METHOD OF PREDICTING FIRE LOCATION AND INTENSITY BASED ON CEILING JET TEMPERATURE UNDER UNCONFINED CEILING

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Background

Fires….
in a factory where the floor area exceeds
a thousand square metres or
in a merchandise shop where various goods
are exhibited and stacked

Due to the deterioration of visibility according to
smoke and fixture and furniture, etc,
it is difficult to specify the breaking out position
with the naked eye.

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unexpectedly long period of time would be required
to identify the fire break out point.

A delay in fire detection and access to the fire break out point causes an
expansion of area of damage and expose the fire fighters to more hazardous
conditions

Present automatic fire alarm system
- inform us the area where fire breaks out but we do not know the precise location.
- detects the fire occurrence but it does not inform the status of progress of fire.

If the origin and the intensity of the fire can be specified by analyzing the information obtained from the fire detectors and/or temperature sensors,
and these information be transmitted to fire brigade in real time,
it is possible to localize it without expanding the damage from the origin of fire.

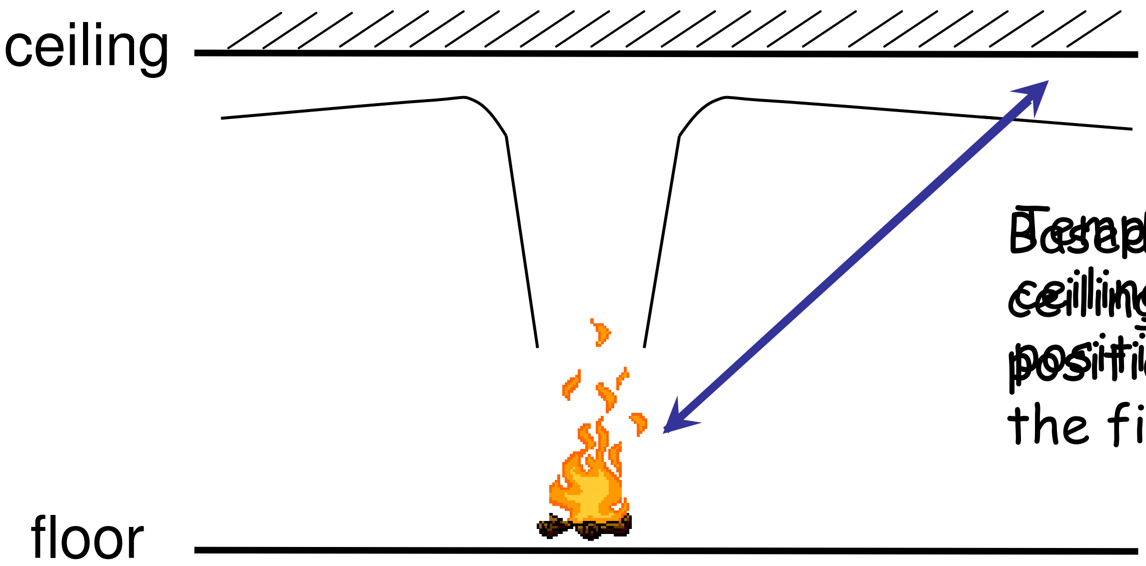
Objective of current work

- to develop a simple method for predicting the fire break out point by using the information transmitted from two or more sensors mounted on an unconfined flat ceiling
- to examine the validity of the proposed method by a comparison with experimental results

Approach to predicting the fire break out point (1/3)

In the conditions

- smooth, flat unconfined horizontal ceiling
- quasi-steady state fire source

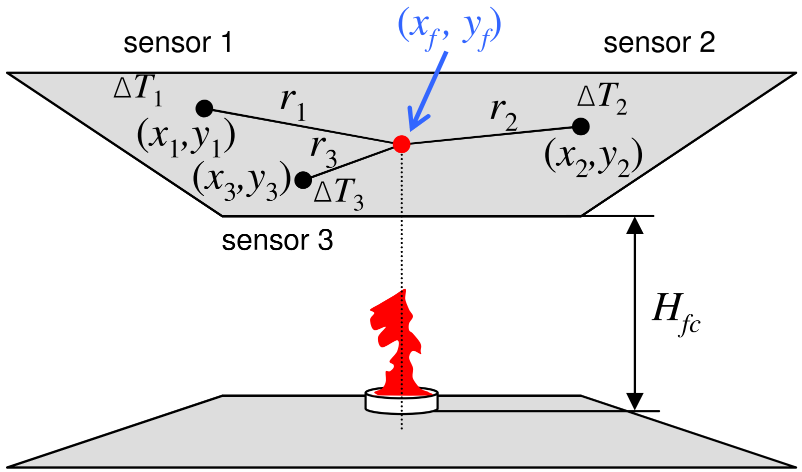


Temperature and velocity of ceiling jet at an arbitrary position are predictable.

Based on the temperature of ceiling jet at arbitrary position, we adversely predict the fire break out point.

The method we applied is the same approach as is used to estimate the intensity of an earthquake and the location of its hypocentre from seismic wave data (P-wave or S-wave).

Approach to predicting the fire break out point (2/3)



The temperature rise of the ceiling jet is expressed as

$$f¢T = k\,\dot{Q}_f^{\ \alpha}\cdot H_{fc}^{\ \beta}\cdot r^{\gamma} \qquad (2)$$

If the coordinates of the fire break out point are assumed to be (x_f, y_f),

$$r_1 = \sqrt{(x_1 - x_f)^2 + (y_1 - y_f)^2} \qquad (3)$$

Substituting Eq.(3) into Eq.(2), we obtain the temperature rise of sensor 1.

$$\Delta T_1 = k\cdot\dot{Q}_f^{\ \alpha}\cdot H_{fc}^{\ \beta}\left\{\sqrt{(x_1 - x_f)^2 + (y_1 - y_f)^2}\right\}^{\gamma} \qquad (4)$$

