# Multi-functional louvers at half-covered roads and intermittent tunnels in urban areas: Performance and Characteristics

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A louver system for half-covered road structures and intermittent tunnels has been developed in Japan, in which three functions of light control (for visual environment in roadway space), noise reduction and ventilation control (both for environmental conservation of surrounding urban areas) are combined in one and the same system (in this paper referred to as multi-functional louver, or M.F. louver). This solution has been applied in real structures, and the surrounding population as well as the road users are satisfied with the results.
This paper will introduce the basic functions of louvers, outline the development of louvers and describe design / construction examples of half-covered roads structures with M.F. louver application.

***Key Words :*** *Louver, half-covered road, intermittent tunnel, lighting control, noise reduction, ventilation control, environmental conservation*

**Nomenclature**

| | | |
|---|---|---|
| $A_r$ | Cross section of tunnel | $m^2$ |
| $A_s$ | Area of open ceiling part | $m^2$ |
| $C_{CO2}$ | Concentration CO2 | ppm |
| $C_1$ | Concentration at upstream tunnel exit | ppm |
| $C_2$ | Concentr. at downstream tunnel entrance | ppm |
| $C_{e1}$, $C_{e2}$ | Concentration at tunnel entrance | ppm |
| $C_{r1}$, $C_{r2}$ | Concentration at tunnel exit | ppm |
| q | Unit respiration volume | $m^3/s \bullet m^2 = m/s$ |
| $q_{CO2}$ | Flow rate of tracer gas CO2 | ml/s |
| $q_n$ | Dimensionless respiration volume | - |
| $Q_{r1}$ | Flow volume in upstream tunnel | $m^3/s$ |
| $Q_{r2}$ | Flow volume in downstream tunnel | $m^3/s$ |
| $V_r$ | Mean flow velocity in tunnel | m/s |
| $V_{r1} V_{r2}$ | Flow velocity in tunnel | m/s |

## 1. Introduction

In recent years, examples of half-covered road structures are increasing in urban areas. Also in Japan, half-covered road structures have been planned and constructed in Tokyo, Osaka and elsewhere. At the moment the planning and construction has commenced for a large scale half-covered (half-submerged) tunnel in Tokyo.
Half-covered road structures preserve the urban appearance, and compared to a tunnel structure, especially the cost of artificial ventilation can be largely reduced. These structures still have some outstanding issues, such as noise emission to the surrounding area and visual environment in the roadway space.
For these reasons, a louver construction has been developed in Japan, in which three functions of noise reduction, light control and ventilation are combined in one and the same structure, as further described in this paper.

## 2. Basic functions of louvers

Figure 1 shows louvers installed in front of tunnel entrances. In this case, the main function is normally in terms of entrance lighting as alternative for artificial lighting.
In case louvers are installed at the open part of intermittent tunnels (Figure 2), the main function is often to improve the visual environment. Because the lighting level in this case is different from that of tunnel entrances, the shape of the louver blades will normally also be different.

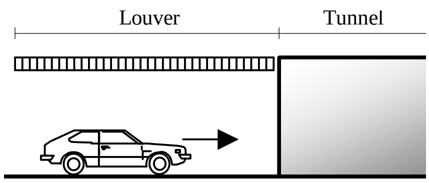



Figure 1 Louver at tunnel entrance

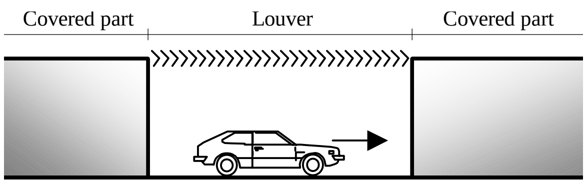



Figure 2 Louver at open part of intermittent tunnel

In addition, louvers at open part of intermittent tunnels will cause part of the ventilated air from the upstream tunnel to flow into the downstream tunnel, and may therefore affect the ventilation requirements of the downstream tunnel.
It is important to carry out investigations for louvers in terms of tunnel planning.

