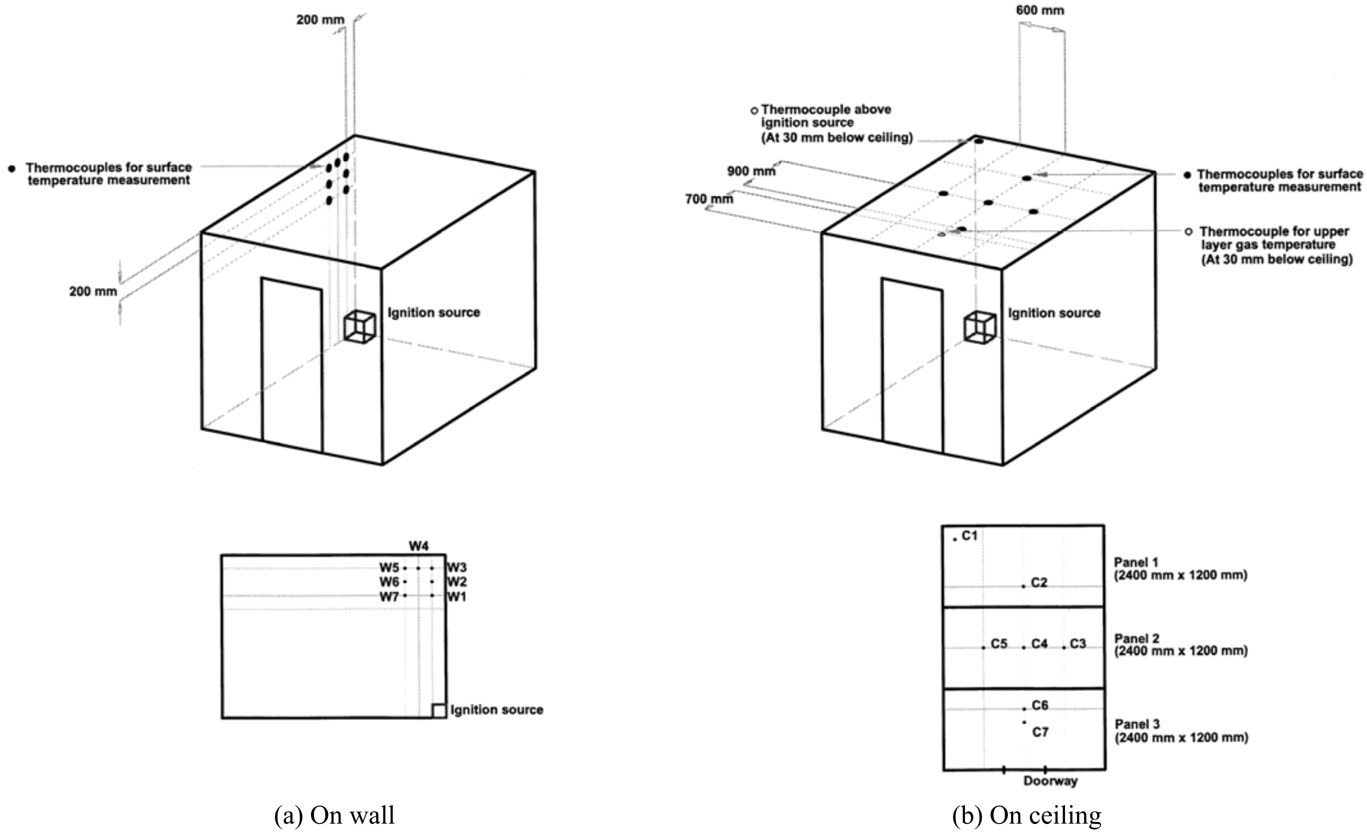


Fig. 4: Locations of thermocouples for measuring wall surface and upper layer gas temperatures

4. RESULTS

The temperature-time curves, heat release rates and heat flux-time curves are shown in Figs. 5 to 18. Heat release rate was recorded at time intervals of 3 s. Ignition of materials and emerging of flame out of the doorway were judged visually. Flame spread over walls and ceiling were observed. Ceiling panels are identified as panels 1, 2 and 3 as shown in Fig. 4a for easier illustration of flame spread progress. The temperatures and heat flux data were measured and monitored every 0.5 s. Upper layer temperature of 600^{o}C, floor heat flux of 20 kWm^{-2} and flame emerging the doorway are indications of flashover. Water mist was discharged when flashover was reached to prevent thermal damage to equipment and hazard to operators.

For M1, the left sidewall and rear wall behind the ignition source were ignited at 159 s. Flame emerged the doorway at 351 s and heat release rate of 1 MW was recorded at 564 s. For M1a, longer time was required for ignition, at 285 s. There was only very limited burning and char was formed over the surface of the material. No flashover occurred in the total testing period of 20 minutes. The chipboard was ignited at 152 s in M1b. A flame layer was formed over the ceiling at 452 s with flame emerging the doorway. A large fire plume came out of the opening at 892 s and heat release rate of 1 MW was reached at 945 s. With a painted surface in M1c, the materials were ignited at 147 s. A ceiling flame layer was formed at 349 s with flame emerging at 582 s. Large fire plume came out of the doorway at 602 s. Heat release rate of 1 MW was recorded at 636 s. In M1d, ignition occurred at 208 s. Flame spread to ceiling, forming a flame layer at 488 s. Flame emerged the doorway at 730 s with a large fire plume out of the opening at 750 s. Heat release rate reached 1 MW at 804 s. For chipboard with wallpaper in M1e, ignition was observed at 139 s. Flame spread to ceiling at 299 s, causing one of the ceiling panels falling off. A flame layer was formed over the ceiling and flame emerged at 579 s. Heat release rate reached 1 MW at 612 s. When fire retardant was added in M1f, the material was ignited at 174 s. The ceiling was ignited at 364 s and then ceased. Re-ignition occurred at 586 s and a flame layer over ceiling was formed at 802 s. Flame emerged the doorway at 879 s and a large plume of fire emerged at 958 s. Heat release rate reached 1 MW at 999 s.