Similarly, temperature rise of sensor 2 is also expressed as

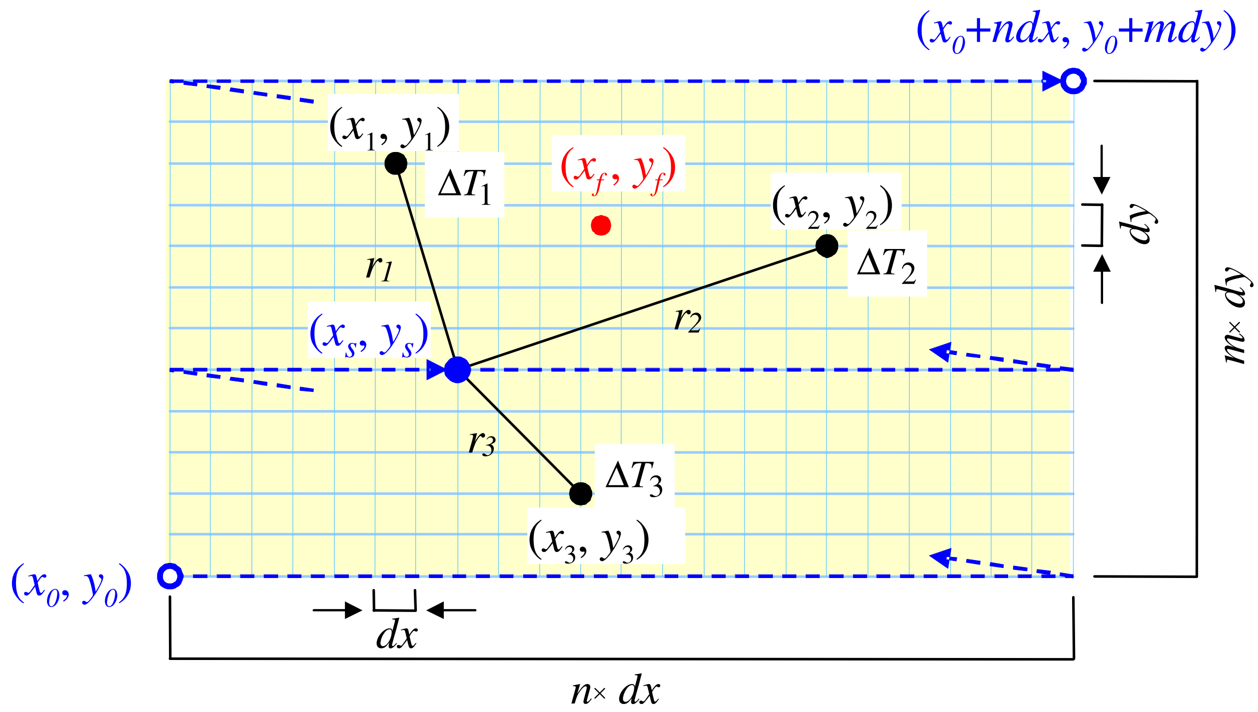
$$\Delta T_2 = k\cdot\dot{Q}_f^{\ \alpha}\cdot H_{fc}^{\ \beta}\left\{\sqrt{(x_2 - x_f)^2 + (y_2 - y_f)^2}\right\}^{\gamma} \qquad (5)$$

To eliminate the parameters such as $\dot{Q}_f$ and H_{fc} Eq.(4) is divided by Eq.(5); then, the ratio of ΔT_1 and ΔT_2 is expressed as a function of the coordinates of the sensors and the fire break out point. Similarly, the ratio of ΔT_2 and ΔT_3 is also expressed,

$$\frac{\Delta T_1}{\Delta T_2} = \left\{\frac{\sqrt{(x_1 - x_f)^2 + (y_1 - y_f)^2}}{\sqrt{(x_2 - x_f)^2 + (y_2 - y_f)^2}}\right\}^{\gamma} \qquad (6)$$

$$\frac{\Delta T_2}{\Delta T_3} = \left\{\frac{\sqrt{(x_2 - x_f)^2 + (y_2 - y_f)^2}}{\sqrt{(x_3 - x_f)^2 + (y_3 - y_f)^2}}\right\}^{\gamma} \qquad (7)$$

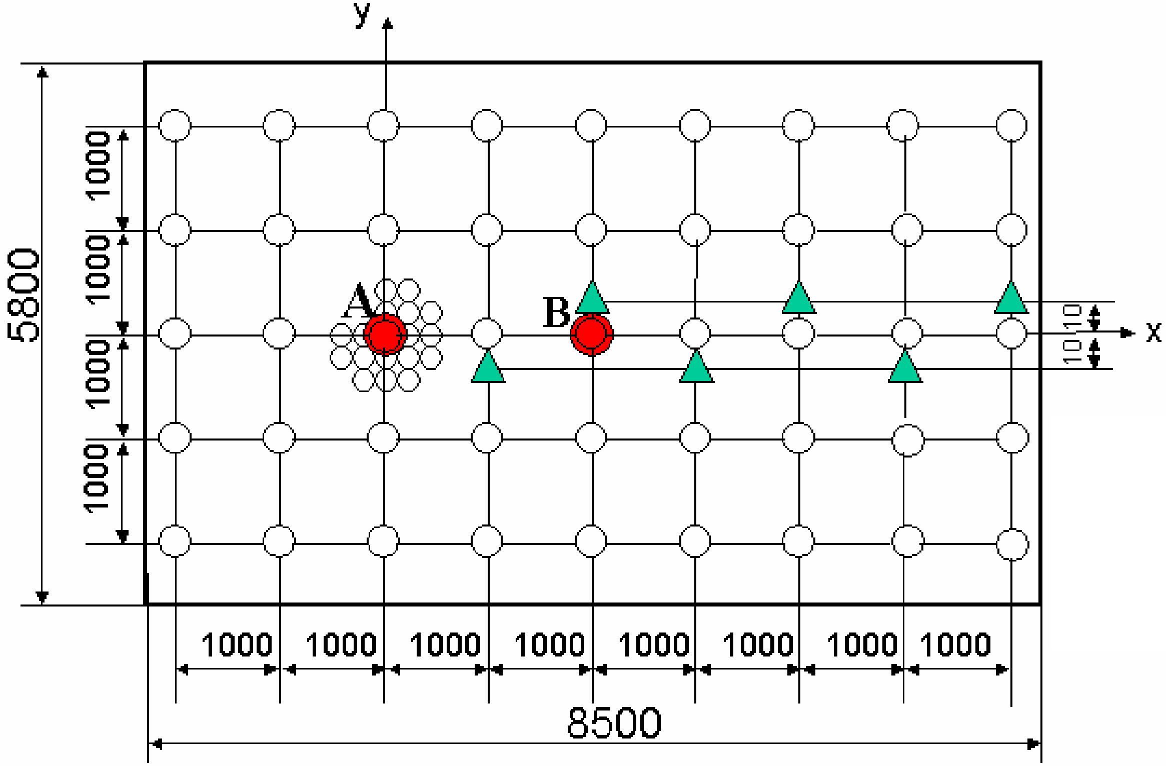
Approach to predicting the fire break out point (3/3)



