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INVESTIGATION OF ACTUAL TEMPERATURE DISTRIBUTIONS IN MAIN BUILDINGS OF COAL-FIRED POWER PLANTS

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SUMMARY

Actual room air temperatures and air movements in very large spaces with both forced ventilation and natural ventilation were investigated at four coal-fired power plants.

The plants investigated have main buildings designed to keep some areas under 40°C in spite of numerous heat sources existing inside.

An equation to estimate vertical air temperature distribution in a boiler room is derived from the measured data.

With a strong radiant atmosphere in a very large space, air temperature distribution is brought about not only by "original heat sources," but also by the indoor structural materials which function just as if they are "secondary heat sources" heated by radiation from "original heat sources." The measured data suggest that heat quantities from "secondary heat sources" amount to approximately twice as much as from "original heat sources."

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INTRODUCTION

In Japan, coal-fired power plants to be newly constructed are designed to have indoor boilers which contribute to improvement of plant efficiency by recovering heat which would ordinarily be lost through transmission from the surfaces of the boilers.

Ventilator sizes and configurations of main buildings, which have numerous heat sources such as boilers inside, are designed to keep some areas under 40°C for protection of electrical equipment and to minimize pressure differences across building shells under fan pressurization.

This paper describes the results of an investigation of actual temperature distributions in main buildings of coal-fired power plants and discusses how temperature distributions result in very large spaces with both forced ventilation and natural ventilation.

Figure 1 is a schematic diagram of a coal-fired power plant. Coal is sent to the bunker and, in order to make it burn more easily, is finely pulverized in mills. The coal then enters the boiler and is burned. Outdoor air entering through ventilators on the main building shell is warmed by radiation from equipment. Forced draft fans (FDFs) convey the warmed air into the boiler as air for combustion from FDF openings at the top of the boiler room. Flue gas is exhausted through the stack after special devices have removed SO_x, No_x, and particulates from the gas.

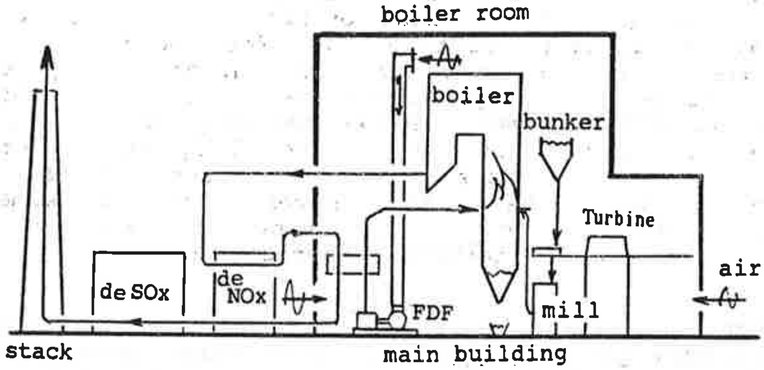

Fig. 1. Schematic diagram of a coal-fired plant.

FIELD MEASUREMENTS

Figure 2 shows the scales of the main buildings investigated.

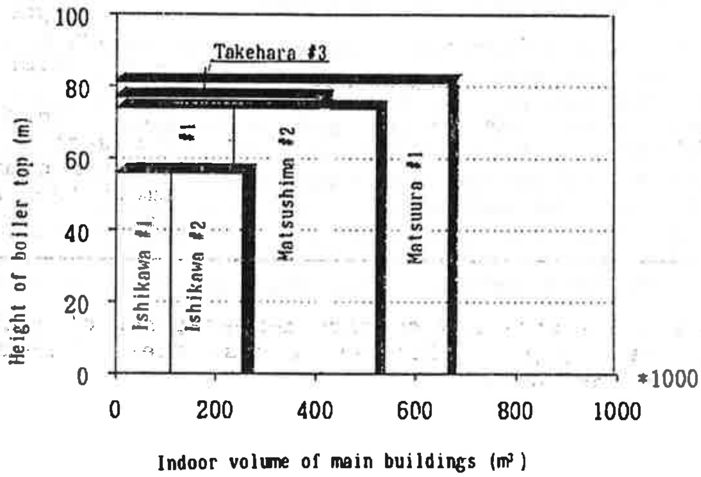

Fig. 2. Scales of main buildings investigated.