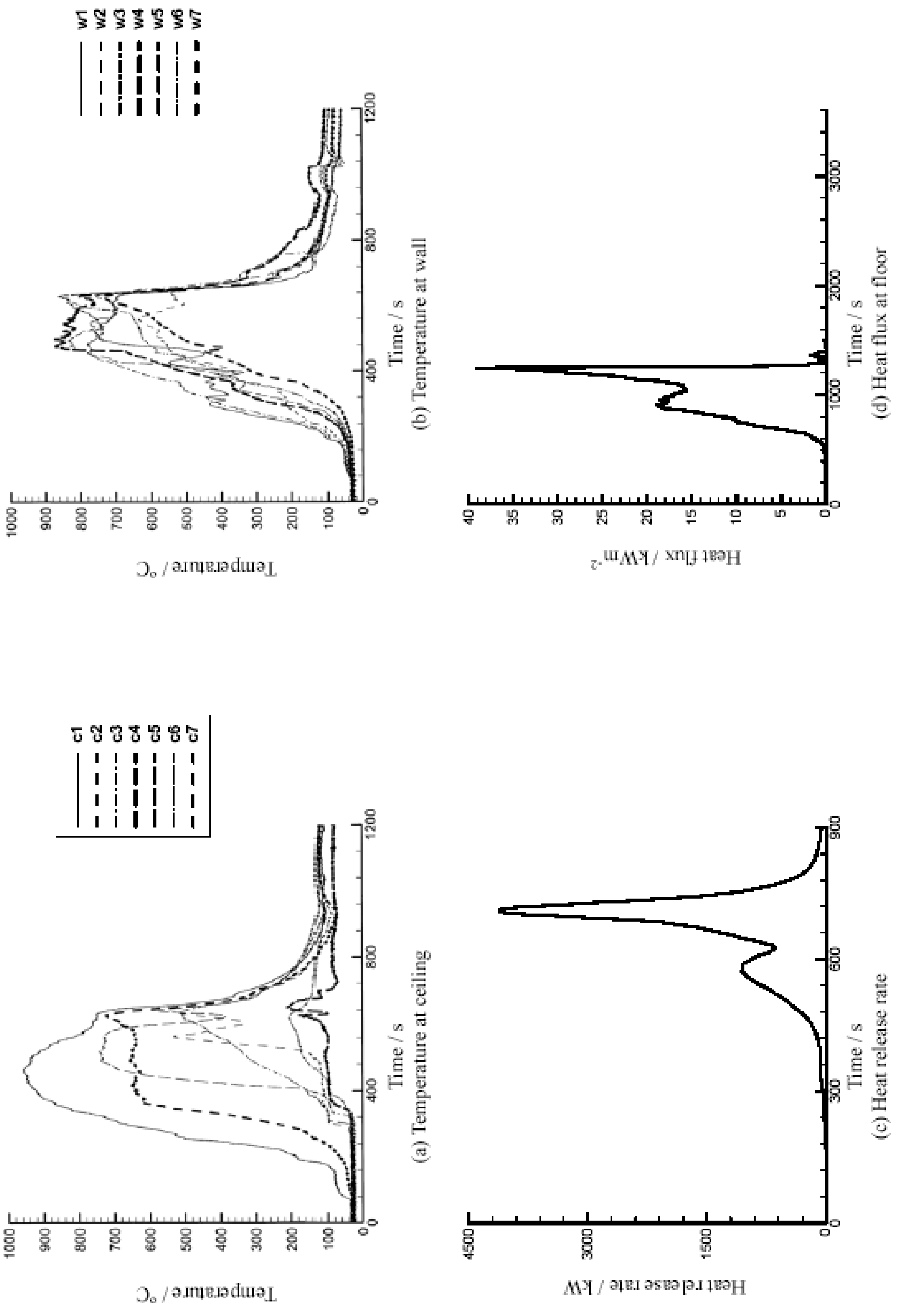
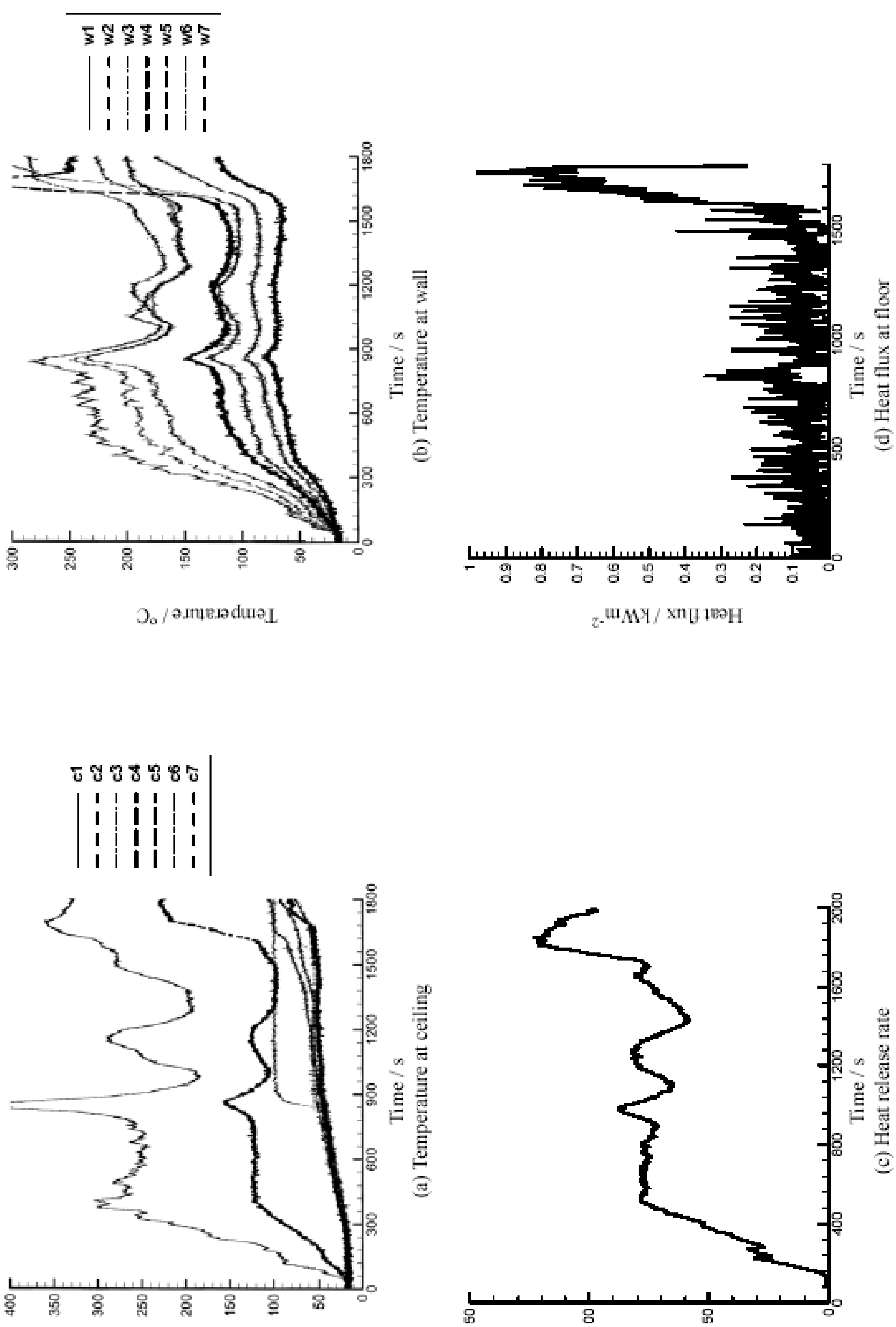


