3 Heat transfer in building components

Page 108: New sentences were added after “is the *air fow rate*.”

In the calculation we have assumed that the water vapour mass content of the external and internal air is the same, so the calculated losses only included sensible heat transfer. If this is not the case, ventilation facilitates the net transfer of water vapour. This corresponds latent heat transfer, because the energy used to evaporate the water into vapour that has left the room through ventilation is also lost. If we want to calculate total losses, we must use enthalpy.

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4 Moisture in building components

Page 225: After the Section 4.5.6, new section is added:

4.5.7 Moisture transfer through ventilation

In Section 3.3.4 we calculated the amount of heat transferred by ventilation. Now we will calculate the amount of moisture.

Due to ventilation, the internal air of volume V_a and water vapour concentration v_i is replaced by external air of the same volume and water vapour concentration v_e. The mass of water vapour was changed for (4.8)

$$\Delta m = m_\mathrm{i} - m_\mathrm{e} = V_\mathrm{a}(v_\mathrm{i} - v_\mathrm{e}).$$

If we divide the equation by the time in which the air is replaced, we get the mass flow rate of water vapour due to ventilation $q_{m,\mathrm{ve}}$ (4.2)

$$q_{m,\mathrm{ve}} = q_V(v_\mathrm{i} - v_\mathrm{e}), \tag{4.48}$$

where q_V is the air flow rate (3.42). Note that this expression is the moisture equivalent of expression (3.41).

We have assumed above that the temperatures of the external and the internal air are the same. If this is not the case, the external air must be heated or cooled isobarically from the external to the internal temperature; in the process, its volume changes and in the end it is equal to the volume of the air it replaces V_a. This also changes the water vapour concentration v_e, which must be recalculated for the internal temperature before it is used in the expression.

The water vapour concentration is usually calculated from the temperature and relative humidity using expressions (4.9) and (4.7).

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Page 217: A new figure was added:

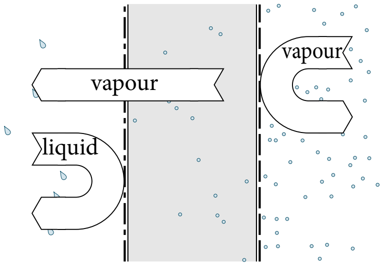

Figure 4.30: The water vapour barrier on the right-hand side prevents water vapour from penetrating the building component. The water vapour permeable membrane on the left-hand side allows water vapour to escape from the wall and prevents liquid water (precipitation) from penetrating the building component.

7 Building acoustics

Page 217: A new text was added after the first paragraph:

In contrast to the previous section, the sound energy is almost uniformly distributed and the *net energy flow* must therefore be zero everywhere in the room. Consequently, the sound pressure no longer relates to the density of sound energy *flow rate* through a given point, but to the density of sound energy at a given point. Although the original concept of sound intensity becomes obsolete, it can still be used to demonstrate basic room phenomena because it relates to the density of sound energy (6.21). Under the new conditions, the sound intensity at a given point is conceptualised as the sum of the sound intensities of all sound waves passing through that point, regardless of their direction.

Page 225: After the Section 7.2.3, new section is added:

7.2.4 Specular reflections from room boundaries

In Section 7.1 we defined the quantity that describes the fraction of energy that is reflected by the material. Now we will take a closer look at how individual sound waves are reflected and what consequences this has.

Depending on the properties of the waves and the surfaces, reflections generally fall into two categories: If the wavelengths are larger than the dimensions of the surface imperfections, the reflection is specular, meaning that the angle of the reflected wave is equal to the angle of the incident wave. However, if the wavelengths are smaller than the dimensions of the surface imperfections, the reflection is diffuse, which means that the reflected waves have several different directions.

Heat transfer by radiation and light are facilitated by waves with short wavelengths, generally less than 100 μm. With the notable exception of perfectly flat mirrors, the surface imperfections are larger, so the reflections are diffuse. The reflected waves are then treated as if they were generated by these surfaces, as explained in Section 8.3.3.

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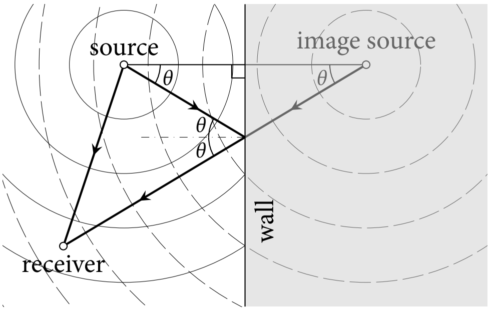

Figure 7.7: The paths of direct and reflected sound waves. The path of the reflected sound wave, assuming that the angles of incidence and reflection θ are equal, can be easily determined by the image source method. The wavefronts of the direct and reflected waves are shown by solid and dashed lines, respectively.