Table 1 shows the items of measurements made on Matsuura Power Plant (installed capacity: 1,000 MW x 1) in midsummer of 1990. The same kinds of measurement were also made on the three other sites.

Outdoor air temperature and wind direction/velocity were measured every hour of plant operation. As for boiler room air temperature distribution, four points at equal intervals vertically were scanned automatically every 10 minutes by data loggers. However, the other points in the boiler room were measured manually by handy meters because it was too difficult to set long cables between data loggers and sensors covering the large space. All measured data obtained during a period of approximately 2 days were corrected as simultaneously measured data at the time of peak outdoor air temperature.

Table 1. Items of measurements

item	point	data acquisition system
pressure difference	across building shell	micro-anemometer (manoster guage)
wind velocity	openings	hot wire anemometer
	equipment surface	hot wire anemometer
	outdoor	3-cup-anemometer
wind direction	outdoor	arrow type
	indoor	smoke tester
air temperautre	fixed	thermocouple (data logger)
	mobile	thermocouple (handy meter)
surface temperature	equipment	infrared radiometer (for spot)
		infrared radiation camera (for surface)

Figures 3 and 4 show how surface temperatures of equipment, such as steam pipes, flue gas ducts, steel columns, and boilers were measured.

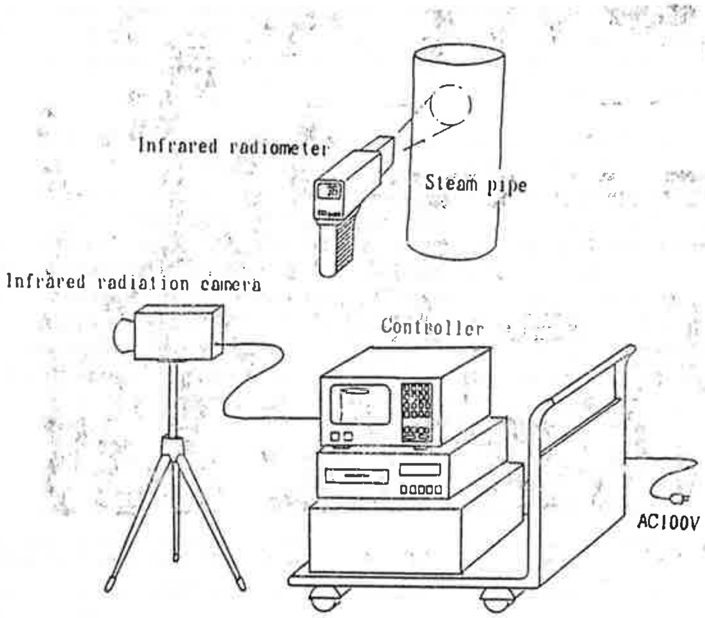

Fig. 3. Infrared radiometer (mobile use) and infrared radiation camera (limited location use).

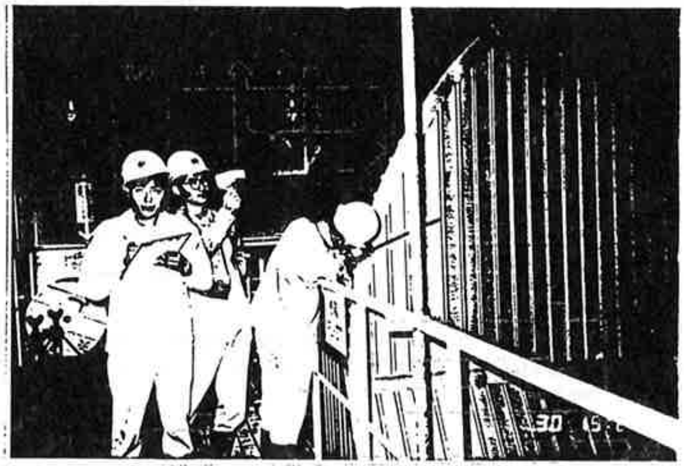

Fig. 4. Measurement of surface temperature and air velocity at flue gas duct.

