Some Considerations on the Floor-Film Ratio of Plastic House.*

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Abstract

The relation of the floor-film ratio ($\beta$) of plastic house to the inside air temperature and its role in the mechanism of the thermal radiation loss are discussed. It is clearly shown that the inside temperature is higher and the thermal radiation is lower with the larger floor-film ratio and the shape factor of the wavy roof of plastic house complex to the sky is equal to the floor-film ratio. Thus, the thermal radiation from the wavy roof is equal to that from the horizontal roof with the same floor area.

1. Introduction

One of the most significant factors specified by the house shape in heat transfer of the plastic house is the floor-film ratio, which is the ratio of the floor area of the house to the roof area. It has been generally accepted that the larger floor-film ratio keeps higher the inside air temperature by the fact that the floor serves as the heat source whereas the film surface acts as the radiator.

The clear explanation of this mechanism would be indispensable. The present paper describes some theoretical considerations on the functioning of the floor-film ratio in relation to inside air temperature and thermal radiation from the house. The shape factor of the wavy roof of plastic house complex is clarified.

2. The inside air temperature

The heat transmission through the film ($E_{ft}$), usually composed of thin plastic film, is expressed by

$$E_{ft} = F \alpha_r (t_i - t_a)$$

(2-1)

where $F$ is film area, $t_i$ is inside air temperature, $t_a$ is outside air temperature and $\alpha_r$ is the over-all heat transmission coefficient which includes every effect of the sensible and latent heat transfer from the inside air to the inside film surface, the heat flow into the film and the heat transfer from the outside surface to the outside air. General state in daytime is $t_i > t_f > t_a$ where $t_f$ is the film temperature. At night, generally there are two cases, one is $t_i > t_f > t_a$ and the other is $t_i > t_a > t_f$. Thus, if we focus on the temperature difference of inside and outside air, it is always $t_i > t_a$. Therefore under such conditions $\alpha_r$ could be considered as a coefficient similar to the so-called over-all heat transfer coefficient.

The inside air is heated by the storing heat of the floor which absorbs solar radiation in daytime.

The heat transfer from the floor surface to the inside air ($E_{di}$) is expressed by

$$E_{di} = D \alpha_{di} (t_d - t_i)$$

(2-2)

where $D$ is the floor area, $t_d$ is the surface temperature of the ground and $\alpha_{di}$ is the overall heat transfer coefficient of the sensible and the latent heat.

As the heat generated from the ground would be dissipated from the film surface, the equation (2-1) is forced to be equal to the equation (2-2) in the steady state.

Thus, the inside air temperature without ventilation is decided by the equation (2-3).

$$F \alpha_r (t_i - t_a) = D \alpha_{di} (t_d - t_i)$$

(2-3)

$$\therefore t_i = \frac{D}{F + \frac{\alpha_r}{\alpha_{di}}} t_d + \frac{\alpha_r}{ \alpha_{di}} t_a$$

(2-4)

where $D/F$ is the floor-film ratio ($\beta$); $t_i$ becomes near $t_d$ when $\beta$ increases up to unity and when $\alpha_r/\alpha_{di}$ becomes smaller. This is the case when the house is low and wide, the wind velocity is low and the downward radiation from the night sky is large. On the contrary, $t_i$ becomes decreasingly near $t_a$ when the house is

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Fig. 1. Calculated $\frac{\alpha_T}{\alpha_{DI}}$ with different $\beta$ from the equation (2-5).

Square tunnel with transparent polyethylene film of 0.05mm. Clear sky of May 28, 1967. Inside air temperature is the mean of four points. Floor temperature is the mean of two points at 3 cm depth.

tall, the wind velocity is high and the thermal radiation from the film is large at night.

The equation may be the simplest expression of the matter that when $\beta$ is larger, the inside air temperature becomes higher. Rearranging the equation (2-3), the relation of $\frac{\alpha_T}{\alpha_{DI}}$ to $\beta$ is expressed by the following equation.

$$\frac{\alpha_T}{\alpha_{DI}} = \beta \frac{t_4 - t_i}{t_i - t_a}. \quad (2-5)$$

The result of the calculation of $\frac{\alpha_T}{\alpha_{DI}}$ from experimental data\textsuperscript{1)} is presented in Figure 1.

At 14:00, the ratio $\frac{\alpha_T}{\alpha_{DI}}$ is almost constant about 0.1 regardless of $\beta$, but at 4:00, this value decreases from about 2 to 1 when $\beta$ increases.

3. Thermal radiation from a wavy roof

The radiation to the sky from the roof of a plastic house complex is not yet known. However, if the roof is the perfect diffusing surface and if the emissivity of the film is unity, the simple solution is obtained.

When the wavy roof is the repetition of a same shape as shown in Figure 2, the shape factor of a roof (a) to the sky is equal to the shape factor of the part of the roof from a top to another top (b) and also to the shape factor of the whole roof to the sky (c).