Louvers can play an important role in (Figure 3, 4, 5):
1. reducing the emission of noise to the surrounding area

2. functioning of ventilation effect
3. eliminating the flicker effect caused by cross beams and strong contrast caused by incoming sunlight

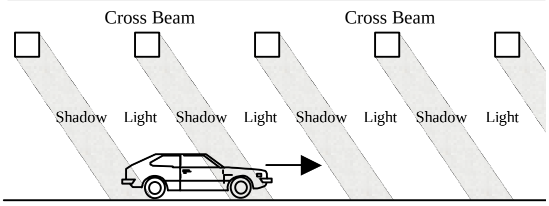



Figure 3 Flicker effect due to cross beams

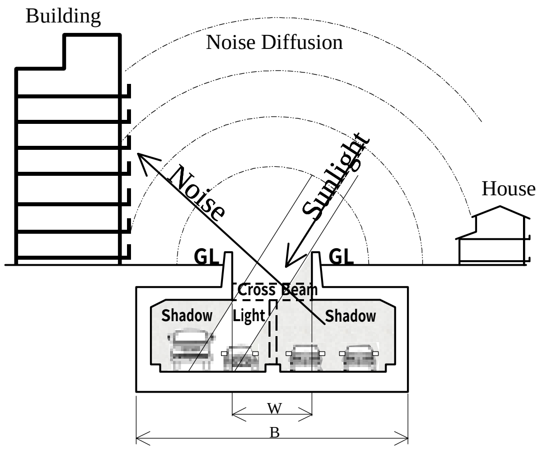



Figure 4 Visual environment and noise reduction

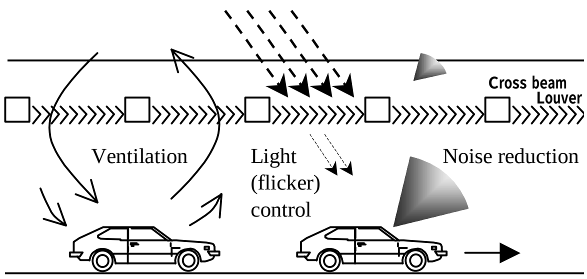



Figure 5 Possible functions of louvers

Louvers must be designed in such a way that
- the required ventilation air volume is preserved
- the required reduction of traffic noise to the surrounding area is preserved
- the required luminance level in the roadway space is preserved

With these basic conditions, louvers have been developed and applied successfully to Japanese highways since the 1980's.

### 3. Basic shape of louver blades

Based on several research experiments carried out in the 1970's, it was concluded that the above conditions are met in the best way in case the louvers consist of plates bended at 120º (mostly weather protection steel or stainless steel), and are installed with the blades pointing in the same direction as the traffic (Figure 6 a.), for the purpose to maintain the ventilation effect (in case the blades are installed in the opposite direction, the ventilation effect will decrease). When required, sound absorbent is added to the louver blades (Figure 6 a., 6 b.). The spacing between the blades is such that sunlight does not enter the roadway directly. At the same time, this means that traffic noise cannot directly (i.e. without reflection) be emitted to the surrounding area.

### 4. Noise reduction function

4.1 Scale model experiment

From previous scale-model experiment [1), it is known that a noise reducing function can be attained to louvers in case a noise absorbent is applied to the louver blades. It is also possible to use louvers solely for the purpose of noise reduction.

Here, the noise reduction effect of louvers is introduced by describing a scale model experiment. Figure 7 shows one example of the experiment results. From this Figure, it can be seen that the noise reduction over 180 degrees is in the order of 15dB.