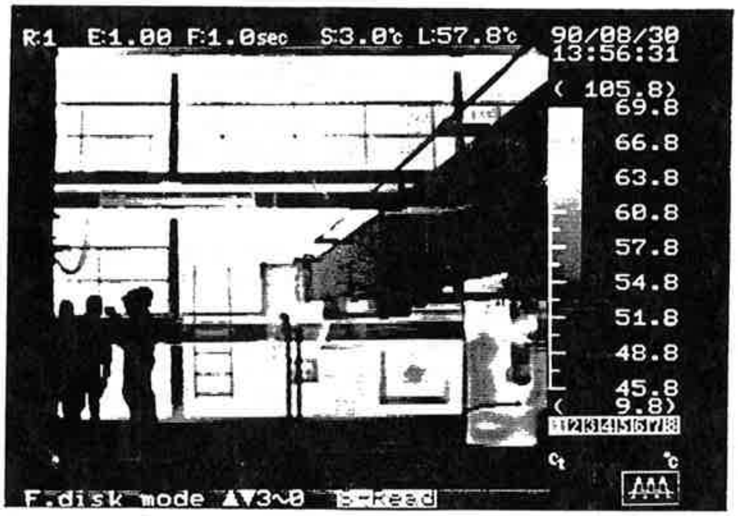

Fig. 5. Thermal image of part of boiler surface.

MEASUREMENT RESULTS

Air Movement in Main Building

Air movement in the main building of a coal-fired power plant is formed by both forced ventilation and natural ventilation. Figure 6 shows the general pattern of air flow measured in main buildings at the four different sites.

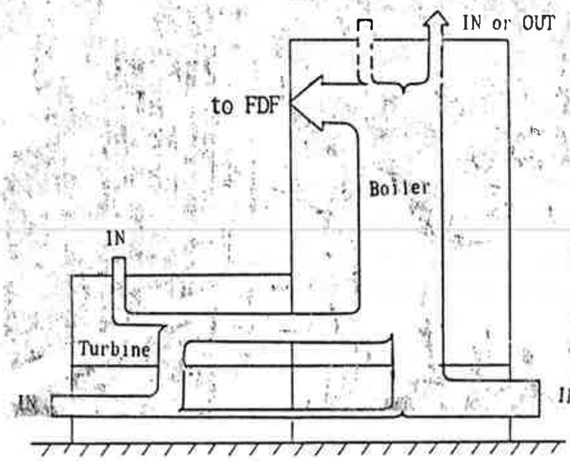

Fig. 6. Air flow pattern measured in main buildings at four different sites.

Table 2 gives total calorific values, air flow volumes, pressure differences, etc. in the main buildings. The total calorific value from each piece of equipment is indirectly estimated from total heat balances with heat gain/loss going out/in through openings in the building shell, heat transmission through walls and heat recovery from FDFs.

Table 2. Total calorific values, air flow volumes, pressure differences, etc. in main buildings.

site	generation capacity (MW)	total calorific value (KW)	air flow volume FDF (kg/s)	natural (kg/s)	total (kg/s)
Ishikawa	156*2	9,984/2	332/2	106/2	438/2
Matsushima	500*2	25,501/2	997/2	186/2	1,183/2
Takehara	700*1	16,799	747	91	838
Matsuura	1,000*1	16,451	884	0	884

site	Δp_B (p_a)	Δp_T (p_a)	θ_O (°C)	θ_T (°C)	h (m)
Ishikawa	-21.6	10.8	30	51	53
Matsushima	-19.6	17.7	30	53	72
Takehara	-53.9	18.6	10	38	73
Matsuura	-37.3	0.0	30	48	81

Δp_B = pressure difference between inside and outside at bottom of boiler room (p_a)
Δp_T = pressure difference between inside and outside at top of boiler room (p_a)
θ_O = outdoor air temperature (°C)
θ_T = indoor air temperature at top of boiler room (°C)
h = height of boiler top (m)

Figure 7 shows vertical distributions of pressure differences between outdoors and indoors at the same levels of boiler rooms. In all boiler rooms a high neutral pressure zone means inflow of outdoor air through all openings except boiler top openings and FDF openings.