On the other hand, the wavelengths of sound waves are much larger, 0.02 m–20 m, usually larger than the dimensions of the surface imperfections, so that the reflections are specular. The path of the reflected sound wave between the source and the receiver is unique and well defined, because there is only one point on the surface that satisfies the condition that the angle of incidence and the angle of reflection are equal. This point can be easily determined by the image source method: The image source is obtained by mirroring the real source over the reflecting surface (Fig. 7.7).

In the calculation, it can be assumed that the reflected sound actually originates from the image source and not from the real source.

Sound fields near reflective surfaces

Specular reflection causes a 3 dB increase in the sound pressure level near reflective surfaces.

To demonstrate this effect, we first consider the plane wave reflected perpendicularly from the perfectly hard surface at $z = 0$. The wave functions of the displacement for the incident wave x_1, reflected wave x_2 and standing wave x can be written (Section 5.5)

$$\begin{aligned} x_1 &= x_0 \ \sin(\omega t - kz), \\ x_2 &= x_0 \ \sin(\omega t + kz + \pi), \\ xx_1 + x_2 &= -2x_0 \ \cos \omega t \ \sin kz. \end{aligned}$$

As shown in Section 5.4.1, the pulse is inverted for a hard surface (fixed boundary), which is described by a phase difference of π for the reflected wave. Consequently, the displacement amplitude of the standing wave at the surface, $z = 0$, is zero, as expected. However, when we calculate the pressure wave functions (6.2)

$$\begin{aligned} p_1 &= p_0 \ \cos(\omega t - kz), \\ p_2 &= p_0 \ \cos(\omega t + kz), \\ p_1 + p_2 &= 2p_0 \ \cos \omega t \ \cos kz, \end{aligned}$$

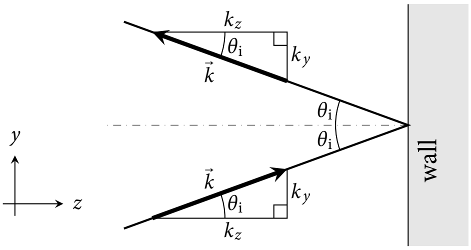

Figure 7.8: The paths of a wave of wavenumber k incident at an angle θ_i. The wavenumber k must be decomposed into a component perpendicular to the surface k_z and a component parallel to it k_y. The reflection reverses only the perpendicular component of the wavenumber k_z.

we see that the pressure amplitude of the standing wave at the surface has the maximum.

Let us also calculate the sound intensity of the plane wave in the free sound field I_f, that is, the incident sound wave without the reflected sound wave by calculating the time average of the squared sound pressure p_1 (6.14)

$$I_f = \frac{1}{\rho c} \cdot \frac{1}{t'} \int_0^{t'} p_1^2(t)\,\mathrm{d}t = \frac{p_0^2}{2\rho c}.$$

We have already established that in the *diffuse sound field*, the incident sound waves come from all directions. For a wave incident at an angle θ_i, the wavenumber k must be decomposed into a component perpendicular to the surface, along the z-axis, and a component parallel to it, along the y-axis (Fig. 7.8). The reflection reverses only the perpendicular component of the wavenumber

$$\begin{aligned} p_1 &= p_0\ \cos(\omega t - k\cos\theta_i\, z - k\sin\theta_i\, y), \\ p_2 &= p_0\ \cos(\omega t + k\cos\theta_i\, z - k\sin\theta_i\, y), \\ p = p_1 + p_2 &= 2p_0\ \cos(\omega t - k\sin\theta_i\, y)\ \cos(k\cos\theta_i\, z). \end{aligned}$$

The superposition of the incident and reflected waves forms a standing wave perpendicular to the surface and a travelling wave parallel to the surface. To calculate the intensity, we must calculate the time average of the squared sound pressure (6.14)

$$\begin{aligned} I(z,\theta_i) &= \frac{1}{\rho c} \cdot \frac{1}{t'} \int_0^{t'} p^2(t)\,\mathrm{d}t, \\ I(z,\theta_i) &= 2\,I_f\,[1 + \cos(2\,k\cos\theta_i\, z)]. \end{aligned} \tag{7.33}$$

Finally, we can find the total intensity for plane waves coming from all angles of incidence, using the same procedure as in Section 7.2.2

$$I(z) = 2\,I_f \int_0^{\pi/2} [1 + \cos(2\,k\cos\theta_i\, z)]\,2\pi\sin\theta_i\,\mathrm{d}\theta_i = 4\pi\,I_f \left(1 + \frac{\sin 2kz}{2kz}\right).$$

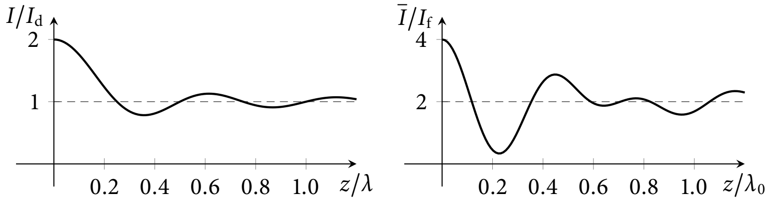

Figure 7.9: Sound intensity near hard surfaces: Single frequency sound intensity near the room boundary relative to the sound intensity of the diffuse field (left) and octave band averaged sound intensity for a perpendicular sound wave near the façade relative to the sound intensity of the free field (right).