Fig. 5: Testing results for M1



(a) Temperature at ceiling

(b) Temperature at wall

(c) Heat release rate

(d) Heat flux at floor

Fig. 6: Testing results for M1a

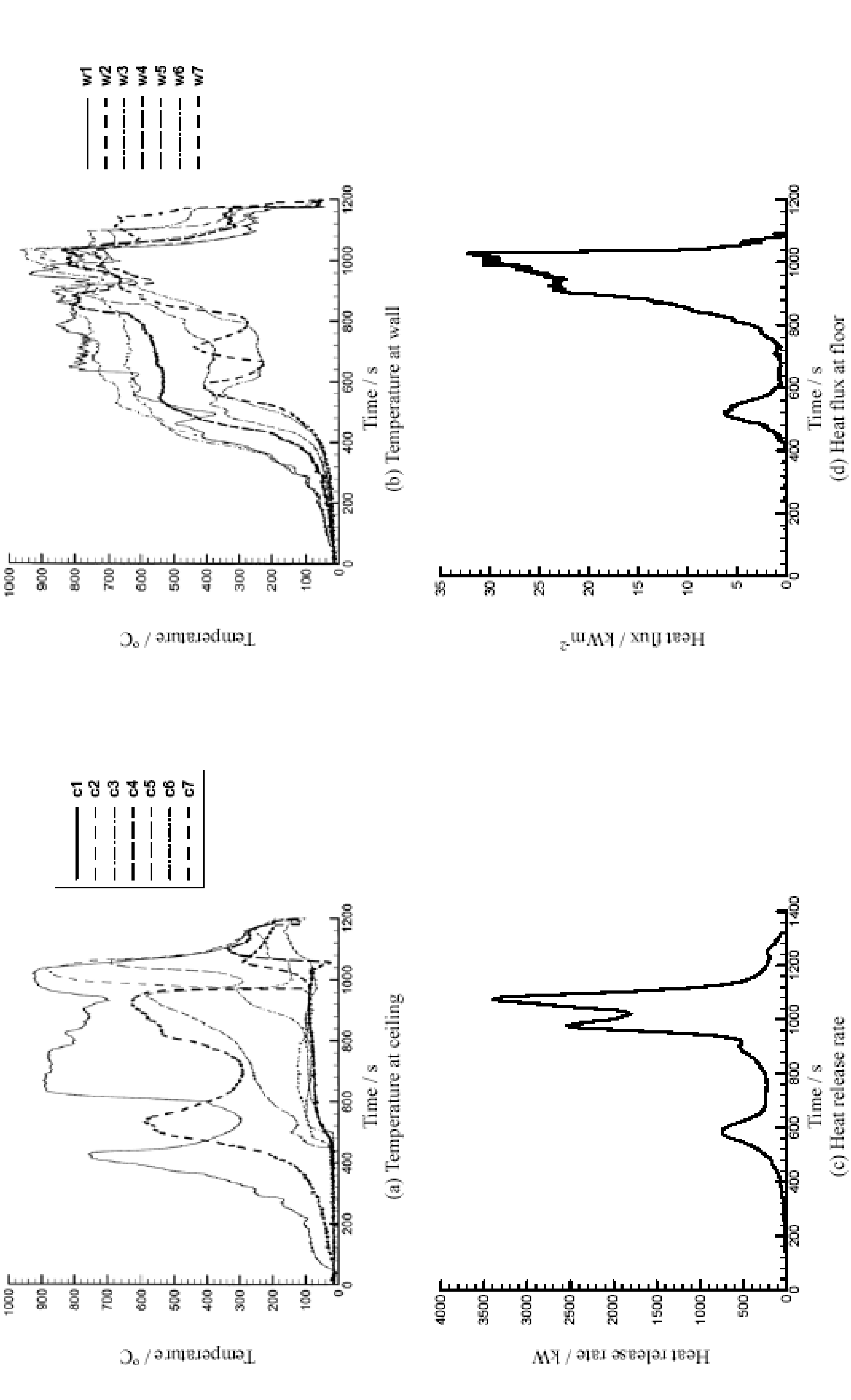


Fig. 7: Testing results for M1b

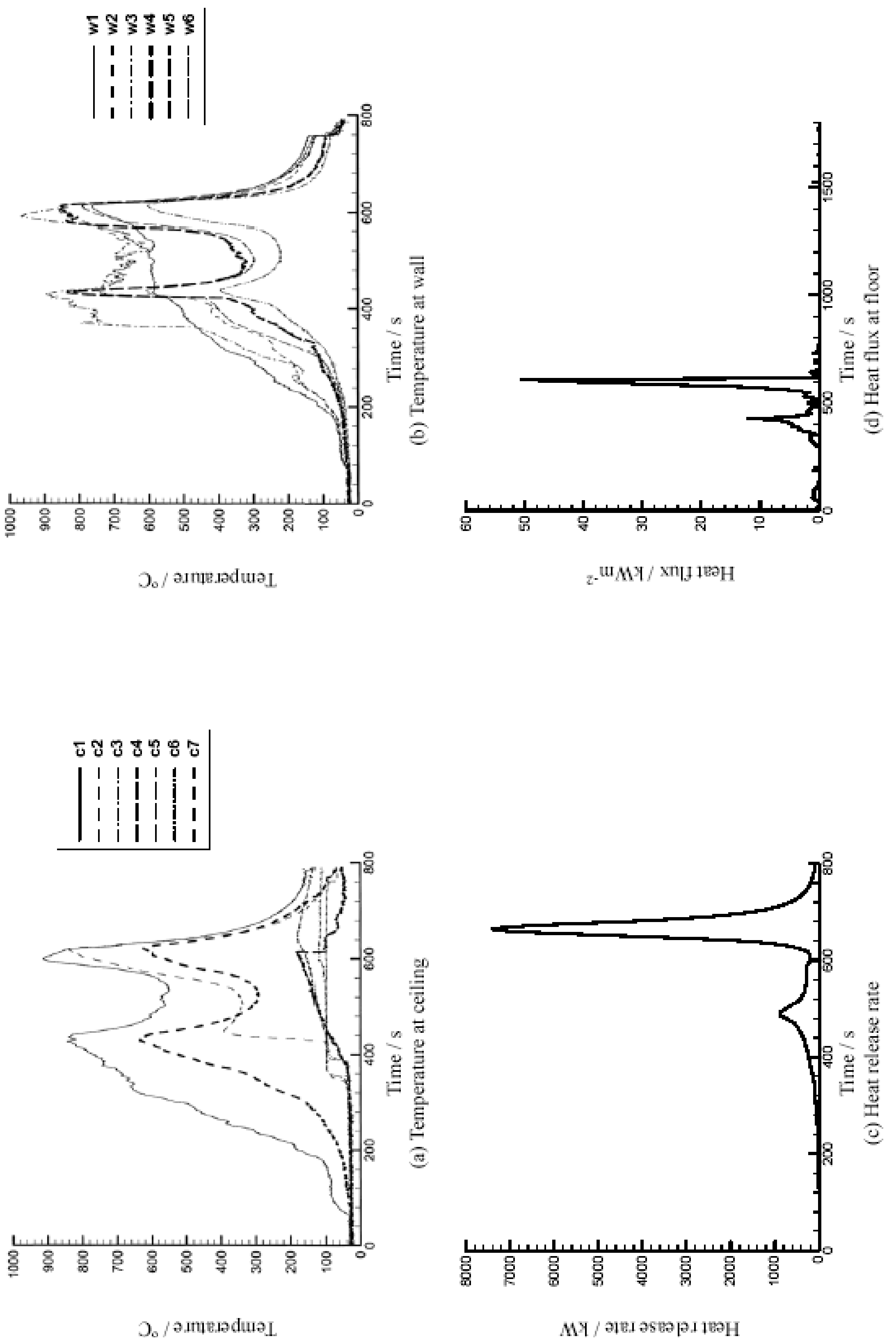