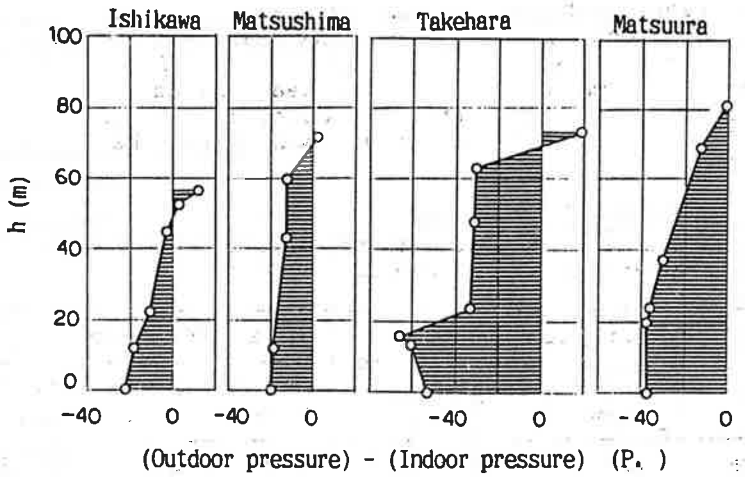

Fig. 7. Vertical distributions of pressure differences between outdoor and indoor at the same level in boiler rooms.

Vertical Air Temperature Distribution in Boiler Rooms

A thermal image of the surface of a boiler (Fig. 5) reveals that the surface temperature distribution of the boiler is not uniform but of a grid pattern, because the boiler structural steel, by which the boiler casing is reinforced, causes heat bridges to be produced.

Considering that in a boiler room the main heat source is a huge boiler, and air movement is upward, it is to be expected that air temperature will be higher exponentially in proportion to height.

For practical purposes, therefore, an equation to predict the vertical air temperature distribution in a boiler room is derived from measured data as follows:

$$T_Z = T_O + (T_T - T_O)*(z/h)^{1/2} \qquad (1)$$

where

T_Z = room air temperature in boiler room at height z from the bottom (K)
T_O = outdoor air temperature (K)
T_T = indoor air temperature at top of boiler room (K)
z = height z from bottom of boiler room (m)
h = height of boiler top (m)

Figure 8 shows measurement results of boiler room vertical air temperature distributions compared with predictions.

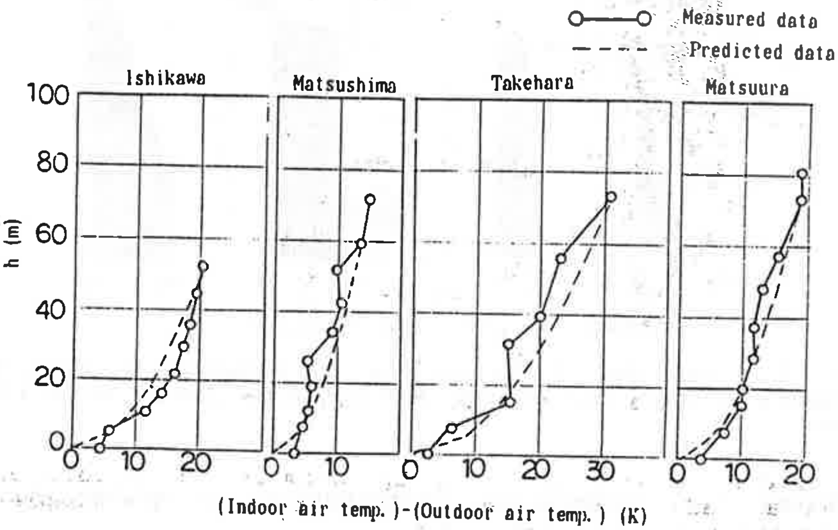

Fig. 8. Measured data and predictions of vertical air temperature distributions in boiler rooms.

DISCUSSION OF RESULTS

In the boiler rooms measured, room air temperatures were very high and, due to forced ventilation, air movement very fast. In such a thermal environment, therefore, in order to estimate total heat quantity Q_T (KW) from the boiler surface, it is classified into the following four elements (see Fig. 9.).

