FIRE SAFETY AND TECHNOLOGY RESEARCH CENTRE FOR LARGE SPACE

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ABSTRACT

A Fire Safety and Technology Research Centre for Large Space was established by the University of Science and Technology of China (USTC) and The Hong Kong Polytechnic University (PolyU) in 1997. That was housed in the campus of USTC in Hefei, Anhui, China. Objectives of setting up such a full-scale burning facility are to study atrium fires and smoke movement, evaluate performance of existing appropriate fire protection systems and develop new technology for fire protection in atrium. The facility will be used for teaching, research and high-level consultancy for serving the community. What have been carried out in the past 5 years will be reported briefly in this paper.

1. BACKGROUND

Many fire accidents were reported in China with a significant part related to large spaces or atriums [e.g. 1]. Typical examples are exhibition centres, sports stadiums, large garages, godowns, atriums and shopping malls. Characteristics of fires in those large spaces are:

- Fire and smoke can spread easily and rapidly;
- Difficult to detect and suppress the fire at an early stage;
- Difficult to evacuate the building.

At present, there is inadequate understanding of atrium fire characteristics; and a lack of full-scale experimental data to support the fire codes related to large space. Therefore, further investigations are necessary.

Studying large space fires is an important fire research topic in the international arena. After many discussions and exchange of views, research workers at the University of Science and Technology of China (USTC) and The Hong Kong Polytechnic University (PolyU) agreed to have collaborative research on large space fires. A full-scale burning facility [2,3] was then constructed for carrying out full-scale burning tests in 1997. What have been done in the past 5 years will be reported in this paper.

2. RESEARCH COLLABORATION

Since 1992, both leaders and staff of USTC and PolyU have contacted many times on the collaboration on fire research. In December 1994 and March 1995, research workers of both universities visited each other and came up with an agreement on studying atrium fires. In March 1996, Presidents of both universities signed the agreement. Construction of the PolyU/USTC Atrium started in the same year. Both parties worked closely on the design and construction of this full-scale burning facility, the PolyU/USTC Atrium.

Objectives [e.g. 2,3] of setting up the PolyU/USTC Atrium are:

- Teaching: to upgrade teaching quality through high-level experimental studies.
- Research: to provide a basic facility for fire safety science and engineering research; and to carry out large-scale fire tests [4] on smoke filling, exhaust, natural ventilation, fire detection, and automatic sprinkler system.
- Services to community: to provide reliable design data and consultancy services to the construction industry and related fire authorities; and to raise public awareness on fire safety.

For the management of PolyU/USTC Atrium, a Monitoring Committee is set up and chaired by Presidents of both universities. The Management Committee is chaired by the principal investigators of USTC and PolyU. Sufficient number of research personnel from both universities will be kept when funding is adequate.

3. STAGES OF DEVELOPMENT

There were two stages of development:

- Stage 1 - Design and Construction of PolyU/USTC Atrium

In stage 1 construction, about HK$2.3 million was transferred from the PolyU to USTC. An equivalent amount was also invested by USTC for the construction of the facility. In June 1997 before the smooth reunification of Hong Kong to China, the main hall of the PolyU/USTC Atrium (shown in Fig. 1) was completed.

The atrium is located at the State Key Laboratory of Fire Science (SKLFS) of USTC. The overall size of the atrium is 30.6 m x 18.4 m x 30.6 m, with internal dimensions 22.4 m x 12.0 m x 27.0 m. There are six corridors on the external wall, 14 windows of size 1.4 m x 1.1 m on each floor, and eight horizontal vents each of size 1.2 m x 1.2 m on the ceiling for natural smoke exhaust or installing ventilation fans. A water system is installed for studying fire suppression by sprinklers. Studies on natural smoke-filling can be carried out.

- Stage 2 - Construction of Large Space Fire Integrated Test Platform

There were encouragement and financial support to the collaborative research from the Chinese Academy of Sciences. Both parties decided to expand their collaboration by building a Research Centre for Thermal Safety Engineering and Technology. USTC gave more support to the research centre by combining the collaboration with the "211 Project" of China. A new laboratory building was built on the south of the atrium. A large space fire integrated test platform was agreed to be built for carrying out research on thermal safety. While visiting USTC for celebrating the 40th anniversary in September 1998, President of PolyU inspected the fire laboratory and the research progress on large space fires. Another HK$2.5 million was invested by PolyU in stage 2 construction, and an equivalent amount was also invested from USTC. Full-scale experiments on fire growth, smoke control, fire detection, fire suppression with sprinklers, etc. can be carried out in the laboratory. Actually, research was being carried out actively in parallel with the construction of the laboratory. Facilities of the laboratory were basically completed in three years' time. The laboratory was appraised by experts in April 2001.