$$R(x_s, y_s) = \left| \frac{\Delta T_1}{\Delta T_2} - \left\{ \frac{\sqrt{(x_1 - x_s)^2 + (y_1 - y_s)^2}}{\sqrt{(x_2 - x_s)^2 + (y_2 - y_s)^2}} \right\}^{\gamma} \right| + \left| \frac{\Delta T_2}{\Delta T_3} - \left\{ \frac{\sqrt{(x_2 - x_s)^2 + (y_2 - y_s)^2}}{\sqrt{(x_3 - x_s)^2 + (y_3 - y_s)^2}} \right\}^{\gamma} \right|$$

The position in which the value of $R(x_s, y_s)$ is minimized is made a breaking out point.

Schematic diagram of experimental set up & Experimental condition



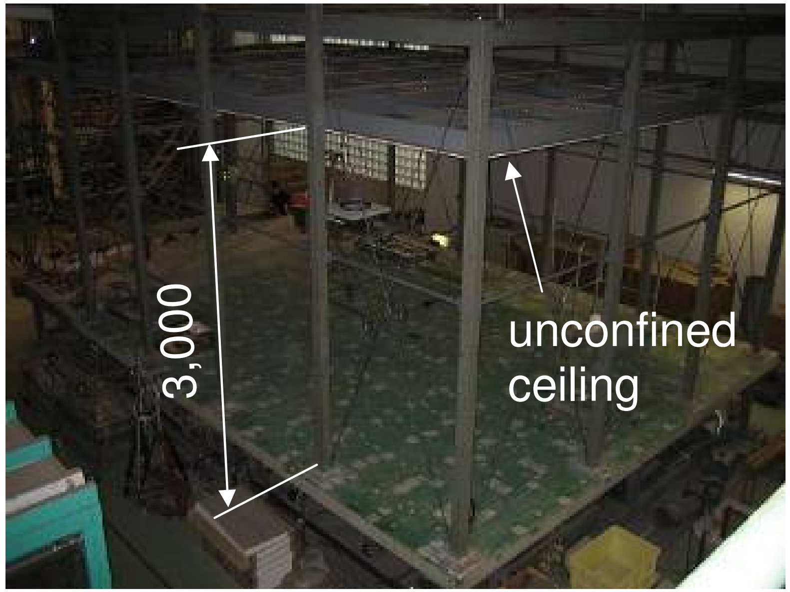
fire source location (A & B)

thermocouples

by-directional probes

Temperature : installed at 5cm below the ceiling, 45 points
K type thermocouples with a diameter of 0.32mm

velocity : 6 point with by-directional probes



Experimental condition

No	height H_{fc} [m]	diameter of fuel pan D [m]	measuring range of temperature
1	2.81	0.2	0.36□ r/H_{fc} □ 2.3
2		0.4	
3		0.6	
4	2.17	0.2	0.46□ r/H_{fc} □ 2.9
5		0.4	
6		0.6	
7	1.56	0.2	0.64□ r/H_{fc} □ 4.1
8		0.4	
9		0.6	
10	0.94	0.2	1.1□ r/H_{fc} □ 6.7
11		0.3	
12		0.4	

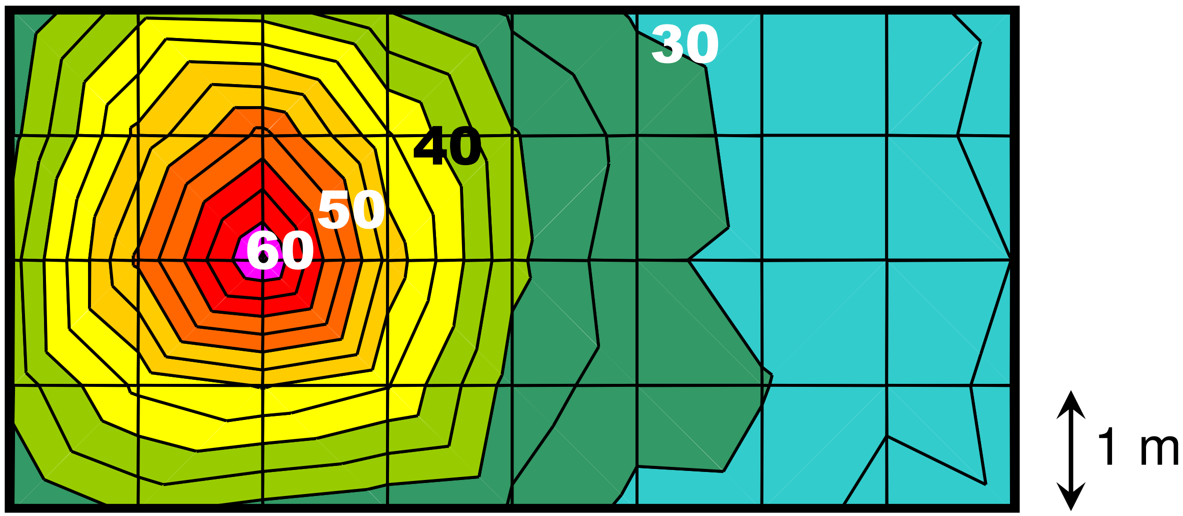
Heat release rate : estimated with fuel consumption rate of methanol

φ0.2m 8.3 kW
φ0.3m 20 kW
φ0.4m 40 kW
φ0.6m 93 kW

average 200-300 s after ignition

Isothermal diagram of the instantaneous temperatures 120 s after ignition

(a) based on all lattice temperature data (45 points)