- q_c = convective heat transfer between boiler surface and room air (KW/m^2)
- q_{ra} = radiant heat transfer between boiler surface and room air (KW/m^2)
- q_{r1} = radiant heat transfer between boiler surface and inside wall of boiler room (KW/m^2) (heat transmission loss through wall neglected as very small compared with Q_T)
- q_{r2} = radiant heat transfer between boiler surface and structural surface such as column, beam, and floor grating made of steel (KW/m^2)

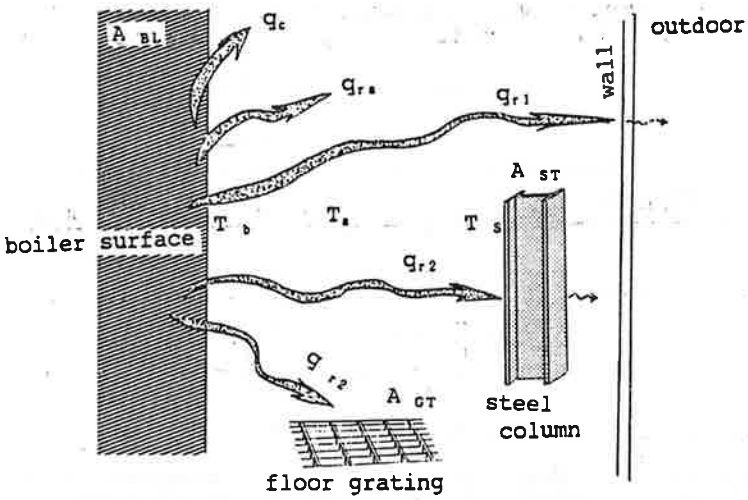

Fig. 9. Heat balance model in a boiler room.

To estimate q_c and q_{ra}, the approximate temperature of ambient air adjacent to the boiler surface (T_a), a complement of the boiler surface, is assumed as

$$T_a = (T_1 + T_2)/2 \qquad (2)$$

where

T_1 = air temperature adjacent to boiler surface (K)
T_2 = boiler room air temperature (K)

To estimate q_{r1}, the approximate ambient temperature adjacent to inside walls (T_s), also a complement of the boiler surface, is assumed as

$$T_s = (T_b + T_2)/2 \qquad (3)$$

where

T_b = boiler surface temperature (K)

Convective heat transfer coefficient α_c ($W/m^2 \cdot K$) is given by following Jürges's experimental equations [1] using the velocity of ambient air adjacent to the surfaces.

$$\alpha_c = 6.2 + 4.2\ V \ (V \leq 5m/s) \qquad (4)$$

where

V = velocity of ambient air adjacent to surface (m/s)

Introducing radiant heat transfer coefficient α_r, (W/m^2 K) [2]:

$$\alpha_r \fallingdotseq 4E\sigma\{(T_b + T_S)/2\}^3 \qquad (5)$$

where
E = effective emissivity : 1/(1/ε + 1/ε - 1)
ε = emissivity (0.9)
σ = Stefan Boltzmann's constant (5.67 *10^{-8} W/m^2 K^4)

$$\therefore q_c = \alpha_c\ (T_b - T_a) \qquad (6)$$

$$q_{ra} = \alpha_{ra}\ (T_b - T_a) \qquad (7)$$

$$q_{r1} = \alpha_{r1}\ (T_b - T_S) \qquad (8)$$

$$q_{r2} = \alpha_{r2}\ (T_b - T_S) \qquad (9)$$

The area of the structure surface, a complement of the boiler surface concerning radiation, is as follows.

Regarding columns and beams, thermal conductivity of steel is so high that radiant heat is transferred quickly from boiler-face side to the opposite side and thus, total surface area of columns and beams should be counted.

$$A_{ST} = (\text{total surface area of columns and beams})*1.0 \qquad (10)$$

As for floor grating surface, its conductivity is also high. However, taking shape factor into consideration, the total surface area of floor gratings should be reduced.

$$A_{GT} = (\text{total surface area of floor gratings})*0.2 \qquad (11)$$

$$\therefore Q_T = Q_{BL} + Q_{r2}$$

$$= A_{BL}\ (q_c + q_{ra} + q_{r1}) + (A_{ST} + A_{GT})\ q_{r2} \qquad (12)$$

where
A_{BL} = total surface area of boiler (m^2)