Equipments installed include:

- Smoke control system
  - Experiment on mechanical smoke extraction and natural smoke extraction can be carried out
- Sprinkler system
  - Sprinkler head for discharging large water droplets
  - Fire nozzle with auto-positioning function
- Automatic fire detection system
  - Image-type fire detection system
  - Infrared fire detection system
- Data acquisition system
  - Centralized data acquisition system can complete real-time acquisition of 128 route mV voltage signals (temperature, weight, radiative heat flux, etc.)
  - Distributed data acquisition system has four front acquisition modules, each with 28 routes. With these network communication modules, data can be transmitted from the sensors to the computer rapidly through the ports.

Fig. 1: PolyU/USTC Atrium

4. PROGRESS

The following is a list on the achievements:

- Smoke movement and control in a large space

  A self-developed model of natural smoke-filling for an axisymmetric plume in an atrium was reported [5-11]. The smoke layer interface height Z was predicted.

  (i) Steady burning fire of heat release rate Q:

$$Z = [0.12(\frac{Q\ g}{\rho_0 C_p T_0 A^3})^{1/3} t + H^{-2/3}]^{-3/2} \quad (1)$$

(ii) t^2-fire with Q given by:

$$Q = \alpha t^2 \quad (2)$$

$$Z = [0.075(\frac{ag}{\rho_0 C_p T_0 A^3})^{1/3} t^{5/3} + H^{-2/3}]^{-3/2} \quad (3)$$

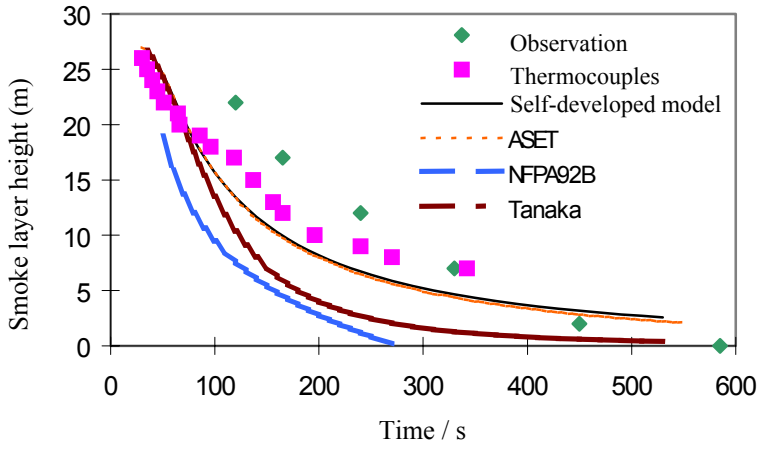
(iii) t^2-fire with a cut-off value Q:

$$Q = \begin{cases} \alpha t^2 & t \le t_s \\ Q_s & t > t_s \end{cases} \quad (4)$$

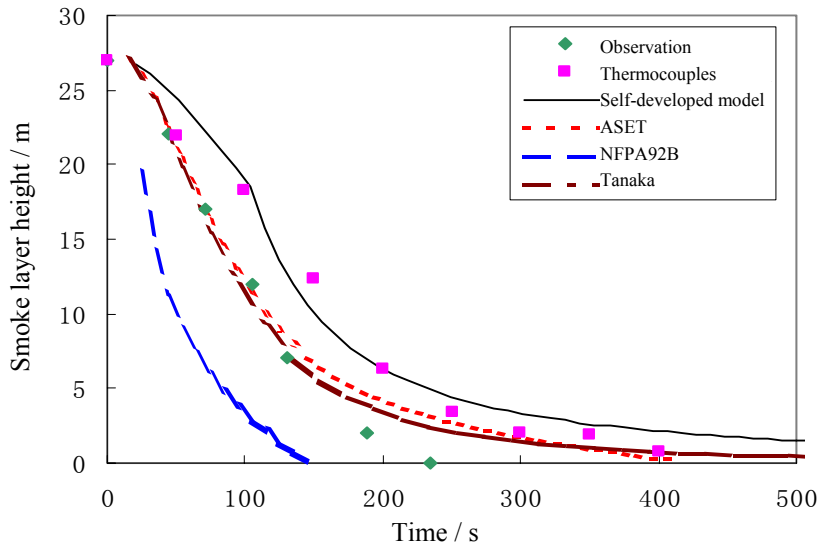
$$Z = \begin{cases} [0.075(\frac{ag}{\rho_0 C_p T_0 A^3})^{1/3} t^{5/3} + H^{-2/3}]^{-3/2} & t \le t_s \\ [0.12(\frac{Q\ g}{\rho_0 C_p T_0 A^3})^{1/3} (t - t_s) + Z_s^{-2/3}]^{-3/2} & t > t_s \end{cases} \quad (5)$$