Fig. 8: Testing results for M1c

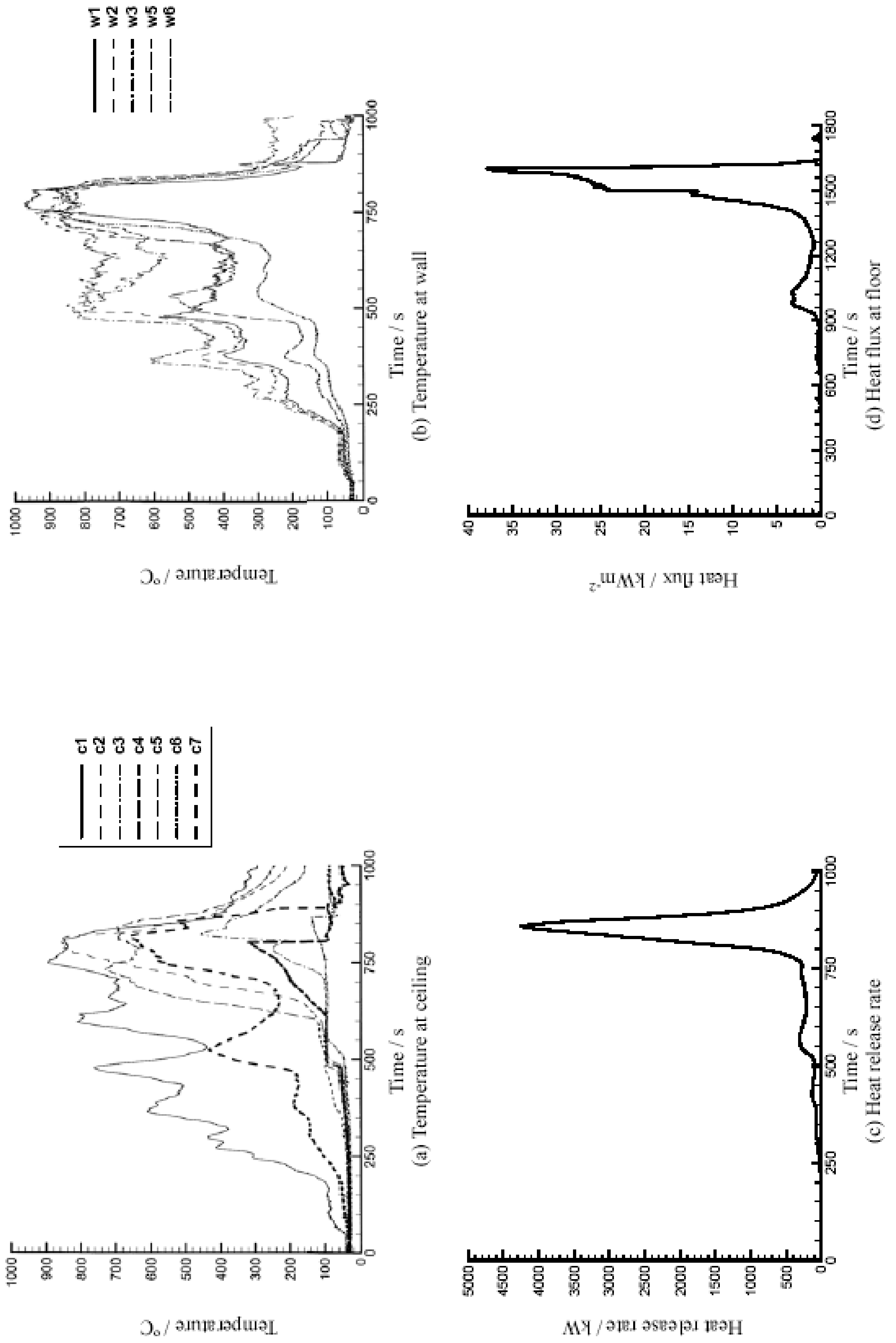


Fig. 9: Testing results for M1d

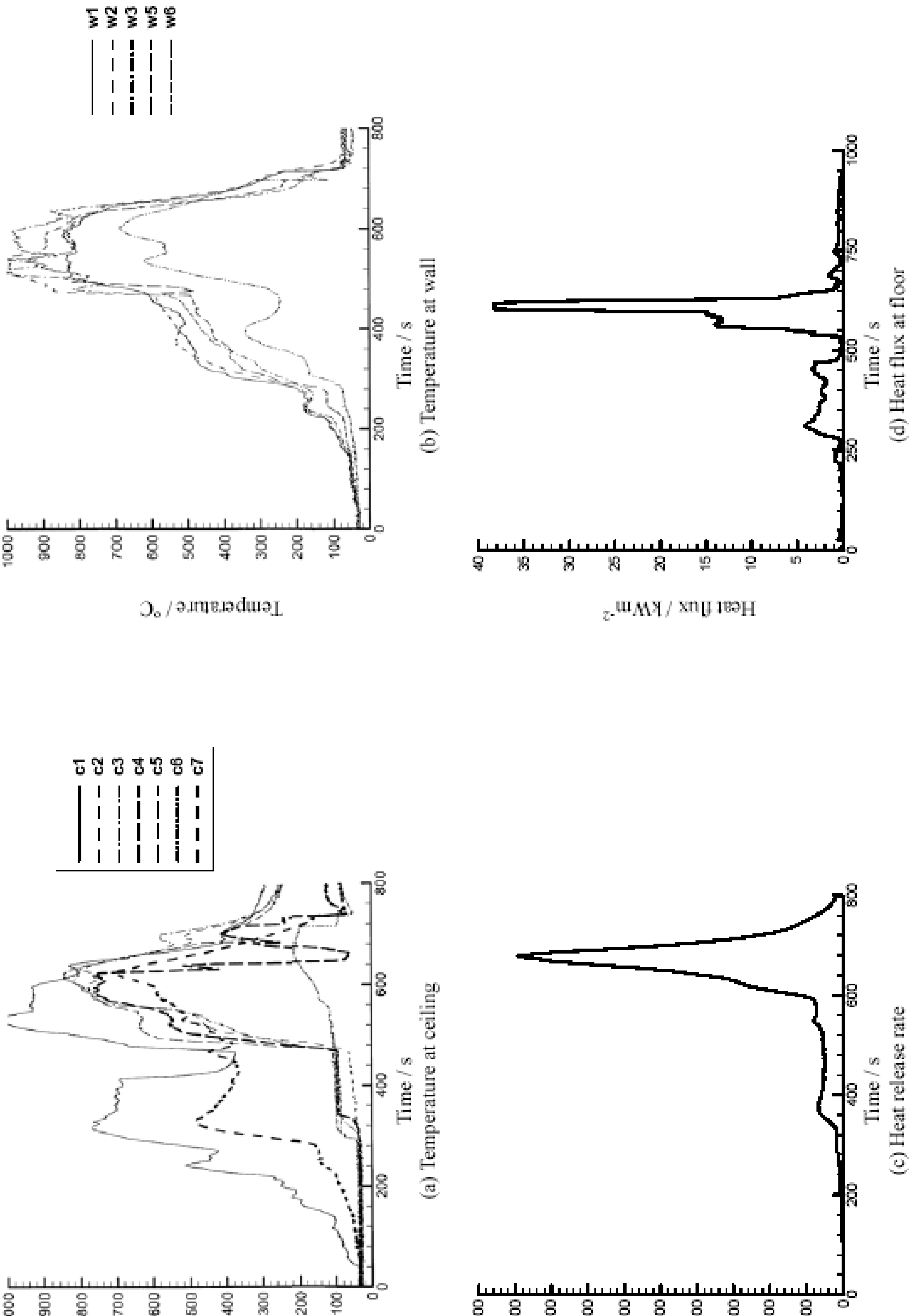


Fig. 10: Testing results for M1e

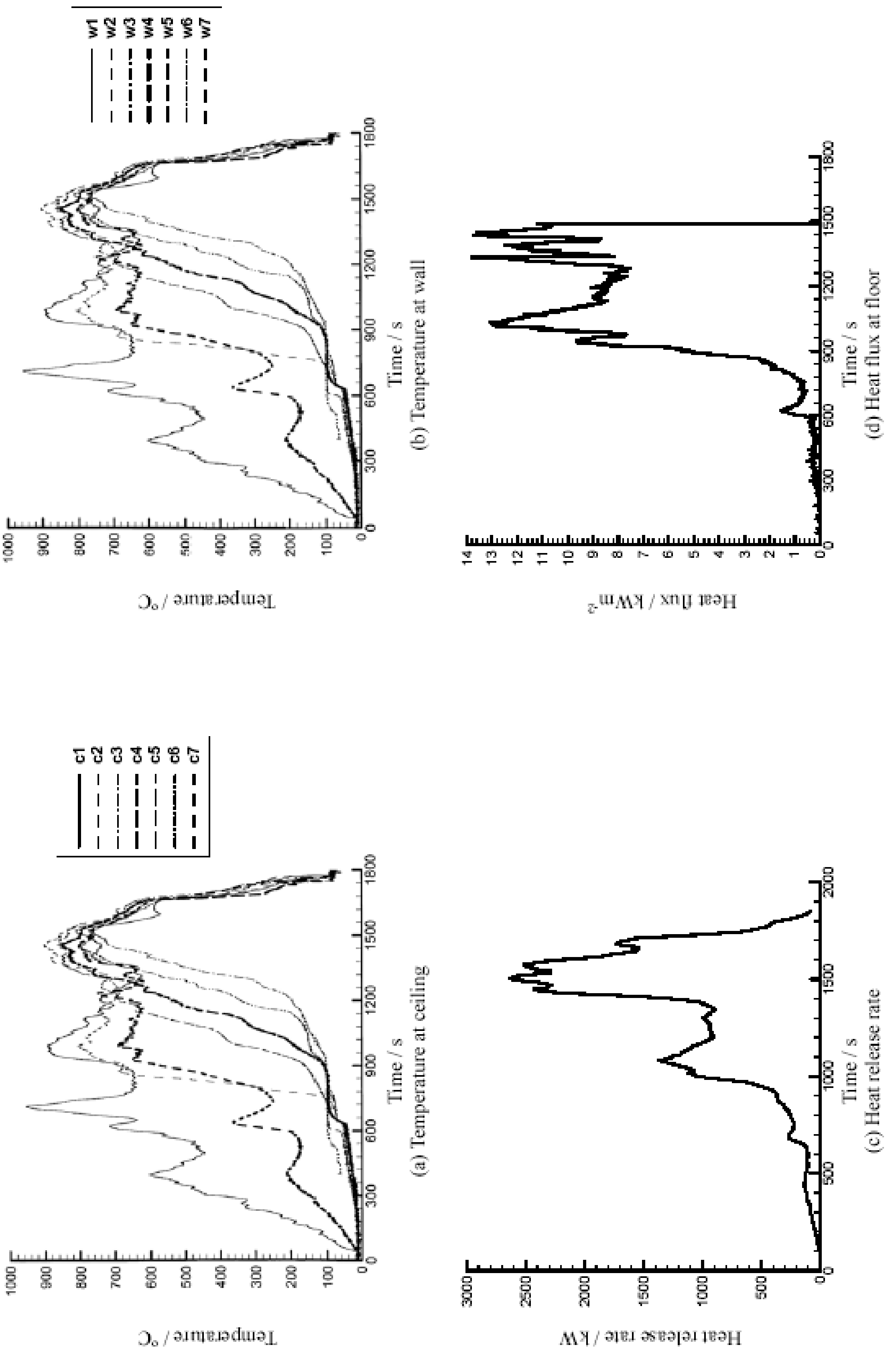


Fig. 11: Testing results for M1f

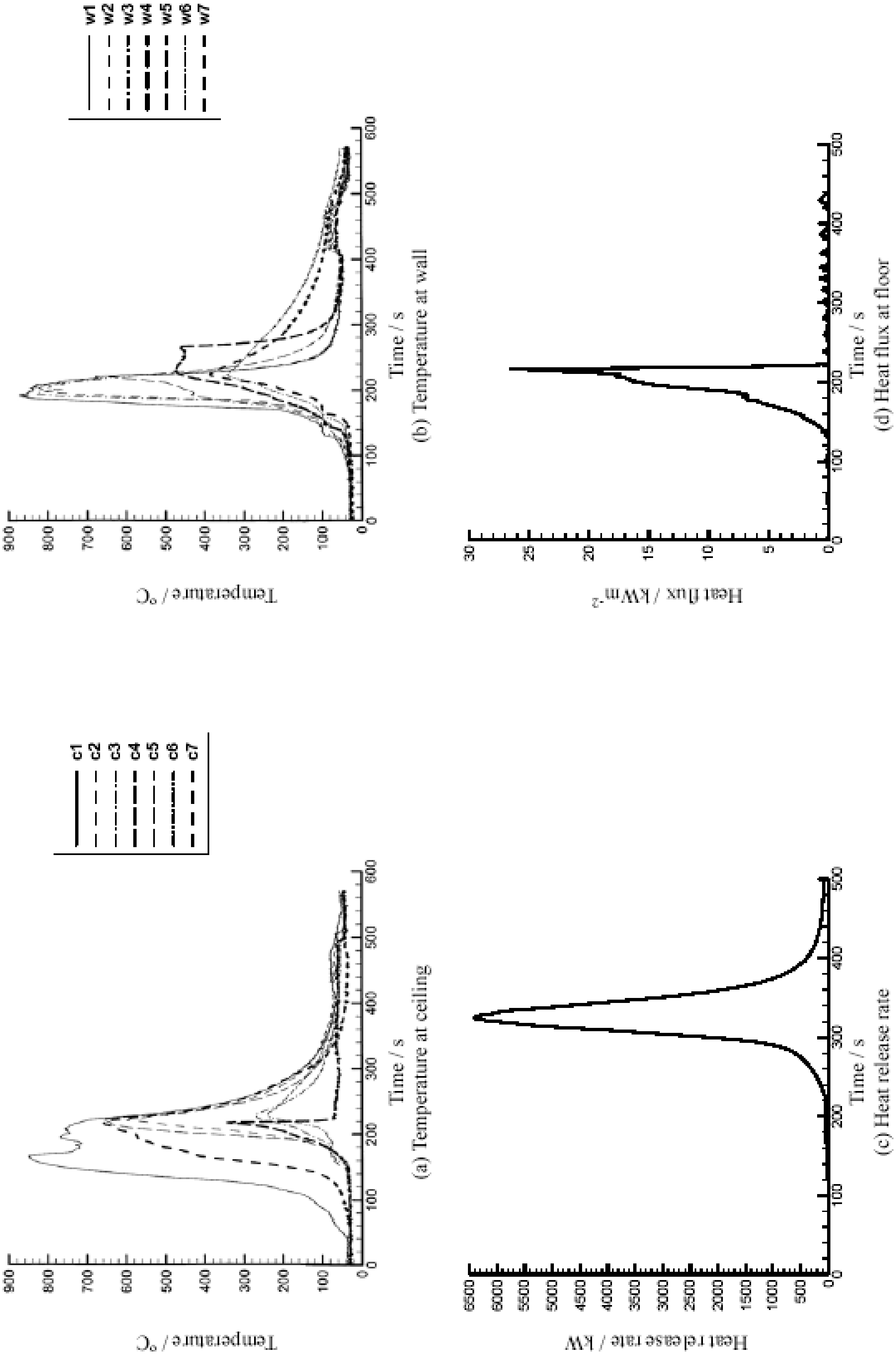


