The Influence of the Sound Absorber Application to the Acoustics Conditions and the Thermal Transfer Value of the Building Envelope in Open Plan Office

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Abstract. In open plan office concept, the acoustical distraction problems have become a common problem. Besides, it also needs to deal with thermal issues to have a comfortable work environment. Since the concern of sustainable design is highly discussed, design solutions need to consider energy-saving and environmental health. Commonly sound absorber materials are used to improve acoustics quality. To increase the absorptance, the absorber is installed with air gap and filled with additional insulation e.g. mineral wool. These extra layers potentially give benefit to reduce the thermal transfer when being applied on the envelope walls and ceilings. It is because some of the sound absorber material, air gap, and mineral wool have a low thermal conductivity resulting in lower thermal transfer. This research observes the influences of various sound absorber applications on the acoustics condition and also the impact on the overall thermal transfer value (OTTV and RTTV). The thermal transfer calculation refers to Indonesia National Standard SNI-03-6389-2000, while the rooms acoustics is simulated with Software CATT Acoustics v9 referring to BS EN ISO 3382-3:2012. Absorber materials that been involved are wood wool and PET panel. The result shows that wood wool that applied with 30 mm air gap and additional insulation have reduced the OTTV and RTTV of the room envelope. The initial room condition with Reverberation Time 3.71 second has been reduced to 0.48 second, while OTTV and RTTV are reduced from 48.65 W/m\textsuperscript{2} and 37.38 W/m\textsuperscript{2} become 44.24 W/m\textsuperscript{2} and 14.27 W/m\textsuperscript{2} respectively.

Keywords: open plan office, acoustics distractions, sustainable materials

1. Introduction

Building design can contribute to the sustainable environment by developing the concept design that minimizes energy consumption, using recycled material, and implementing multi-function room elements and furniture. In the context of open plan office, where the staff is working in the large same room, the need to achieve thermal comfort is crucial due to the number of people and electronic devices. In tropical countries such as Indonesia, the overheat condition that is not resolved by the building design will cost extra energy for the cooling system.

This open layout concept also has a higher distraction for acoustical comfort and concentration \textsuperscript{1}. Room acoustics can be improved by applying absorptive materials inside the room in order to reduce the reverberation time. The absorptance of the material can be increased by installing the material with air gap and filled with acoustic insulation material e.g. mineral wool \textsuperscript{2}\textsuperscript{3}\textsuperscript{4}. These extra layers of the walls potentially give a benefit to reduce the thermal transfer of the building envelope. It is because
some of the sound absorber material, air gap, and mineral wool have a low thermal conductivity that results in a lower overall thermal transfer [5][6][7][8].

The parameter that been used in this research is Overall Thermal Transfer Value (OTTV) and Roof Thermal Transfer Value (RTTV). OTTV and RTTV describe the average transmittance value of the whole building envelope including the solar radiation effects [5]. In Indonesia and some other countries in South-East Asia e.g. Malaysia, Singapore, and Thailand, require the OTTV must be under 45 W/m² [6][9].

For the room acoustics, the simulation and parameters are referring to BS EN ISO 3382-3 2012 about the open plan office acoustics measurement. The reverberation time standard for office is 0.6 s [10], while in Indonesia the workspace is suggested to have a reverberation time between 0.6-0.8s [11]. Beside the reverberation time (T₃₀) the distraction distance (r₀) and privacy distance(r₀) are also be observed [12]. Room acoustics conditions in open plan office influenced by the absorber shapes and configuration on wall and ceiling [13][14].

Since the main acoustics distraction in open plan office come from human activity such as conversation [15][16], the absorber materials that been involved are wood wool and polyethylene terephthalate (PET) panel that have sufficient absorption coefficient for speech frequencies [17][18]. Both materials also have a low thermal conductivity that suitable to reduce the thermal transfer thru the wall and ceiling [19][20]. Wood wool and PET have a fine finish look that not necessarily being covered by other materials for interior use.

2. Methods
2.1. Room Model
The room’s size is 8 x 19.2 x 3.5 m (538 m³). Walls at the south and east sides consist of 70% glasses or Window to Wall Ratio (WWR) 70%. The simulations are done by varying the interior finishes and its method of application on the north wall, west wall, and ceiling in order to evaluate the room acoustic condition and thermal transfer.
Wood wool and PET panel are simulated with several methods of application: direct clad to the main wall (no air gap), with air gap, and with air gap and filled with lining (mineral wool).

**Figure 1.** Room’s view (a) 3 Dimension; (b) Elevation

**Figure 2.** Configuration with Wood Wool (a) Wall; (b) Ceiling
The materials are placed on the north and west place or around 50% of the total wall area. It is also observed the condition when the wall finishes are reduced to 39.3% only. The other wall surface are concrete, where south and east walls have 70% of glass, or around 35% of the total wall area.