Typical results are shown in Fig. 2a and b.

- Experimental studies on natural smoke extraction [12] in an atrium, with typical results shown in Fig. 3.
- Experimental studies on mechanical smoke extraction in an atrium [13], with typical results shown in Fig. 4.

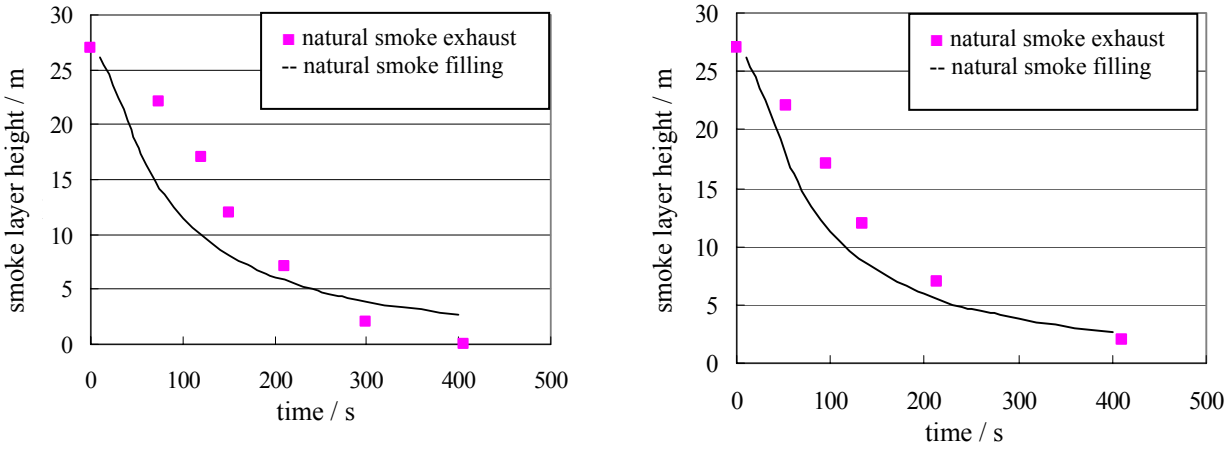


(a) 400 kW pool fire



(b) 5 MW pool fire

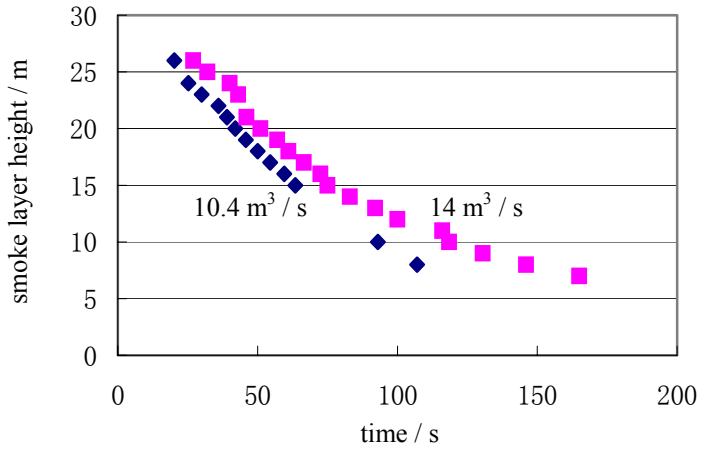
Fig. 2: Smoke layer height predicted



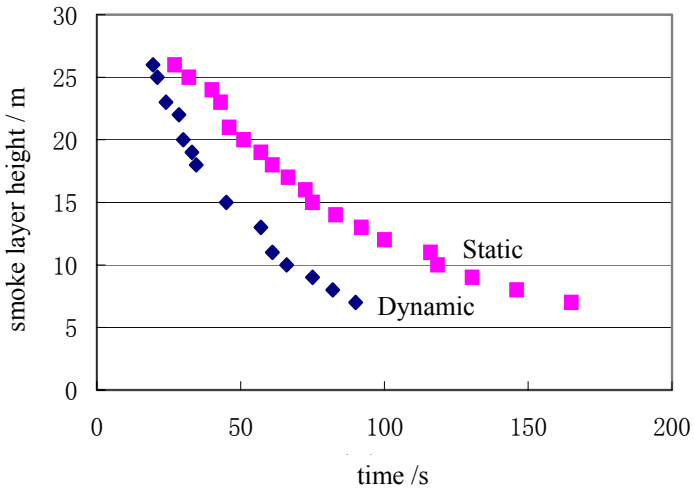
(a) 4 ceiling vents

(b) 8 ceiling vents

Fig. 3: Natural smoke exhaust for a 1.2 MW pool fire



(a) Different extraction rates



(b) Comparison between static and dynamic smoke exhaust

Fig. 4: Typical results on dynamic smoke exhaust

- Studies on operation time of natural vents [12] in an atrium fire.

  Smoke movement at the ceiling vents is driven by both buoyancy and pressure difference. When the smoke layer thickness is thinner than a certain value, bi-directional flow of smoke flowing out and air flowing in was observed at the natural vent. However, uni-directional flow will be found when the smoke layer is thick enough. The critical pressure difference leading to uni-directional flow has to be determined.

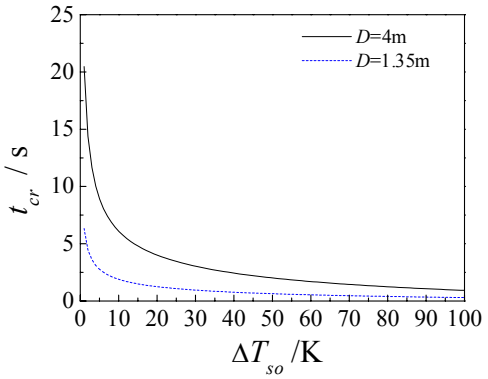