Fig. 12: Testing results for M2

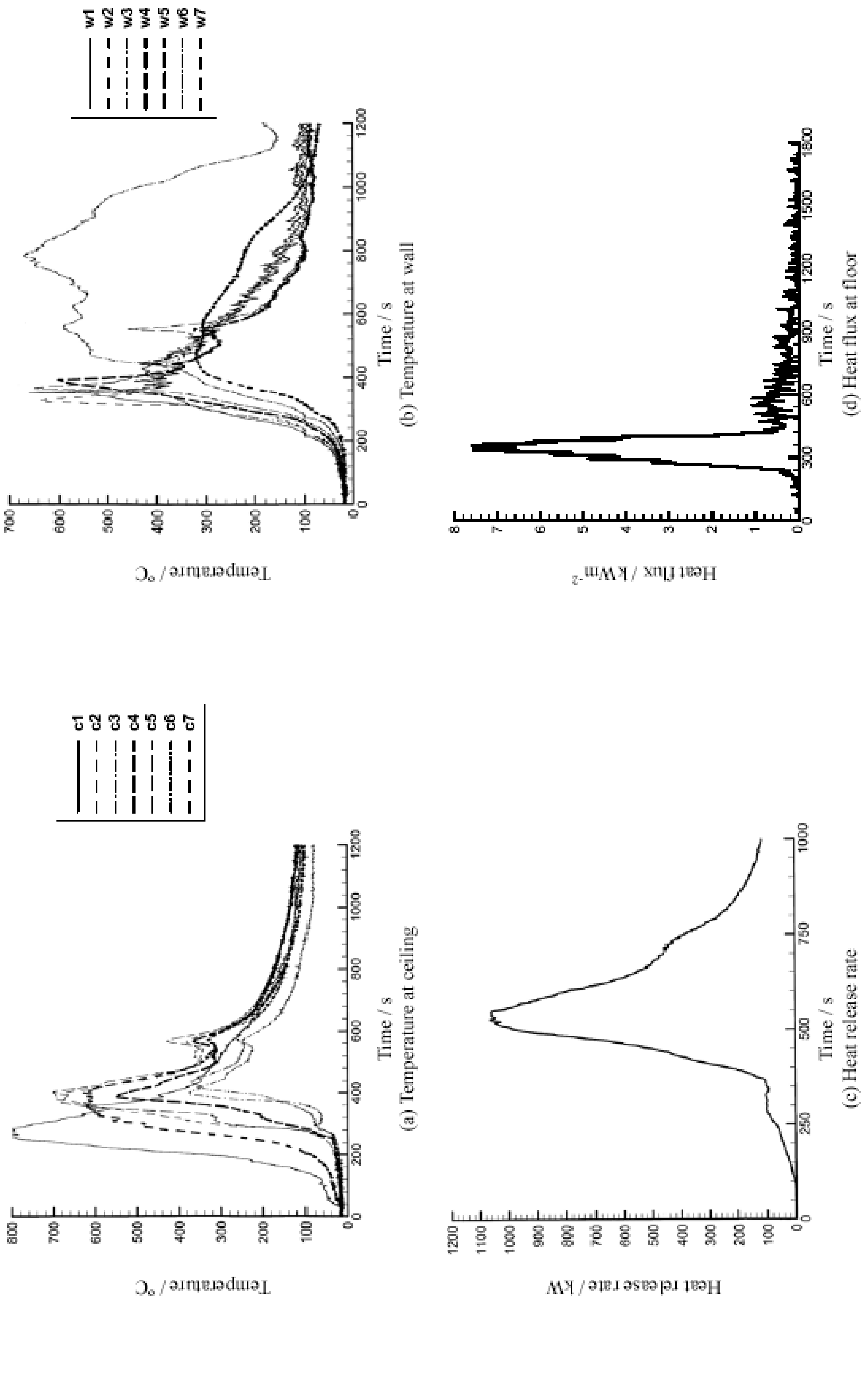


Fig. 13: Testing results for M2a

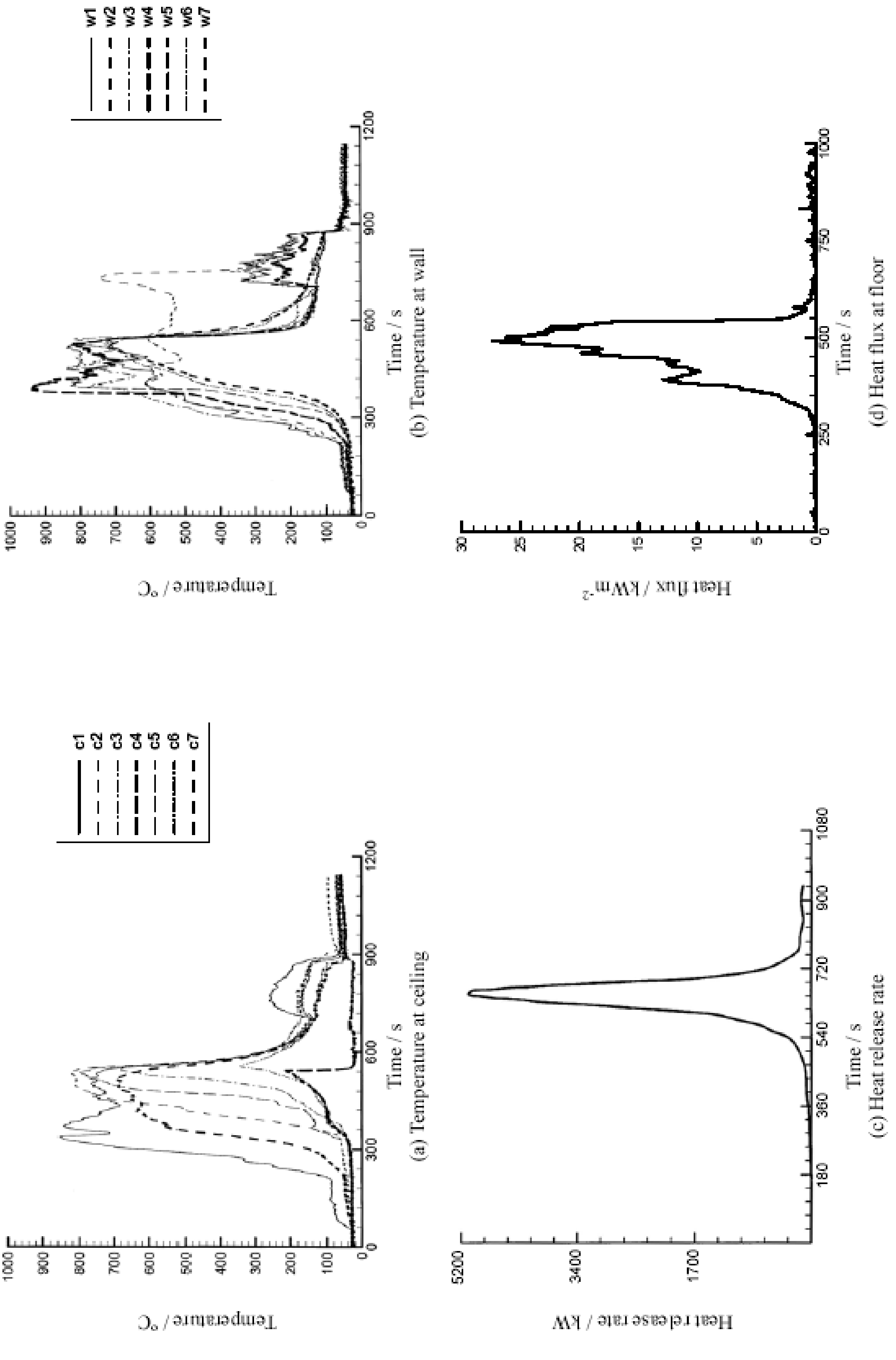


Fig. 14: Testing results for M3

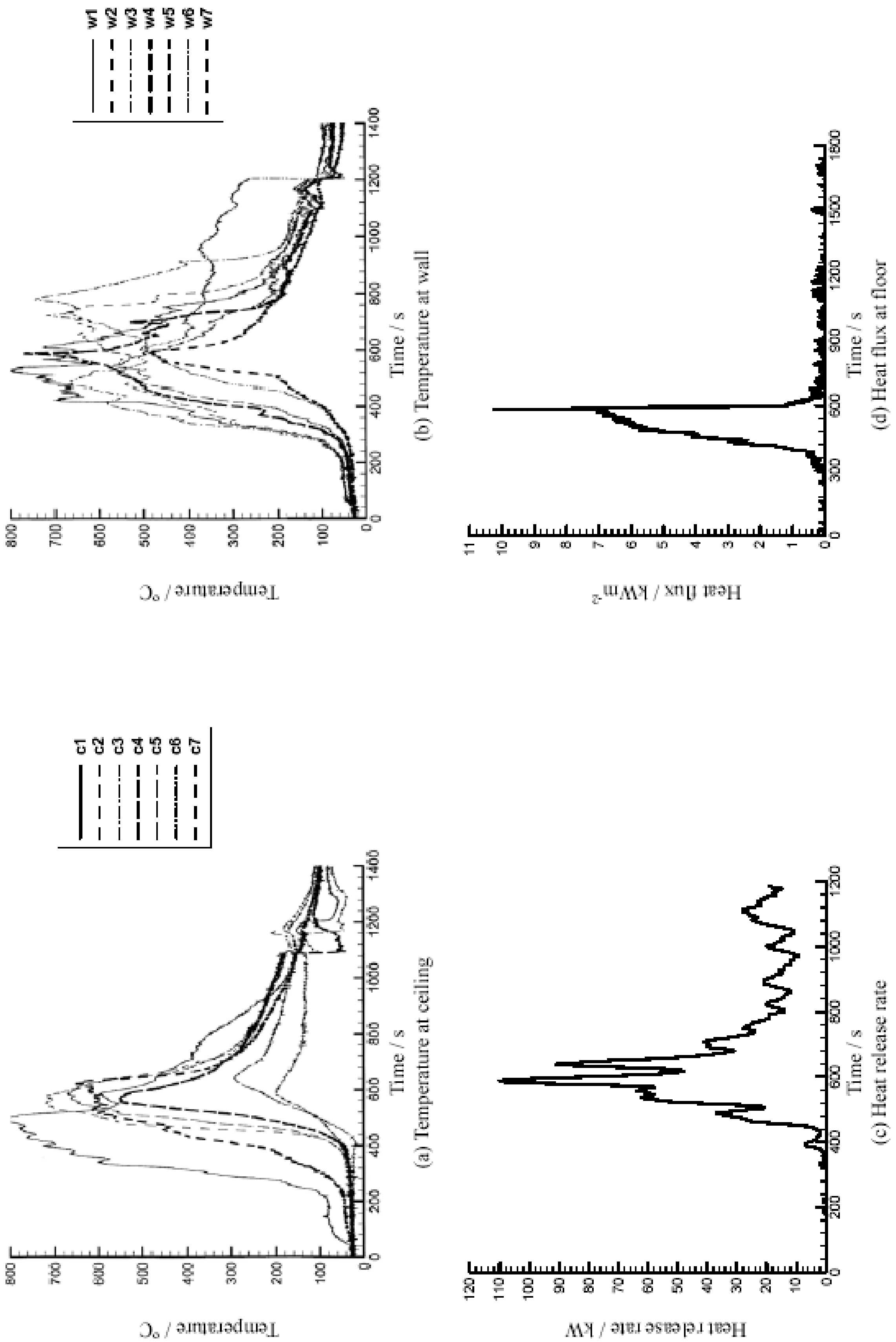


Fig. 15: Testing results for M3a

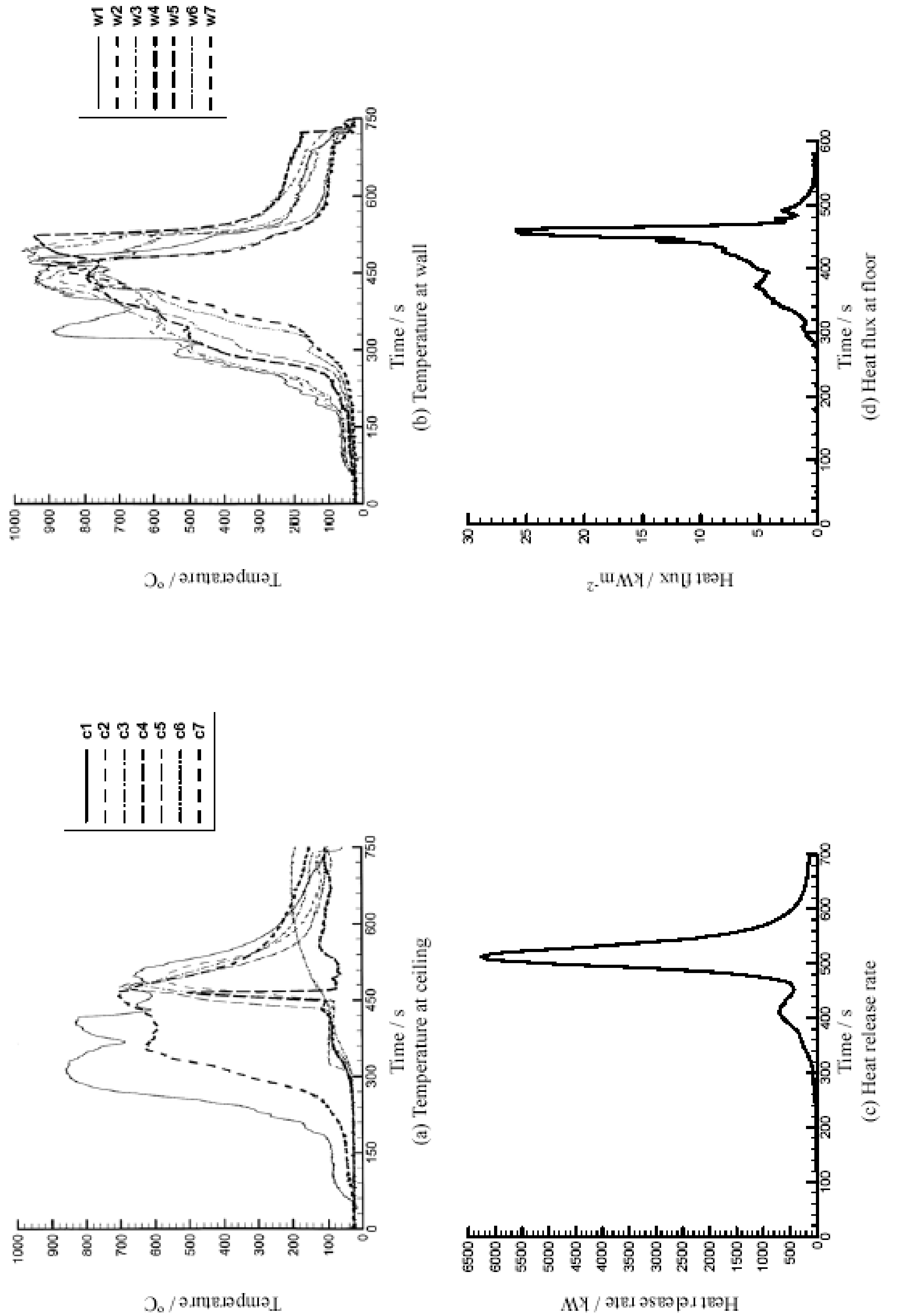