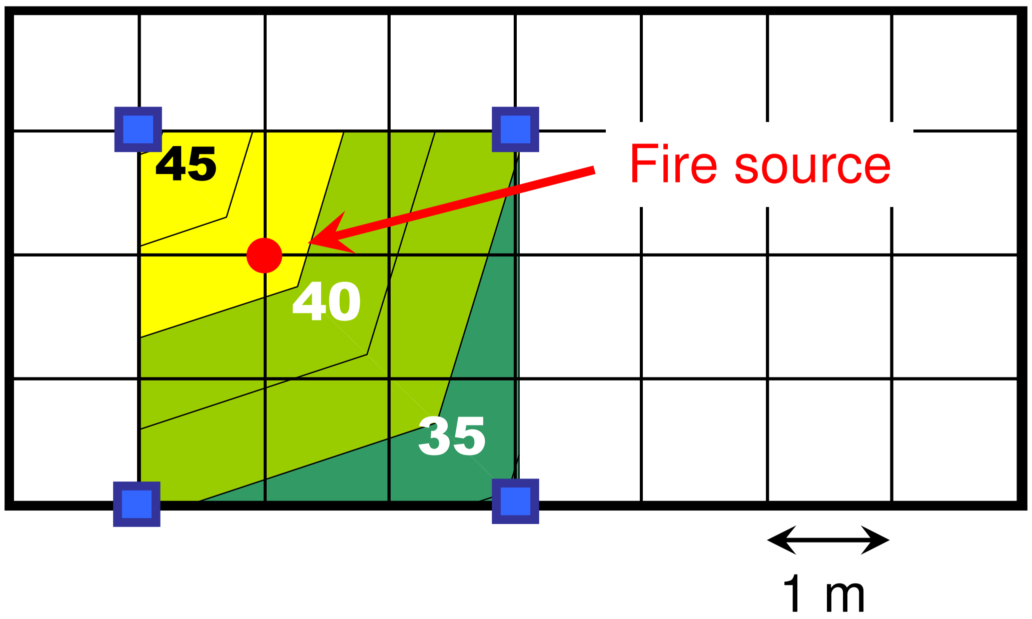


Test 2

$H_{fc} = 2.81\,\mathrm{m}$

$D = 0.4\,\mathrm{m}$

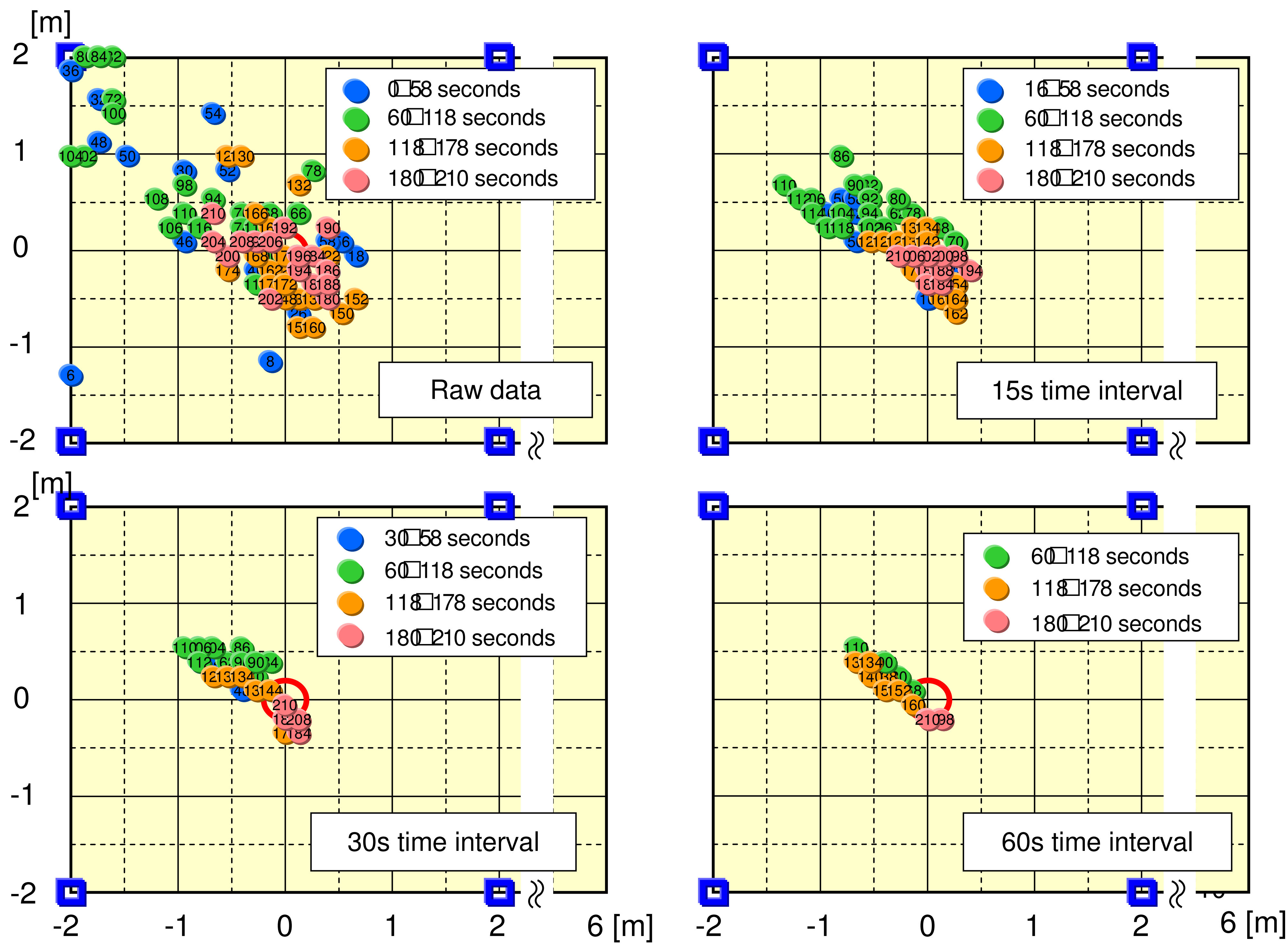
(b) based on temperature data denoted by ■ (4 points)



legend

■	20-22.5	■	22.5-25
■	25-27.5	■	27.5-30
■	30-32.5	■	32.5-35
■	35-37.5	■	37.5-40
■	40-42.5	■	42.5-45
■	45-47.5	■	47.5-50
■	50-52.5	■	52.5-55
■	55-57.5	■	57.5-60
■	60-62.5	■	62.5-65
■	65-67.5	■	67.5-70