  During a fire, the pressure difference at the vent will vary with the fire growth. The optimum time for opening the natural vents is at the time to reach the critical pressure difference. Typical results are shown in Fig. 5.

- Studies on the effectiveness of mechanical smoke extraction with different positions of air inlets were carried out. Experimental results are compared with the prediction by Computational Fluid Dynamics through the Fire Dynamics Simulator (FDS) with typical results shown in Fig. 6 and Fig. 7.

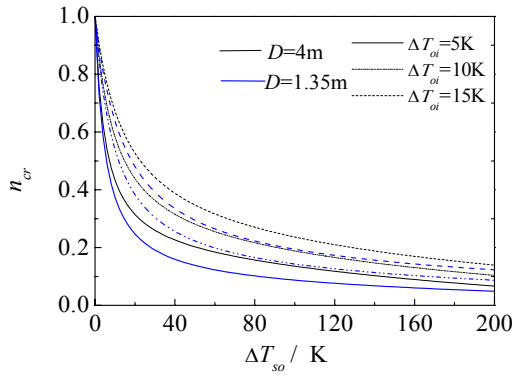
- Studies on the effect of the position of air inlets on the fire source under mechanical smoke exhaust. Typical results on the pool fire are shown in Fig. 8.

- Experimental studies on characteristics of cabin fires in large space.

  Retail shops in public buildings with large space would have relatively high fire load. Examples are kiosks selling snacks or newspapers. If a shop is on fire, heat and smoke will spread rapidly into the atrium as in Fig. 9. Therefore, it is important to study the fire characteristics in a retail shop and its effect on the atrium. A small shop of size 4 m × 3 m × 3 m has been built inside the atrium for this purpose.