**Figure 3.** Configuration with PET (a) Wall; (b) Ceiling

**Figure 4.** Materials position (a) 50% of total wall area; (b) 39.3% of total wall area
The below image shows the ceiling plan for the combination condition of ceiling finishes

![Ceiling Plan](image)

- : Absorber Material (Wood Wool / PET),  : Gypsum Board

**Figure 5. Ceiling plan**

### 2.2 Room Acoustics Simulation

The room acoustics conditions are simulated using ray-tracing software CATT Acoustics v9 and referring to Standard BS EN ISO 3328-3:2012 about the Acoustics Measurement of Room Acoustic Parameters for Open Plan Office. Output parameters that been observed are reverberation time ($T_{30}$), A-weighted sound pressure level at 4 meters distance from the source ($L_{pA,s,4m}$), and distraction distance ($r_D$) and privacy distance ($r_P$) which are derived from the Speech Transmission Index (STI).

The involved interior materials’ absorption coefficient listed in below table:

| Position     | Material                        | Absorption Coefficient (%) |
|--------------|---------------------------------|----------------------------|
|              |                                 | 125 | 250 | 500 | 1000 | 2000 | 4000 |
| Wall         | Concrete                        | 1   | 1   | 1   | 2    | 2    | 2    |
| Wall         | Glass 8 mm                      | 10  | 6   | 4   | 3    | 2    | 2    |
| Ceiling      | Concrete                        | 1   | 1   | 1   | 2    | 2    | 2    |
| Floor        | Parquet                         | 4   | 4   | 7   | 6    | 6    | 7    |
| Workstation  |                                 | 28  | 22  | 17  | 9    | 10   | 11   |
| Interior     | Gypsum Board, suspended         | 29  | 10  | 5   | 4    | 7    | 9    |
| Finishes     |                                 |     |     |     |      |      |      |
|              | Wood wool 25 mm, no air gap     | 5   | 15  | 35  | 95   | 75   | 80   |
|              | Wood wool 25 mm, air gap 100 mm | 15  | 55  | 85  | 60   | 70   | 65   |
|              | Wood wool 25 mm, air gap 30 mm, with lining | 15  | 75  | 99  | 75   | 80   | 80   |
|              | Wood wool 25 mm, suspended 200 mm, with lining | 60  | 90  | 90  | 80   | 80   | 90   |
|              | PET 24 mm, no air gap           | 5   | 15  | 55  | 85   | 95   | 95   |
|              | PET 24 mm, air gap 50 mm        | 15  | 40  | 90  | 99   | 95   | 95   |
|              | PET 24 mm, suspended 400 mm     | 70  | 80  | 90  | 90   | 99   | 99   |
The room acoustics simulations are done with several variations of material arrangement. The source used is omni-directional with 7 receivers in straight line position. As the sound source used normal effort unisex speech, while for environmental noise used an open plan office background noise characteristic.

| Table 2: Sound source |
|------------------------|
| **Frequency [Hz]** | 125 | 250 | 500 | 1000 | 2000 | 4000 |
| SPL at 1 m source at free field [dB] | 50 | 54 | 58 | 52 | 44.8 | 38.8 |

| Table 3: Background noise |
|---------------------------|
| **Frequency [Hz]** | 125 | 250 | 500 | 1000 | 2000 | 4000 |
| Background noise [dB] | 45 | 38 | 32 | 28 | 25 | 23 |

Figure 5 shows the 3D view of simulated room in CATT acoustics.

![Figure 5: 3D view of simulated room in CATT acoustics](image)

**2.3 Thermal Transfer Calculation**

To evaluate the thermal transfer of the room’s envelope, the parameter Overall Thermal Transfer Value (OTTV) and Roof Thermal Transfer Value (RTTV) are used. OTTV and RTTV are obtained by calculating the material transmittance. Based on Indonesia National Standard (SNI) 03-6389-2000, below are the formulas for calculating OTTV and RTTV:

\[
\text{OTTV} = \alpha U_w (1 - \text{WWR}) T_{D_{eq}} + \text{WWR} \times U_g \times \Delta T + \text{WWR} \times SC \times SF
\]  

\[
U_w, U_g : \text{Transmittance value (W/m}^2\text{)}; \text{wall, glass}
\]

\[
\text{WWR} : \text{Window to wall ratio}
\]

\[
T_{D_{eq}} : \text{Temperature Difference Equivalent (K)}
\]

\[
\Delta T : \text{Difference between internal and external air temperature}
\]

\[
\text{SC} : \text{Shading Coefficient}
\]

\[
\text{SF} : \text{Solar Factor (W/m}^2\text{)}
\]

\[
\alpha : \text{Absorbance of the surface}
\]