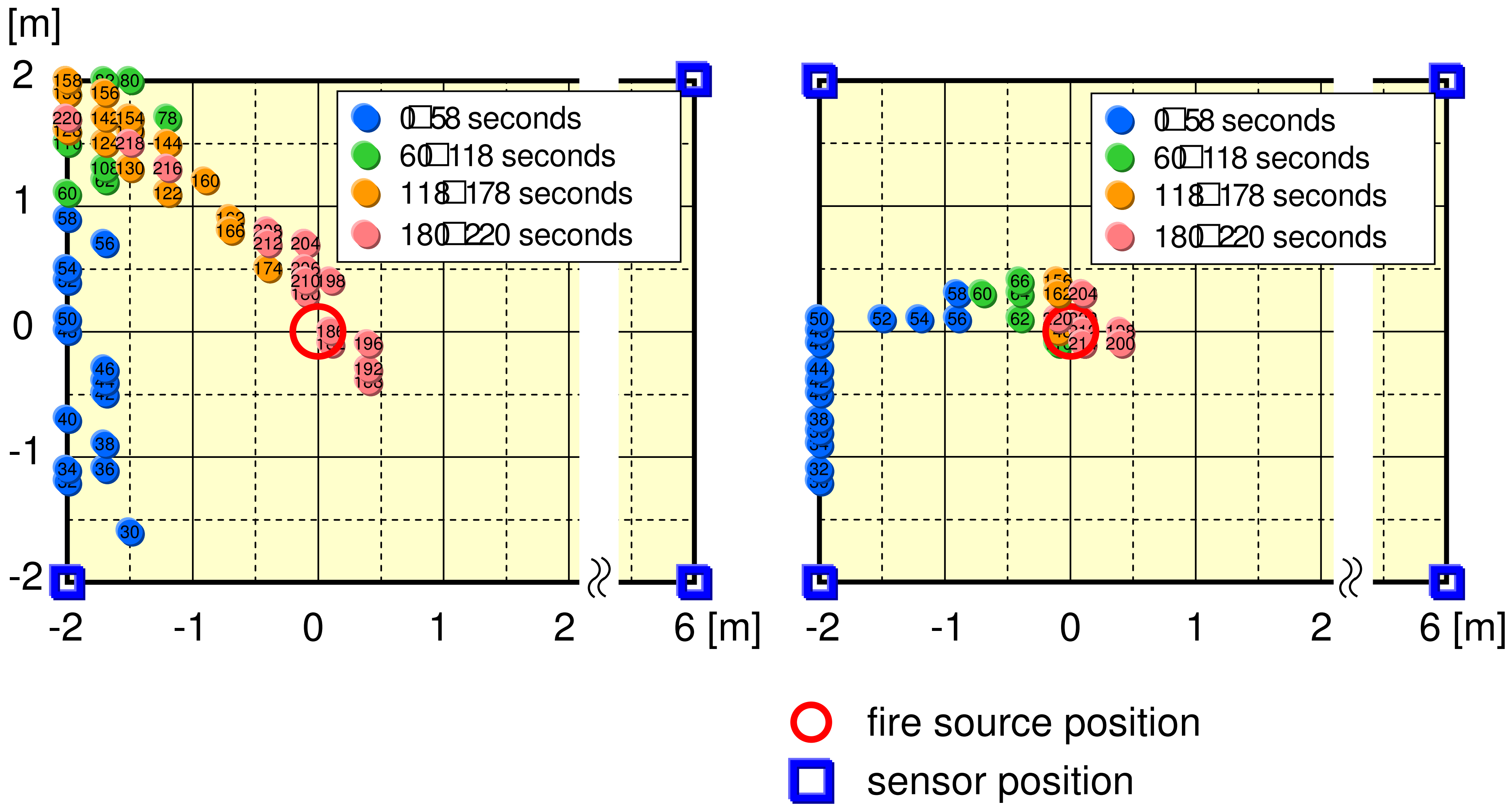
Relationship between the method of sampling the temperature and the prediction accuracy



Relationship between the number of installed temperature sensors and the prediction accuracy

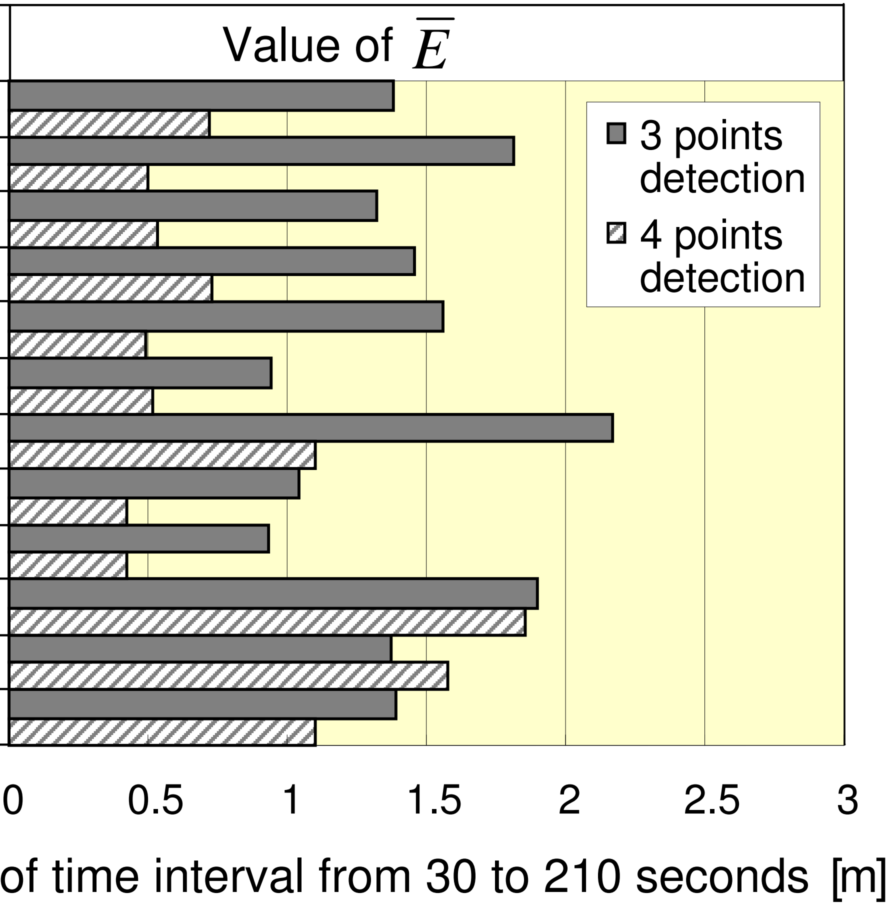
three sensors placed at the three corners