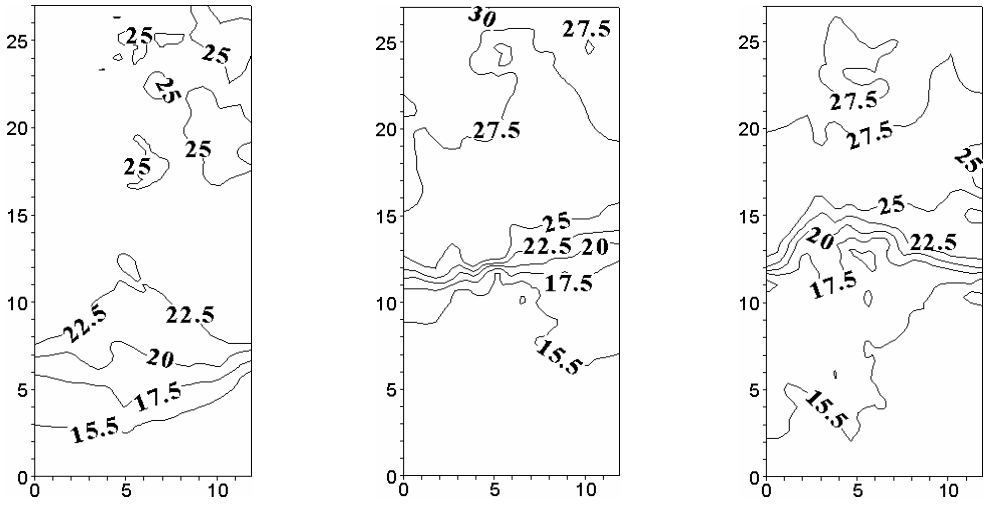


(a) Temperature difference between indoor lower air layer and outdoor ambient air is zero



(b) Temperature difference between indoor lower air layer and outdoor ambient air is not zero

Fig. 5: Typical results on vent operation time



(a) 1st floor (b) 2nd floor (c) 3rd floor

Fig. 6: Temperature distribution predicted by FDS-2 with different positions of air inlets

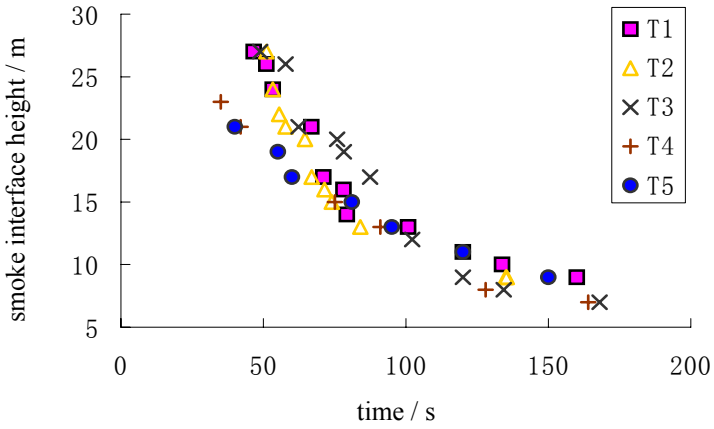


Fig. 7: Smoke layer interface height under different positions and areas of air inlets