Fig. 16: Testing results for M3b

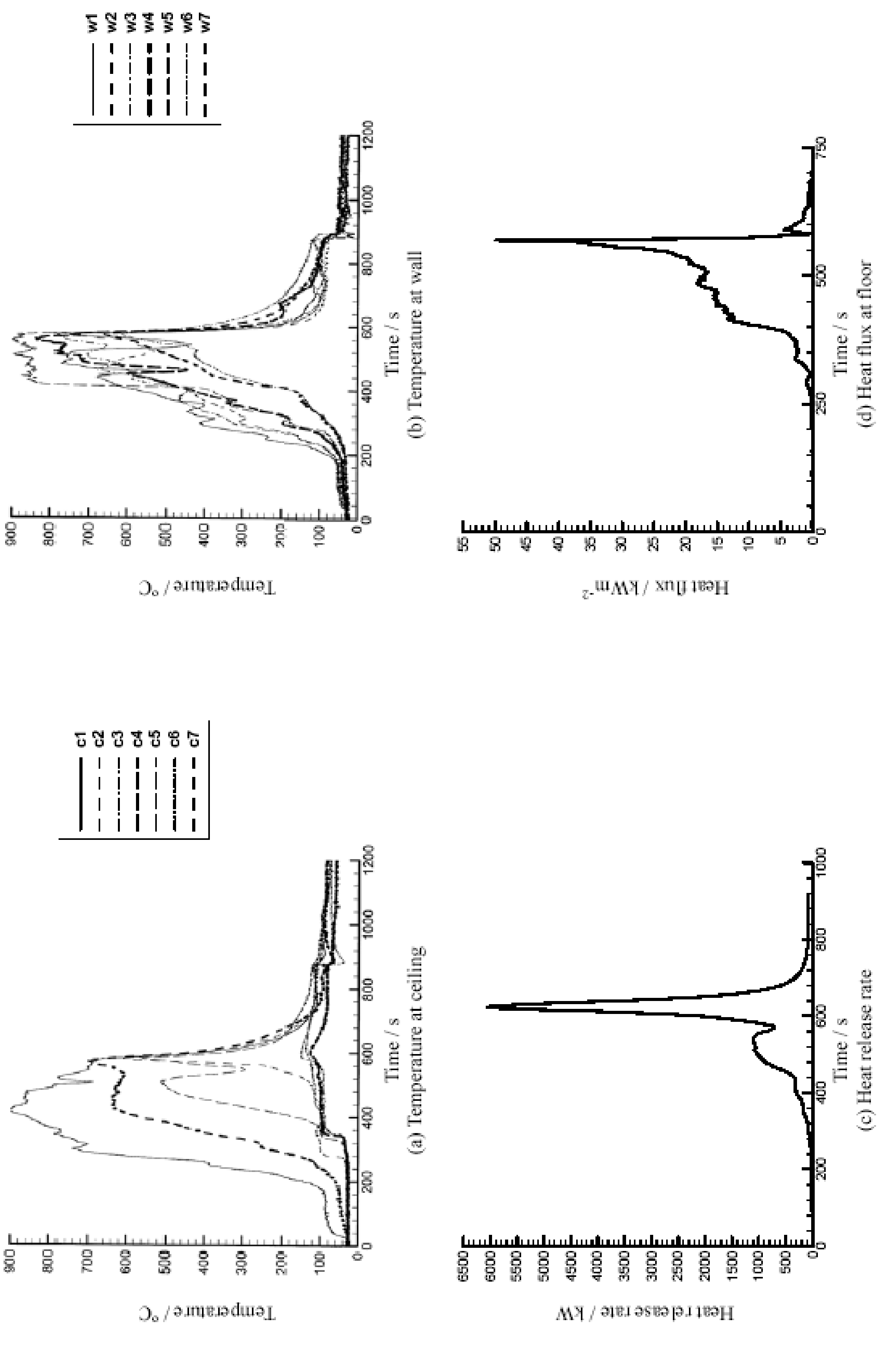


Fig. 17: Testing results for M4

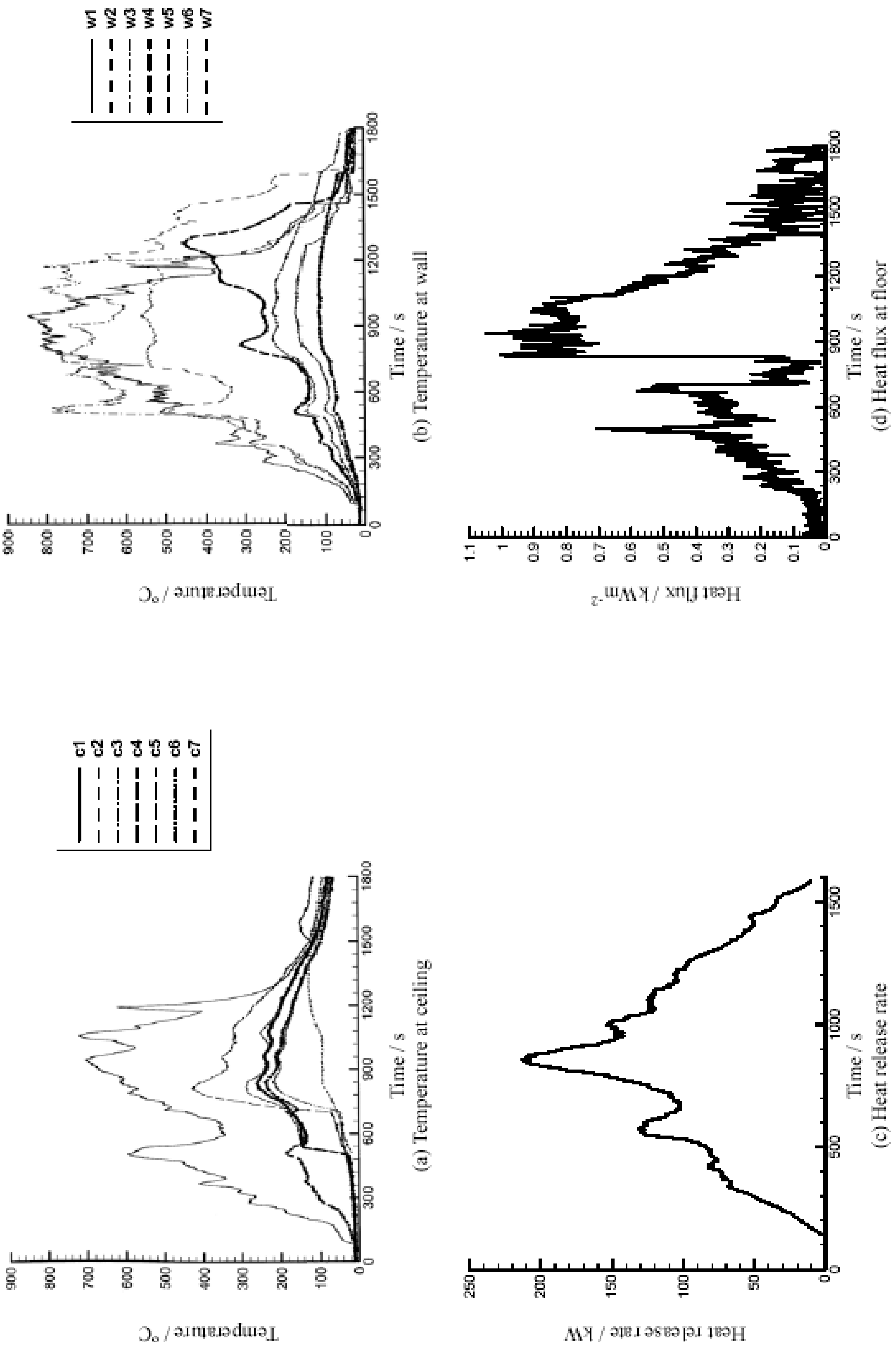


Fig. 18: Testing results for M4a

In testing the bare chipboard in M2, fast ignition occurred at 88 s. A flame layer over ceiling was formed at 163 s with flame emerging the doorway at 178 s. A large fire plume came out at 203 s and 1 MW was reached at 291 s. With fire retardant in M2a, ignition occurred at 136 s. A flame layer over ceiling was formed at 294 s and flame emerged at 338 s. The flame over materials ceased at 1016 s.