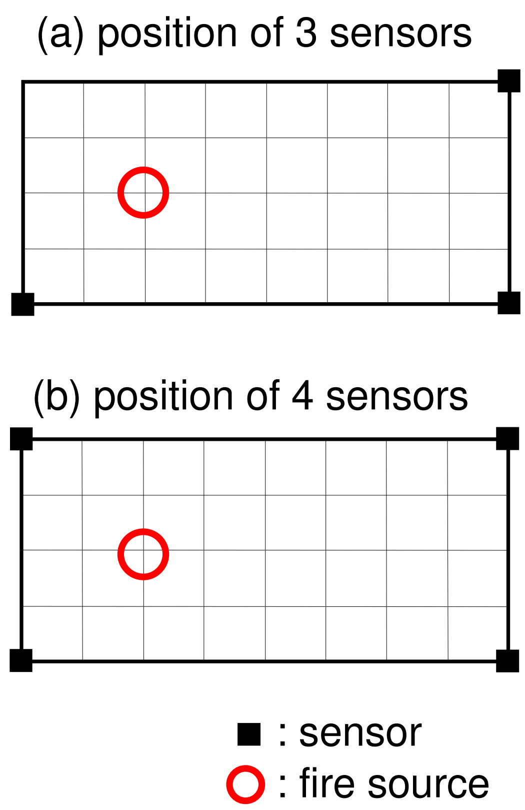
four sensors placed at four corners



Relationship between number of sensors and averaged error

No.	H_{fc}	D
1	2.81m	0.2m
2		0.4m
3		0.6m
4	2.17m	0.2m
5		0.4m
6		0.6m
7	1.56m	0.2m
8		0.4m
9		0.6m
10	0.94m	0.2m
11		0.3m
12		0.4m

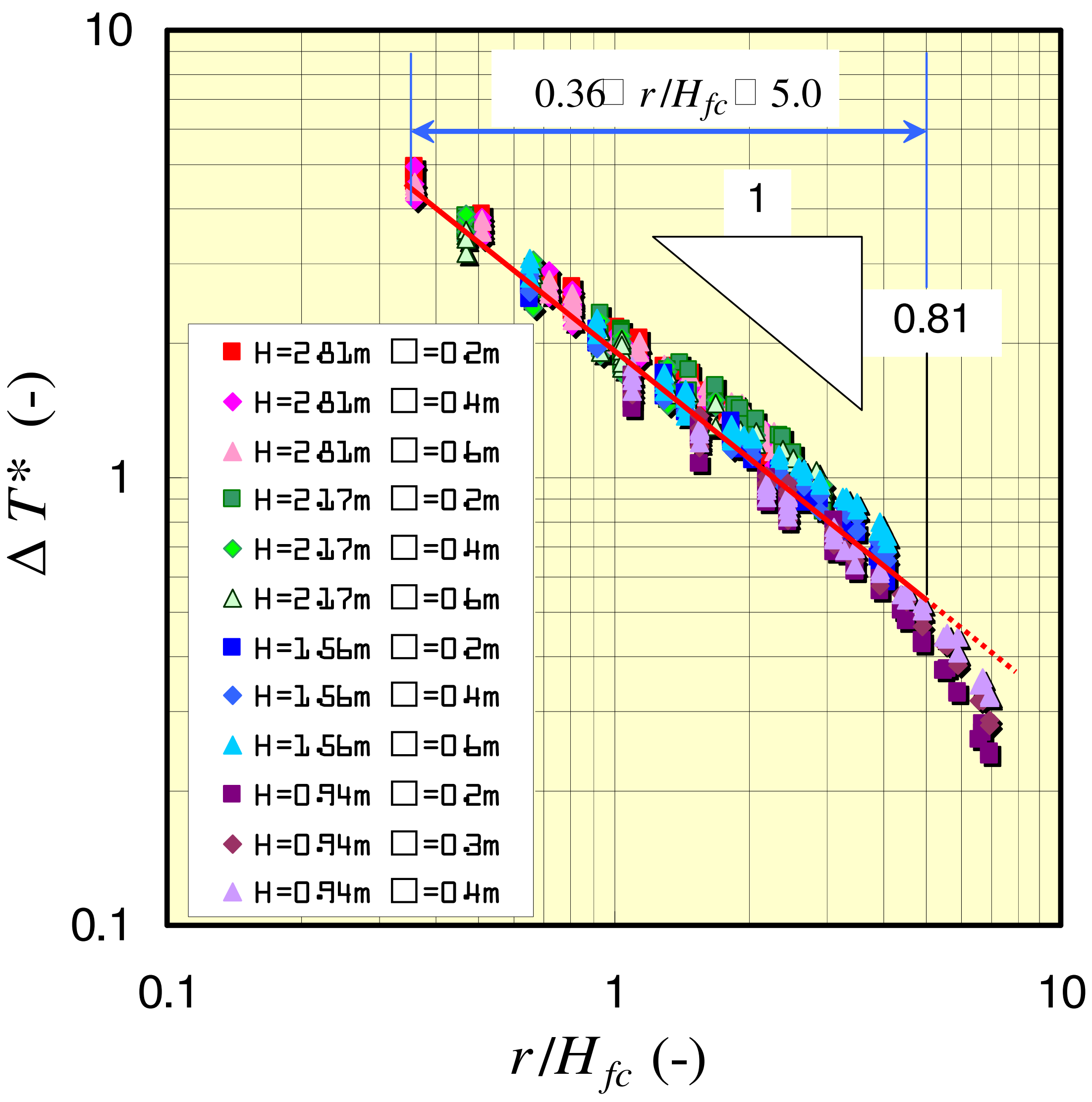




averaged error

$$\overline{E} = \frac{\sum_{i=1}^{N} \sqrt{\left(x^i_{f(s)} - x_f\right)^2 + \left(y^i_{f(s)} - y_f\right)^2}}{N}$$

Temperature decreasing property of the ceiling jet



In this experiment,
attenuation rate with respect to r/H_{fc} in the range $0.36 \leq r/H_{fc} \leq 5.0$ approximately 0.81
because the duration of steady combustion was 120–480 s.