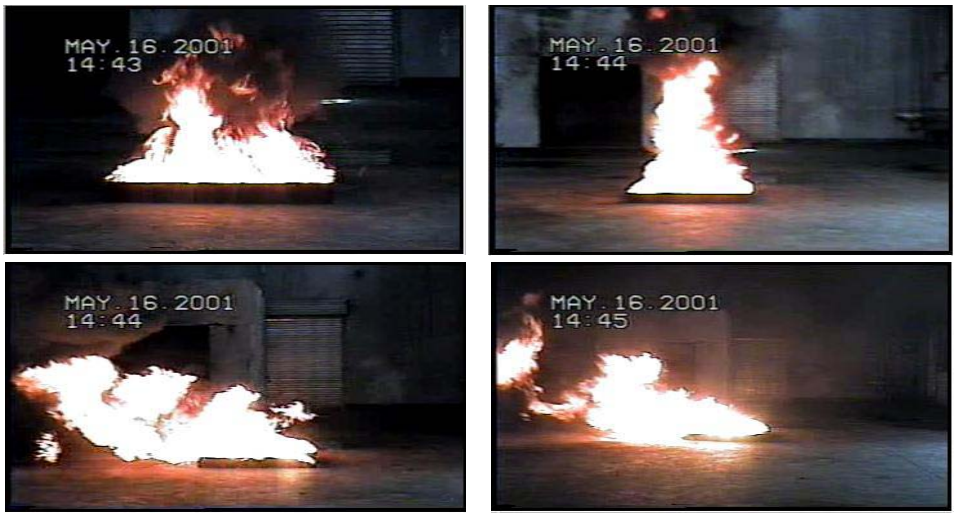


Fig. 8: Pool fire

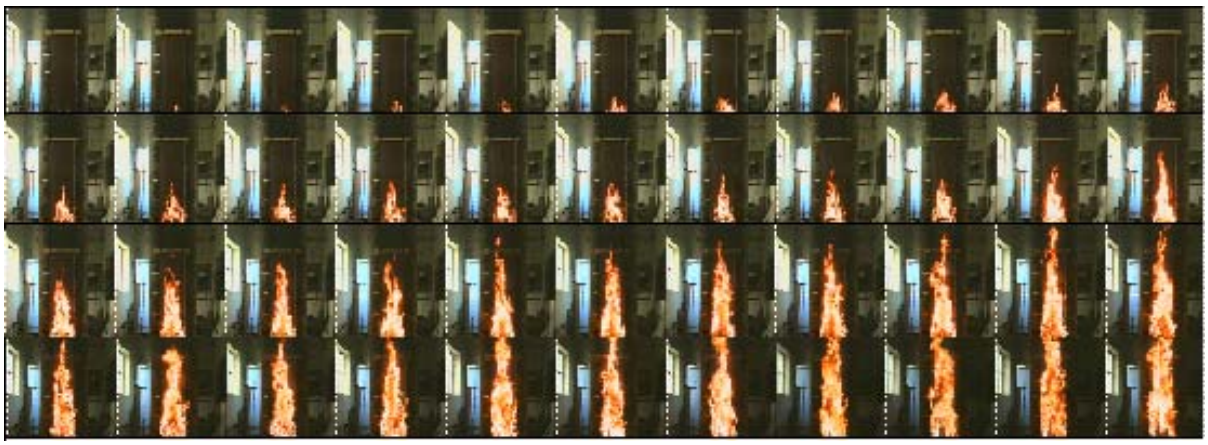


Fig. 9: Development of fire spread along vertical direction, photographs taken at intervals of 0.5 s

5. ACHIEVEMENTS AND TECHNOLOGY TRANSFER

In April 2001, achievements of Large Space Fire Integrated Test Platform were appraised by the Science and Technology Bureau of Anhui Province, and a committee led by an Academician of Chinese Academy of Engineering. In May 2001, achievements on fire characteristics of large space public buildings were appraised by the Science and Technology Group of Anhui Province.

The Large Space Fire Integrated Test Platform provides the basis for development of new technology, for example, research on flame detection by images was awarded the Anhui Province Science and Technology Advancement First Prize and National Science and Technology Advancement Second Prize. The technology was applied in places including the Great Hall of the People, China Central Television and Capital Gymnasium. Large amount of valuable experimental data were provided for revision of the fire codes related to large space.

External funding (apart from PolyU and USTC funded projects) related to atrium fires are:

- 2 sub-projects in The Key Technologies Research and Development Programme of Ninth Five-year Plan of China: 1.32 million RMB
- "211 Project" of China: 0.3 million RMB
- Key project of National Natural Science Foundation of China: 0.45 million RMB
- National Key Basic Research Special Funds of China: 0.76 million RMB
- Construction project of Chinese Academy of Sciences: 0.2 million RMB
- 1 sub-project in The Key Technologies Research and Development Programme of Tenth Five-year Plan of China: 0.7 million RMB
- Research Grants Council (RGC) of Hong Kong: HK$1.8 million

6. ON-GOING ACTIVITIES

On-going research activities are:

- Flashover inside a compartment
  - Variation of temperature and radiative heat flux during the small compartment fire
  - Criteria for flashover
- Spill flow of compartment fire
  - Three-part plume model of outflow stage, transition stage, free axisymmetric plume as in Fig. 10 was developed
  - Effect of smoke control in a small compartment on the atrium
- Characteristics of cabin fire
  - Restricted plume in cabin fire
  - Studies on smoke flow in a cabin
  - Studies on smoke control in a cabin