For M3, the chipboard was ignited at 207 s. A ceiling flame layer was formed at 384 s and flame emerged at 392 s. A large plume of fire came out at 452 s and heat release rate reached 1 MW at 581 s. When fire retardant was applied in M3a, ignition occurred at 210 s. A ceiling flame layer was formed at 382 s and flame emerged at 530 s. The ceiling panel was burnt out at 610 s and flame over materials extinguished at 835 s. The test was terminated at 20 minutes. Except those wall materials close to the ignition source and the ceiling-wall interface, other parts of the wall materials were not consumed in burning. In M3b, ignition was recorded at 160 s. A flame layer over ceiling was formed at 350 s and flame emerged the doorway. A large fire plume emerged at 417 s and 1 MW was reached at 477 s.

In M4, the materials behind the burner were ignited at 155 s. A flame layer was formed over the ceiling at 328 s. Flame emerged the doorway at 401 s and a large plume came out at 435 s. Heat release rate reached 1 MW at 498 s. There was only surface burning over the chipboard and the materials were not totally consumed in burning. In M4a, ignition of the wall surfaces was recorded at 215 s. The ceiling above the ignition source was ignited at 405 s. The ceiling panels fell off at 432 s and at 706 s which greatly affected the flame spread. The test was terminated at 20 minutes.

5. DISCUSSION

For the set M1, the testing on bare chipboard (M1), chipboards with fiberglass (M1b), paint (M1c) and wallpaper (M1e) showed similar results. The time to ignition and flame spread phenomenon from the ignition source to the walls and ceiling are very close. In tests M1c and M1e, the lateral flame spread from the burning region above the ignition source was comparatively faster than in the case of bare chipboard, though still only limited burning was seen. The flame spread in M1e was observed to be slightly faster, which might due to the easier ignition and faster flame spread properties of the wallpaper and glue between the wallpaper and the chipboard. However, in comparing the TTF, no significant difference is observed from the tests, M1, M1c and M1e. The TTF was the shortest in the testing of bare chipboard at 351 s. There was a rapid increase in heat release rate after ignition of the wall and ceiling materials. In other combinations, there was a small peak in heat release rate and then followed by a higher peak at about 1 MW at flashover. The TTF was 602 s for chipboard with paint (M1c) and 579 s for chipboard with wallpaper (M1e). This indicates that those finishing materials might enhance a faster spread of flame, but not necessarily give a shorter time to flashover. More full-scale burning tests should be carried out for further verification. The TTF was the longest in testing of chipboard with fiberglass backing, M1b. The flame spread rate was observed to be comparatively slower. The non-combustible fiberglass might behave as a heat sink behind the chipboard, causing more heat loss from the surface of the chipboard and thus slower surface flame spread.

In testing chipboard with fire retardant (M1a), chipboard and paint with fire retardant (M1d), and chipboard and wallpaper with fire retardant (M1f), it was found that the application of fire retardant was the most effective in bare chipboard. The flame spread rate was much slower. Only very limited burning above the ignition source was observed. Forming of char over the wall surfaces prevented the fire from spreading to other regions. The heat release rate was limited to less than 100 kW. No flashover was recorded throughout the total testing period of 20 minutes. The application of fire retardant on wallpaper was still good where the flame spread rate was reduced. The trend in heat release rate was similar with a small peak and then a high peak leading to flashover. However, the TTF was much lengthened. The effect of the fire retardant over painted chipboard was significant. A high heat release rate of more than 800 kW was released at 500 s for the painted chipboard and then over 1 MW at flashover at 650 s. With the fire retardant coating, the first peak was much reduced to 300 kW and the TTF was 800 s.

In the testing of 2.5 mm chipboard (M2), the TTF was the shortest among testing of all other materials, i.e. M1, M2, M3 and M4. When fire retardant was applied (M2a), lots of dark smoke was released. The heat release rate was kept at low level, about 100 kW for 350 s and then went to flashover. The TTF was increased by about 200 s. The flaming ceiling fell on the ground during the test, causing another fire source on the floor and thus flame spread over the left sidewall away from the ignition source. Proper mounting method should be taken in future tests.

The 4.5 mm chipboard (M3) was tested with fire retardant (M3a) and with fiberglass backing (M3b).

The heat release rate trend in M3b was similar to M1b, both with fiberglass backing. A smaller peak was reached earlier in the test with a peak heat release rate over 1 MW at flashover. However, in M3b, flame spread more rapidly than with bare chipboard only. This is contradicting to the cases on M1 and M1b. Very limited burning was seen in test M3a. There was only little burning over the left sidewall next to the flaming region of the ignition source and char was formed on the rear wall. The heat release rate was kept below 100 kW and the test was terminated after 20 minutes when there was flame from the ignition source only.

In testing of 11 mm chipboard (M4), the flame spread phenomenon was observed to be the same as in the testing of M1, M2 and M3. Upon ignition of the wall behind the ignition source, flame spread upward over the interface of the rear wall and left sidewall. When the flame tip reached the ceiling, flame spread along the wall-ceiling jet region and laterally along the interface between the sidewalls and the ceiling. When it was close to flashover, flame spread downward from the wall-ceiling interface and a limited lateral flame spread from the interface of the left sidewall and rear wall, and flaming region of the ignition source were observed. Prior to flashover, all materials were ignited and the room was filled with fire. With the application of fire retardant (M4a), longer time was required for igniting the material behind the ignition source. Char was formed on the surface above the ignition source after a period of limited burning. The heat release rate was limited to less than 200 kW. There was no further burning over the surface of materials and the test was terminated at 20 minutes. The fire retardant was very effective in reducing flame spread over wood surfaces.

In comparing the bare chipboards of different thickness, the TTF are 291 s for M2 (2.5 mm chipboard), 581 s for M3 (4 mm chipboard), 564 s for M1 (8 mm chipboard) and 498 mm for M4 (11 mm chipboard). The TTF was found to be not proportional to the material thickness. That was also affected by the different configurations of the materials.

6. CONCLUSION

As surveyed, timber materials are commonly used for internal partitioning in Hong Kong, especially for those buildings erected years ago before gypsum plastic boards are popular [5]. Currently, there is no restriction on the use of finishing materials such as paint, wallpaper and acoustic insulation on those partitions in the local fire codes. No statistics or studies have been carried out to assess the flame spreading hazard associated with those partitions. Application of fire retardants [9] might help to reduce the fire hazard but their effects are unknown and will be reported later.

Fourteen full-scale burning tests based on the ISO 9705 [8] were carried out to assess the flame spreading over four types of chipboards of different thickness, paint, wallpaper and fiberglass. A fire retardant coating designed for application on wood surface was selected for investigating the effectiveness of protection. A 0.26 m gasoline pool fire with heat output of about 45 kW was used to simulate an accidental fire in a room, starting from the early stage to flashover. Materials were lined on the surfaces of the room and evaluated for 20 minutes or until flashover, whichever occurred first. The heat release rate, time to flashover, surface temperature of materials, upper layer gas temperature and floor heat flux were recorded. Flame spreading and burning behaviours were observed.

In comparing the flame spreading over the same material of bare surface, with paint or wallpaper, it was observed that there might be more rapid flame spread over the finishing materials due to their combustibility. However, it does not necessarily shorten the time to flashover. It might due to the comparatively little heat release of those finishing materials to the heat output from the chipboards. More tests should be carried out on other substrates, especially those which are easy to ignite. From the results, it took about 2.5 minutes for the bare chipboard to ignite. For other materials, the burning surfacing materials might ignite the substrate in a shorter time. That would cause a high heat release and shorter time to flashover.

The flame spreading behaviours were observed to be similar. Upward flame spread starting from the vicinity of the ignition source dominated, followed by rapid radial spread over the ceiling. Flashover occurred shortly after a flame layer was formed over the ceiling. Downward and lateral spread was observed only at the onset of flashover or after flashover. With fiberglass insulation, a slower spread was observed due to heat loss to the backing which behaved as a heat sink. The fire retardant coating was found to be effective in slowering the flame spread. Its char-forming mechanism helped to limit the burning area which kept the heat output at a low level. However, that might produce more smoke and that raises other concerns on the toxic hazard and psychological effect to occupants.

This is the first step in the study of flame spreading assessment over timber partition materials. More tests will be carried out on different products, finishing materials and fire retardants and the results will be reported later, though there were suggestions [10] in using the ISO 9705 for assessing flame spreading over partition materials.

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