This value is expected to approach –2/3, as proposed by Alpert, if the time duration of steady combustion is extended further.

Relationship between number of sensors and averaged error

No.	H_{fc}	D
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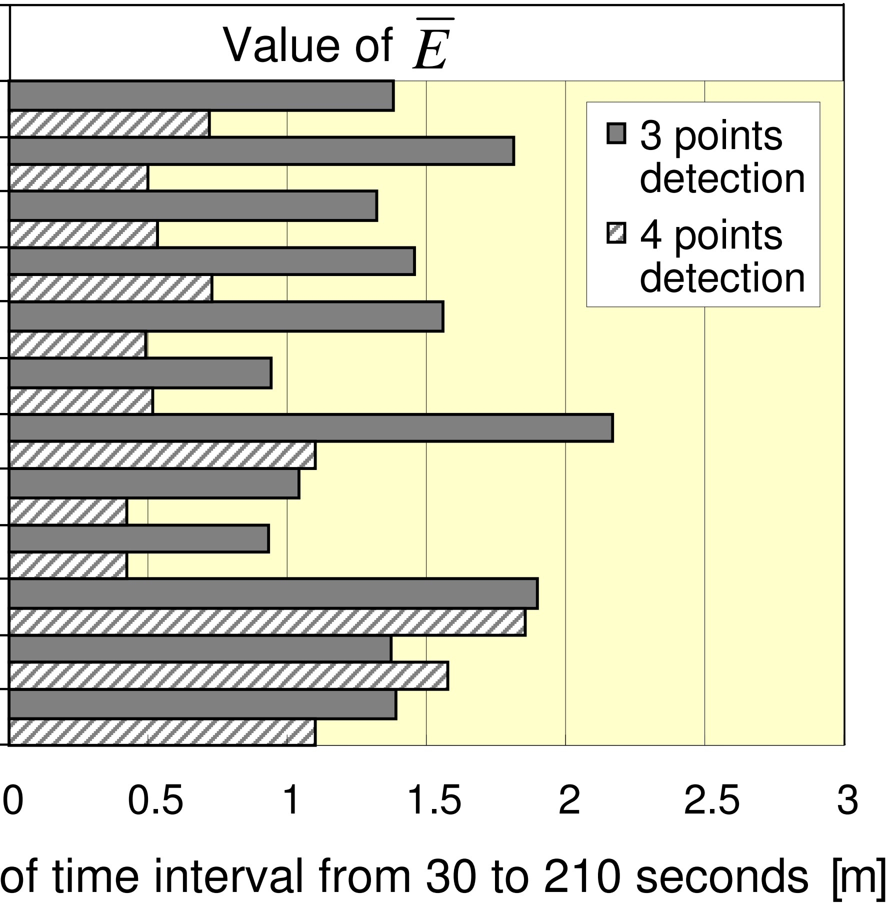
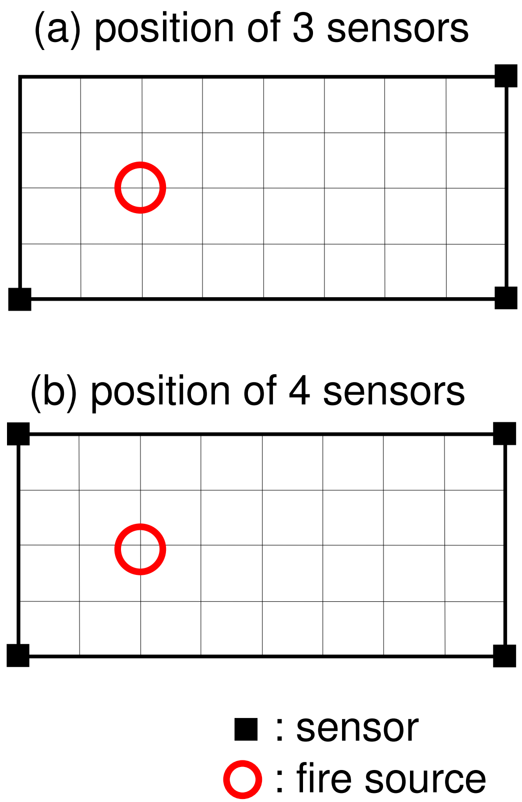




averaged error

$$\overline{E} = \frac{\sum_{i=1}^{N} \sqrt{\left(x^i_{f(s)} - x_f\right)^2 + \left(y^i_{f(s)} - y_f\right)^2}}{N}$$

Prediction method for estimating the heat release rate (1/2)

$$\dot{Q}_f = \left(\frac{\Delta T_i}{k \cdot H_{fc}^{(0.81-5/3)} \cdot r_i^{-0.81}} \right)^{3/2} \qquad k = \frac{2.03 T_\infty}{\left(C_p \rho_\infty T_\infty g^{1/2} \right)^{2/3}}$$

ΔT_i : temperature at sensor i

r_i : travel distance $\quad r_i = \sqrt{(x_i - x_f)^2 + (y_i - y_f)^2}$

H_{fc} : an unknown variable in the prediction, if its value has not been obtained beforehand

Even if the value of H_{fc} is not known, it is possible to estimated the heat release rate by adopting the height of the compartment.

⇨ Note:
by employing the height of compartment, the maximum value of heat release rate is estimated.