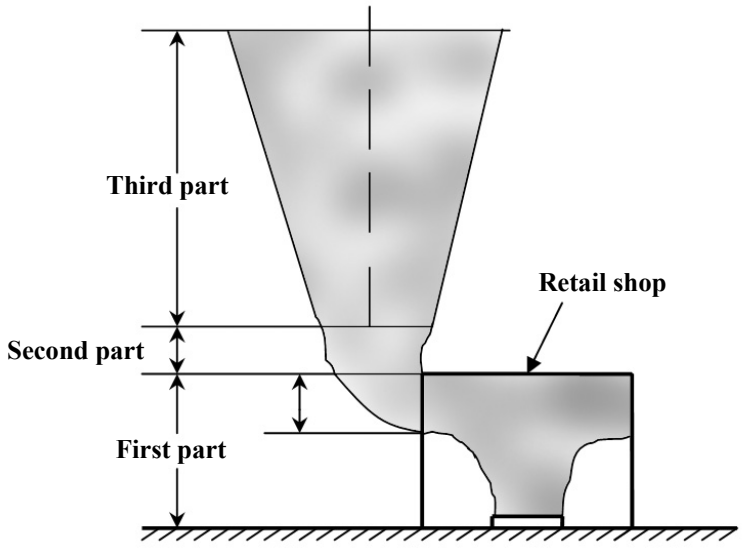


Fig. 10: The three parts of a self-developed plume model

- Development of computing and modelling software

    - Modelling of large space building fires.
      Smoke movement was modelled using the self-developed model and empirical formula to calculate the parameters such as smoke plume and high temperature smoke layer under different fire conditions.

    - Computational and analytical system for smoke movement and control in a large space.
      Variation curves of different parameters such as smoke layer height and temperature can be determined by setting the fire size and modelling dynamically the smoke flow and control in a large space.

    - Fire safety assessment for large space buildings.
      To assess and classify the hazard levels of large space buildings, and to model dynamically the smoke movement inside the atrium.

7. QUALITY TEACHING AND SERVICES TO THE COMMUNITY

It is an important facility for educating the general public on fire safety. Over 5000 persons per year visited the fire laboratory to learn fire safety in the past three years. With this facility, research personnel specialized in fire safety engineering can be trained. Up to now, 5 PhD students, 5 ME students and some undergraduates have completed their theses related to large space building fires. There are another 5 PhD students, several ME students and undergraduates are utilizing the facility for research.

In the past few years, principal investigators of USTC visited PolyU and gave presentations for many times. Staff at USTC also worked at PolyU for short-term appointments and participated in numerous research projects such as studying false alarm in shopping complexes, and water mist fire suppression systems. This gave a good opportunity for young research workers in USTC to learn the updated technology and new problems in fire safety all over the world, falling within the long-term theme of developing China. That should be a social responsibility for all Chinese.

On the other hand, principal investigators and academic staff of PolyU also visited USTC and gave presentations for many times. PhD and MSc students from PolyU also conduct their experimental studies at the PolyU/USTC Atrium for completing their research projects.

An "Education Symposium on Advanced Fire Research" was held from 10 to 15 January, 2003. 7 academic staff, including programme leaders and 30 BEng/MEng in Building Services Engineering students taking the subject "Fire Dynamics", 16 MSc students and 8 PhD students from PolyU; and over 62 academic staff, research and undergraduate students of USTC attended. Final year BEng degree students at PolyU working on fire projects presented their research results in the symposium. All PolyU students had learnt the rapid development of new China, started preparing themselves to serve the country.

8. CONCLUSION

Establishment of this Joint Research Centre for Thermal Safety Engineering and Technology had enhanced closer collaboration between universities in the SAR and Mainland. This is regarded as a right move in promoting the development of Science and Technology in China. Financial support for exchanging research personnel from both parties had been partially funded by the Chinese Academy of Sciences, and by the PolyU President.

Further research on this subject area related to large space building fires will be continued. Both parties will explore more opportunities on key research projects, attempting to feedback the results to serve the country by reducing the fire losses. The scope of collaborative research will be further expanded. This is necessary while implementing performance-based fire safety codes, in the more dense urban areas including 'city groups' in the Mainland. More effort will be paid on technology transfer, safety consultancy and training young staff for serving the community better, since SAR is now part of the country.

ACKNOWLEDGEMENT

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