This expression describes the sound intensity within the room. For larger distances from the room boundary, $kz \gg 1$, the sound intensity tends to its diffuse value I_d, so that the sound intensity in the room relative to the sound intensity of the diffuse field is

$$I(z) = I_d \left(1 + \frac{\sin 2kz}{2kz}\right). \tag{7.34}$$

Because of coherent interference between waves of different directions, the sound intensity at the surface is twice the sound intensity further away (Fig. 7.9, left), which corresponds to 3 dB increase of the sound pressure level.

To avoid boundary effects, standards require that sound pressure levels should generally be measured at a distance of at least 0.5 m from room boundaries [48, 49, 65].

The same effect can be demonstrated in the free sound field, but for a frequency band. We will now examine the situation with sound waves of the same intensity, that is, of the same sound pressure amplitude, perpendicular to the façade. For a single wave intensity we use the expression obtained above (7.33), with $\theta_i = 0$. The average intensity is determined for a one octave band around the central frequency f_0, extending from $f_0/\sqrt{2}$ to $f_0\sqrt{2}$, which corresponds to the average intensity for a one octave band around the central wavenumber k_0 extending from $k_0/\sqrt{2}$ to $k_0\sqrt{2}$

$$\begin{aligned}\bar{I}(z) &= \frac{2\,I_f}{k_0\sqrt{2} - k_0/\sqrt{2}} \int\limits_{k_0/\sqrt{2}}^{k_0\sqrt{2}} [1 + \cos(2\,kz)]\mathrm{d}k \\ \bar{I}(z) &= 2\,I_f \left(1 + \frac{\sin(2\sqrt{2}k_0 z) - \sin(\sqrt{2}k_0 z)}{\sqrt{2}k_0 z}\right).\end{aligned} \tag{7.35}$$

The average sound intensity is twice the sound intensity of the free field (Fig. 7.9, right) because the energy of the sound wave reflected from the surface adds to the energy of the incident sound wave. The average sound intensity at the surface is further doubled by the coherent interference between sound waves of different frequencies, quadrupling the sound intensity of the free field. This corresponds to a 3 dB increase in the sound pressure level near the reflective surface and a 6 dB increase in the sound pressure level at the reflective surface itself compared to the sound pressure level of the free sound field.

The standard ISO 1996-2 [26] prescribes a correction of 6 dB for microphones mounted on the reflecting surface and a correction of 3 dB for the microphone 0.5 m–2 m in front of the reflecting surface to obtain the free sound field value. In addition, the equations in the standard ISO 16283-3 [65] include a 3 dB correction for the positions of the microphone mounted on the façade relative to those further away from the façade.

8 Illumination

Page 264, line 5: A sentence was added at the end of line: ‘These can be divided into two groups:’

Page 264, line 5: A new title was added after the paragraph: ‘A. *Incandescent light sources*

Page 264, line 28: A new title was added after the paragraph: ‘B. *Luminescent light sources*

Page 264, line 30: ‘older types of light sources’ was replaced by ‘incandescent light sources’

Page 265, line 24: ‘old types of light sources’ was replaced by ‘incandescent light sources’

Page 265, line 27: ‘new types of artificial light sources’ was replaced by ‘luminescent light sources’

Page 266, Info box: ‘New types of artificial light sources’ was replaced by ‘Luminescent light sources’

Page 266, line 4: ‘new types of light sources’ was replaced by ‘luminescent light sources’

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Bibliography

Page 283: New references were added:

[65] ISO 16283-3:2016, Acoustics – Field measurement of sound insulation in buildings and of building elements – Part 3: Façade sound insulation.

M. Pinterić, *Building Physics*,
https://doi.org/10.1007/978-3-030-67372-7_5

Existing references used:

[26] ISO 1996-2:2017 Acoustics – Description, measurement and assessment of environmental noise – Part 2: Determination of environmental noise levels.

[48] ISO 16283-1:2014, Acoustics – Field measurement of sound insulation in buildings and of building elements – Part 1: Airborne sound insulation.

[49] ISO 16283-2:2015, Acoustics – Field measurement of sound insulation in buildings and of building elements – Part 2: Impact sound insulation.