Total OTTV for walls are calculated with below formula:

\[
\text{OTTV}_{w, \text{tot}} = \frac{\sum_{j=1}^{n} \text{OTTV}_{j, w, j} A_{w, j}}{\sum_{j=1}^{n} A_{w, j}}
\]
The RTTV is calculated with below formula:

\[ \text{RTTV} = \frac{\alpha U_r A_r T_{\text{eq}} + A_r \times \text{SC} \times \text{SF} + U_s A_s \Delta T}{A_0} \]  \hspace{1cm} (3)

- \( U_r, U_s \) : Transmittance value (W/m²); roof, skylight
- \( A_r, A_s \) : Area; non transparent roof, skylight (m²)
- \( A_0 \) : Total roof area (m²)

The materials specification and environment conditions are showed in below table:

**Table 4: Specification of Materials**

| Material            | Thermal Conductivity [K] (W/m·K) | Thickness [b] (mm) |
|---------------------|----------------------------------|--------------------|
| Concrete            | 1.45                             | 100                |
| Glass               | 1.053                            | 8                  |
| Wood Wool           | 0.04                             | 25                 |
| PET                 | 0.035                            | 24                 |
| Rockwool            | 0.035                            | 50                 |
| Gypsum Board        | 0.17                             | 12                 |
| Cement plaster      | 0.53                             | 15                 |

**Table 5. Condition for OTTV and RTTV calculation**

| Component                        | Value                  |
|----------------------------------|------------------------|
| Orientation                      | South, East            |
| Solar Factor (SF): South; East   | 97; 112                |
| Surfance absorbance \( \alpha \) (wall) | 0.3                   |
| Surfance absorbance \( \alpha \) (roof) | 0.61                  |
| \( T_{\text{eq}} \) (wall)       | 10 (K)                 |
| \( T_{\text{eq}} \) (roof)      | 16 (K)                 |
| Shading Coefficient (SC)         | 0.9                    |
| \( R_{so} \)                     | 0.044 m²K/W            |
| \( R_{si} \)                     | 0.12 m²K/W             |
| Roof Airgap- Horizontal          | 0.17 m³K/W             |
| Wall - Airgap                    | 0.16 m³K/W             |
3. Findings and Discussion
The result of the room acoustics simulation and the thermal transfer calculation are provided in Table 6 and Table 7 below:

Table 6. Results of acoustics simulation and thermal calculation

| Condition | Wall | Ceiling | $T_{30}$ (s) | $L_{pA_s,4m}$ (dBA) | $r_D$ (m) | $r_P$ (m) | OTTV (W/m$^2$) | RTTV (W/m$^2$) |
|-----------|------|---------|-------------|---------------------|----------|----------|----------------|----------------|
| 1         | Concrete | Concrete 100% | 3.71 | 60.62 | 6.87 | 30.63 | 48.65 | 37.38 |
| 2         | Concrete | Gypsum Board 100% | 3.11 | 59.86 | 2.37 | 33.77 | 48.65 | 19.3  |
| 3         | Wood wool, no gap 50% | Concrete 100% | 0.93 | 55.9 | 15.04 | 42.57 | 45.27 | 37.38 |
| 4         | Wood wool, air gap 100 mm 50% | Gypsum Board 100% | 0.76 | 53.59 | 17.61 | 43.47 | 45.03 | 19.3  |
| 5         | Gypsum Board 100% | Gypsum Board 100% | 0.6 | 52.52 | 17.5 | 39.4 | 44.24 | 16.46 |
| 6         | Gypsum Board 100% | Gypsum Board 100% | 0.57 | 51.9 | 15.96 | 33.3 | 44.98 | 16.46 |
| 7         | Wood wool, air gap 30 mm, with lining 50% | Gypsum Board 100% | 0.63 | 53.11 | 18.5 | 41.6 | 44.98 | 16.46 |
| 8         | Gypsum Board 100% | Gypsum Board 100% | 0.51 | 52.3 | 18.08 | 38.21 | 45.18 | 14.97 |
| 9         | Gypsum Board 100% | Gypsum Board 100% | 0.48 | 51.49 | 17.44 | 36.31 | 44.24 | 16.46 |
| 10        | Wood wool, air gap 30 mm, with lining 40% | Gypsum Board 100% | 0.92 | 53.57 | 11.25 | 32.53 | 45.18 | 14.97 |

Table 7. Results of acoustics simulation and thermal calculation

| Condition | Wall | Ceiling | $T_{30}$ (s) | $L_{pA_s,4m}$ (dBA) | $r_D$ (m) | $r_P$ (m) | OTTV (W/m$^2$) | RTTV (W/m$^2$) |
|-----------|------|---------|-------------|---------------------|----------|----------|----------------|----------------|
| 11        | PET 24mm, no gap 50% | Gypsum Board 100% | 0.66 | 54.35 | 17.16 | 40.7 | 45.18 | 19.3 |
| 12        | PET 24mm, no gap 50% | Gypsum Board 100% | 0.47 | 52.51 | 16 | 34.07 | 45.18 | 16.46 |
| 13        | PET 24mm, gap 25mm 50% | Gypsum Board 100% | 0.42 | 51.54 | 16.74 | 34.49 | 44.98 | 16.46 |

Table 6 and Table 7 show that the addition of interior finishes that also functioned as sound absorbers influence the room condition on both acoustics and thermal transfer. The arrangement of the materials and the way the materials being installed whether with air gap and additional insulation have an impact on all the observed parameters.