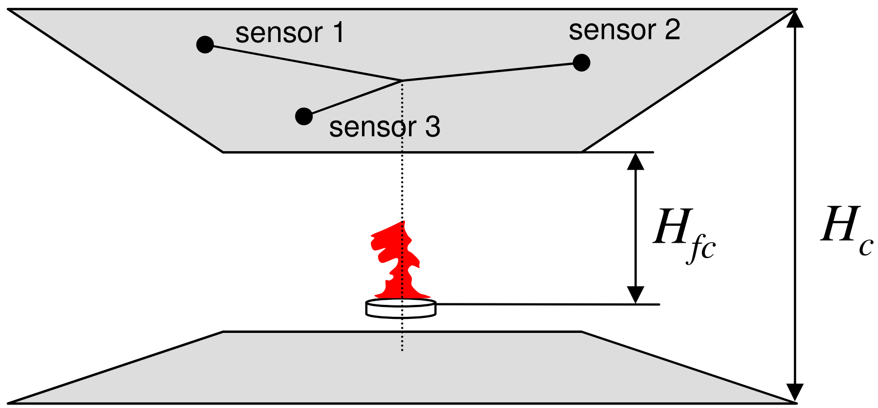
Prediction method for estimating the heat release rate (2/2)

When a relation between H_{fc} and H_c is available in the form $H_{fc} = hH_c$, the following relation between $\dot{Q}_{f(H_{fc})}$ and $\dot{Q}_{f(H_c)}$ can be derived.

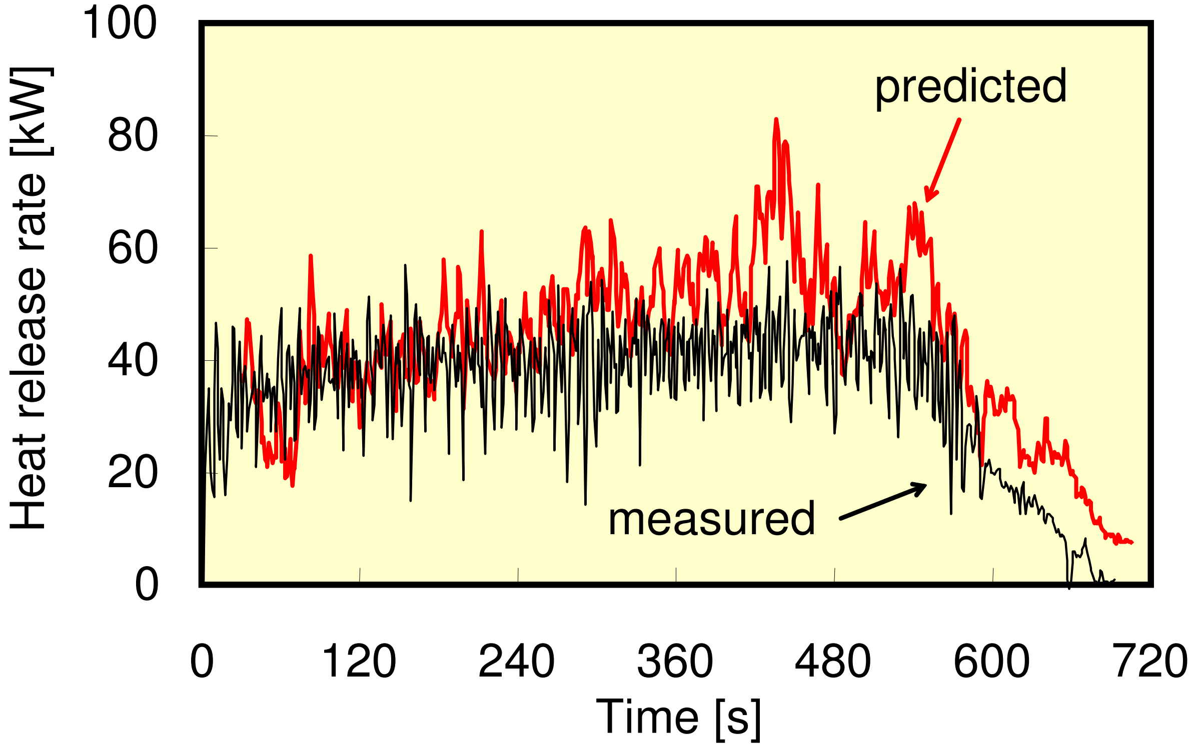
$$\frac{\dot{Q}_{f(H_c)}}{\dot{Q}_{f(H_{fc})}} = \left(h^{(0.81-5/3)}\right)^{3/2}$$

Therefore, it is necessary to accurately estimate the value of H_{fc} in order to predict the heat release rate with a good accuracy.

In fact, if h = 2/3, $\dot{Q}_{f(H_c)}$ has a value that is 1.68 times that of $\dot{Q}_{f(H_{fc})}$.



Relationship between the heat release rate and the prediction accuracy



Measured:

Fuel pan diameter is 0.4 m and

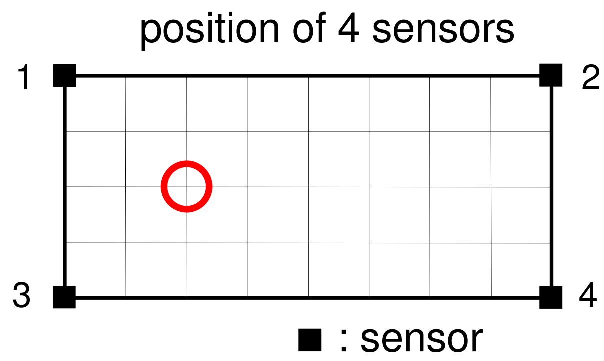
H_{fc} = 2.81 m.

Predicted:

Temperature rise of sensor 2 is used for calculation

Temperature averaging interval is 30 s.

H_{fx} = 2.81 m



Although the estimation of the H_{fc} value remains a problem, the heat release rate can be estimated if the location of the fire break out point is specified.

Conclusions

(1) Even if the values of the heat release rate and the height from the fire source to the ceiling are uncertain, the location of the fire break out point is predicted based on the temperature data from sensors installed on the ceiling.

(2) The prediction accuracy is improved by employing the averaged temperature data.

(3) The distance between the actual ignition position and the predicted location of the fire break out point is nearly halved when the number of sensors is increased from three to four.

(4) In this experiment, the dependency of the prediction accuracy on the heat release rate is small in ranges greater than 40 kW.

(5) The expected prediction accuracy is not obtained if the sensors are installed outside the range that guarantees the relationship between the temperature decreasing property and the travel distance of the ceiling jet.

(6) It is possible to estimate the heat release rate by using the coordinates of the predicted fire break out point and the coordinates and temperatures of the installed sensors.

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