The horizontal plane $S$ in the figure (d) is an imaginary one connecting two tops, then, the shape factor of the roof $F$ to the sky ($\phi_{FS}$) is equal to that of plane $S$. That is, the reciprocity theorem in this closed system is expressed by

$$\phi_{FS}F = \phi_{SF}S, \quad (3-1)$$

where $\phi_{SF}$ is the shape factor of the plane $S$ to the film $F$, which is unity, and $F$ and $S$ refer to the area of the roof $F$ and the plane $S$, respectively. Therefore,

$$\phi_{FS} = \frac{S}{F} = \frac{D}{F} = \beta, \quad (3-2)$$

where $D$ is the floor area (e) and is equal to $S$. Therefore, $\phi_{FS}$ is equal to the shape factor of the roof to the floor $\phi_{FD} = \frac{D}{F} = \beta$. That is, the shape factor of the wavy roof of an arbitrary shape to the sky is equal to the floor-film ratio.

Thus, the thermal radiation of the roof to the sky $Q_{RS}$ is expressed by

$$Q_{RS} = F\sigma T_f^4 \phi_{FS} = \sigma T_f^4 D, \quad (3-3)$$

where $\sigma$ is Steffan-Boltzmann constant, $T_f$ is the absolute temperature of the film. Namely,
the thermal radiation to the sky from the wavy roof of an arbitrary shape is independent from the roof shape and is equal to that of the horizontal roof with the same floor area.

In practice, the thermal radiation from the wavy roof may be larger than that from the horizontal roof because the film is not of a perfect diffusing surface, the emissivity is not unity and the temperature is not constant in every place on the roof.

4. Comparison with the single house

The shape factor to the sky of a small plane \( dF \) with an angle \( \theta \) to the horizontal on the roof of a single house is expressed by

\[
\sigma_{dF} = \frac{1 + \cos \theta}{2}, \tag{4-1}
\]

and

\[
\sigma_{FS1} = \frac{1}{F} \int_{dF} \left( \frac{1 + \cos \theta}{1} \right) dF = \frac{1}{2F} \left( \int_{dF} dF + \int_{dF'} \cos \theta dF' \right), \tag{4-2}
\]

where \( \sigma_{FS1} \) is the shape factor of the total roof of a single house to the sky. The orthogonal projection of \( dF \) to floor \( (F') \) is \( dF' \), then we have

\[
\sigma_{FS1} = \frac{1}{2F} \left( F + \int_{F'} dF' \right) = \frac{1}{2F} \left( F + F' \right) = \frac{1 + \beta}{2}. \tag{4-3}
\]

Therefore, the thermal radiation from the single house to the sky is

\[
R_{FS1} = F_{dF} T^4 \sigma_{FS1}. \tag{4-4}
\]

The ratio of the thermal radiation to the sky for single house to that of combined house becomes

\[
\frac{R_{FS1}}{R_{FS}} = \frac{1}{2} \left( 1 + \beta \right) = \frac{1 + \beta}{2\beta}. \tag{4-5}
\]

Fig. 4. The relation between \( \beta \) and the ratio of thermal radiation \( R_{FS1}/R_{FS} \)

The relation of this ratio and \( \beta \) is shown in Figure 4. The ratio is about 40 per cent larger for the hemi-circle than for the joining style and increases rapidly for taller shapes.

Thus, the floor-film ratio is a good index from the point of view not only of heat transfer mechanism but also of thermal radiation.

In practice, the house radiates thermal rays not only to the sky but also to the surrounding ground. The radiation to the surroundings is considerably larger at the single house than at the complex house. By this reason, the complex style is more preferable than the single.

References


プラスチックハウスの保温比に関する二・三の考察

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保温比と保温性との関係を明確にした。保温比（β）および底面での熱伝達率（α_D1）・フィルムでの熱貫流率（α_T）の比、とハウス内気温（t_i）・外気温度（t_a）・外気温（t_s）との簡単な理論式によって保温比が大になるほど内気温が高くなることを明示した。

\[ t_i = \frac{\beta t_d + \alpha_T t_s}{\beta + \frac{\alpha_T}{\alpha_D1}} \]

連棟ハウスの屋根の天空を見る形態係数（φ_Fs）は保温比（β）に等しいことを示した。したがって連棟ハウスからの理論的熱放射（Q_Fs= FaT_s^4φ_Fs）は、水平屋根からのそれ（Q_Fs= αT_s^4D, D=底面積）に等しく、これに比して単棟ハウスの熱放射（Q_Fs1= FaT_s^4φ_Fs1, F=フィルム面積, φ_Fs1=(1+β)/2）は（1+β）/2β 倍となり、熱放射からも保温比が大なるほど有利なことを示した。