On the wall arrangement with wood wool (Table 6) shows the rooms with general materials such as concrete and standard gypsum board without additional sound absorbers have the highest reverberation times and thermal transfer values. Condition with lowest OTTV is the combination of material wood wool with air gap 30 mm filled with insulation (Condition 7,8,9). Condition 9 also has the most significant reverberation time reduction from 3.71 s to 0.48 s.
When there is an air gap between absorber material and the main wall, the air space acts as a spring that damps the sound energy. Thus, the absorption of the system is increased. Furthermore, the additional insulation which is a porous absorber turns the low frequency sound energy to heat. Meanwhile, OTTV and RTTV are influenced by the material’s thickness and thermal conductivity. The thicker the material, the lower heat transmittance, the higher thermal conductivity the higher heat transmittance. Therefore, the wall with air gap has lower OTTV, due to the extra thickness yet low thermal conductivity. For the condition with additional insulation, the porous material gives an extra layer of thickness with a very low thermal conductivity that reduce the OTTV of the wall system.

The shortest reduction distance and privacy distance is in Existing Room or Condition 1 (without absorber). This is because the $r_D$ and $r_P$ are derived from the STI value. While the reverberation time is high, the speech intelligibility is low. It causing the $r_D$ and $r_P$ are short, even though the overall acoustic condition is actually bad due to high reverberation time. From table 6 the distraction and privacy distance are getting low aligned with the reverberation time, while in table 7 there is inconsistency on the Condition 13. Lp,A,s,4m results show that the value is getting lower aligned with the reverberation time in all conditions.

Comparing the OTTV result between Condition 3 and Condition 11, it can be seen that the acoustic materials give effects to the thermal transfer depending on the thermal conductivity. The thermal conductivity between PET and wood wool is not significant thus the OTTV is only slightly different. It also can be observed at conditions 4 and 5, where the ceiling finishes with gypsum board only has a higher RTTV compared to the condition that combined with lower thermal conductivity which is wood wool because the wood wool has lower thermal conductivity compared gypsum board.

Even though the Condition 9 has the most significant overall improvement, from the acoustics aspects the Reverberation Time 0.48 s needs to be re-evaluated. For office function, it is suggested to have 0.6-0.8s, which RT below that number will be considered not comfortable. Thus, a balanced arrangement needs to be planned carefully to give benefit to all aspects. On the other hand, in Condition 7, the reverberation time value is 0.63s, which is within the standard, this condition also has the lowest OTTV standard 44.24 W/m$^2$. Even though the RTTV 19.3 W/m$^2$ is not the lowest among the others, yet it still an acceptable value for RTTV based on several standards including SNI 03-6386-2000.

4. Conclusion

Interior finishes have several roles other than as the aesthetic function. In room acoustics, interior finishes materials have the main contribution to the sound quality because the room’s surfaces are where the sound is being reflected or absorbed. When the interior finishes material attached to the building envelope, interior finishes material will take part as a barrier to the thermal transfer from outside.

To increase the performance of the sound absorber, it is commonly installed with air gap and filled with additional insulation. Some of the absorber materials, the air gap, and the additional insulation have a low thermal conductivity that gives benefit to reduce the thermal transfer to the room.

The results in this research show that the arrangement to improve the room acoustics condition also give a benefit to reduce the thermal transfer into the room. The room with Condition 9, where its 2 walls are arranged with wood wool, 30 mm air gap filled with lining, and use wood wool on the 40% of the ceiling area, has the lowest OTTV and RTTV. The initial room without absorber with RT value 3.71 s has been reduced to 0.48 s, and OTTV and RTTV are reduced from 48.65 and 37.38 W/m$^2$ become 44.24 and 14.27 W/m$^2$.

However, reverberation time has a range of standard that the lowest reverberation time is not always the most suitable depends on the function and volume of the room. For office function, it is suggested to have reverberation time between 0.6-0.8s. Thus 0.48 s is more likely too low. Therefore, the arrangement of the material finishes needs to be carefully considered for the benefit of both aspects.

The use of wood wool and PET have a different effect on the room’s Reverberation Time because of the differences on the absorption coefficient, yet it resulting almost the same OTTV and RTTV reduction due to the similar thermal conductivity value.

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