Table 3 shows the total heat quantity from boiler surface according to the above equations (at Matsuura Coal-fired Power Plant)

Table 3. Total heat quantity from boiler surface (at Matsuura Coal-fired Power Plant).

level m	T_1 K	T_2 K	T_b K	T_s K	T_a K	V m/s
73.3	327.7	321.3	342.5	331.9	324.5	0.85
57.3	334.2	318.7	336.9	327.8	326.5	0.25
41.4	323.2	315.7	337.2	326.5	319.5	0.32
24.3	315.1	313.2	328.7	321.0	314.2	0.39
7.3	315.5	312.3	325.7	319.0	313.9	0.48

level m	α_c W/m^2 k	α_{ra} W/m^2 k	α_{r1} W/m^2 k	α_{r2} W/m^2 k	q_c KW/m^2	q_{ra} KW/m^2	q_{r1} KW/m^2	q_{r2} KW/m^2
73.3	9.77	7.11	7.11	7.11	176	128	75	75
57.3	7.25	6.81	6.81	6.81	75	71	62	62
41.4	7.54	6.78	6.78	6.78	133	121	73	73
24.3	7.84	6.36	6.36	6.36	114	92	49	49
7.3	8.22	6.21	6.21	6.21	97	73	42	42

level m	A_{BL} m^2	A_{ST} m^2	A_{GT} m^2	Q_{BL} KW	Q_{r2} KW	Q_T KW
73.3	2,120	7,000	400	803	555	1,358
57.3	2,270	22,000	1,400	472	1,451	1,923
41.4	3,850	35,000	2,200	1,259	2,716	3,975
24.3	1,690	31,000	1,900	431	1,612	2,043
7.3	1,570	35,000	2,100	333	1,558	1,891
total	11,500	130,000	8,000	3,298	7,892	11,190

Figure 10 shows vertical distributions of convective and radiant heat transfers from the boiler surface in the boiler room (at Matsuura Coal-fired Power Plant).

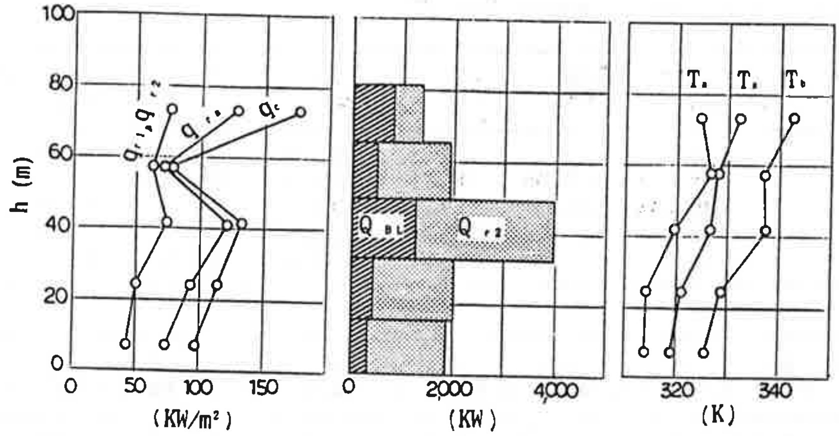

Fig. 10. Vertical distributions of convective and radiant heat transfers from boiler surface in boiler room (at Matsuura Coal-fired Power Plant).

CONCLUSIONS

(1) An equation to predict vertical air temperature distribution in a boiler room is derived from measurement data.

(2) In a strong radiant atmosphere of a very large space, air temperature distribution is caused not only by "original heat sources" but also by indoor structural materials, which function just like "secondary heat sources" which are heated by radiation from "original heat sources." The measured data suggest that "secondary heat sources" account for approximately twice the quantity of heat of "original heat sources."

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REFERENCES

[1] Jürges, W., "Der Warmeubergang an einer ebenen Wand". Beih. Z. Gesündheits Ingenieur, Reihe 1, Heft 19, 1924

[2] Watanabe, K., "The principles of architecural design, II," Maruzen, 1965 (in Japanese)