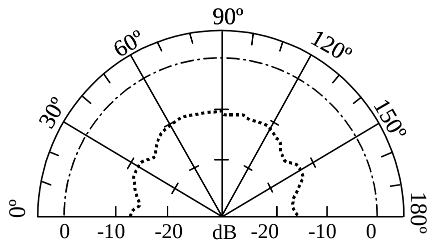
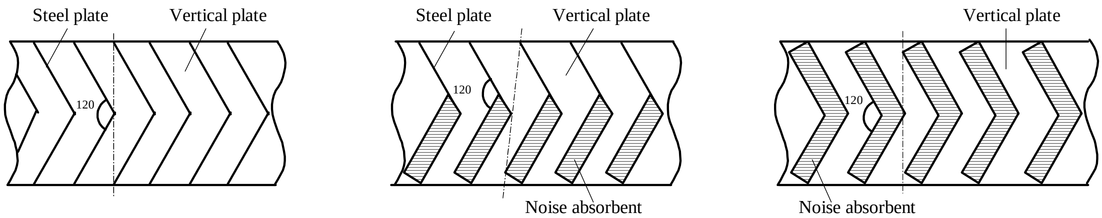



Figure 7 Example of the noise reduction with louver [1)]

4.2 Full scale experiment

4.2.1 Full scale experiment method [2)]

The experiment facility consists of a reverberation chamber with shape and dimensions as shown in Figure 8 and 9, in such a way that noise enters the louver part (height 3.1m, width 2.1m) in all directions. The volume of the reverberation chamber is 165.5m$^3$ and the total




a. Basic shape b. Noise reduction type (1) c. Noise reduction type (2)

Figure 6 Principle shapes of louvers

inner surface area is 183.4m$^2$. A traffic noise source speaker is placed at 1.4m height in the direction of the sidewall, and emits traffic noise through a filter in the range of 50Hz – 5kHz. The 19 measurement points are placed on a circle with 4m diameter at 10º spacing.

Figure 8 Illustration of noise experiment [2)]

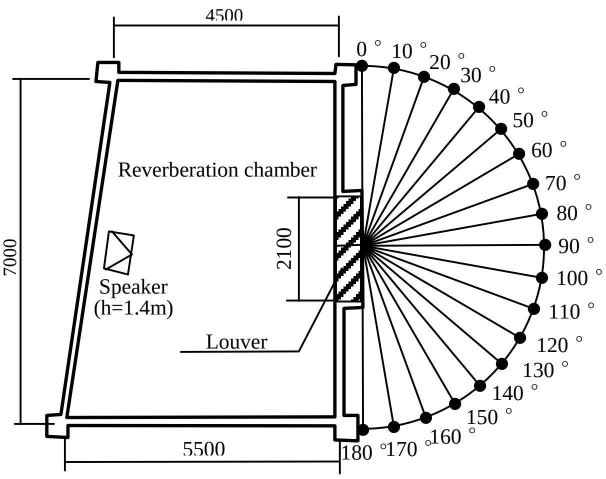



Figure 9 Outside view of noise experiment facility

4.2.2 Full scale experiment results

Figure 10 shows the relation between the area of applied noise absorbent and the noise reduction effect (insertion loss). The results show that the insertion loss increases in a linear way as the area of noise absorbent increases.

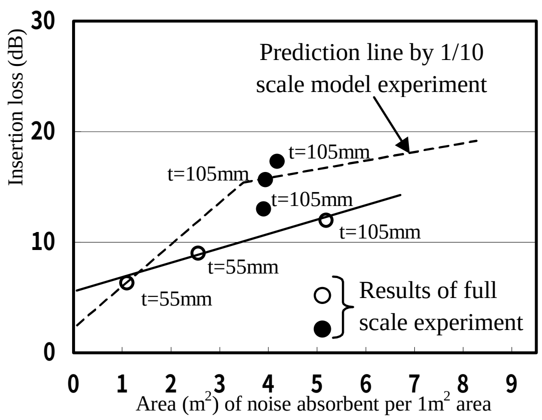



Figure 10 Noise experiment results of open part [2)]

This effect can be controlled to a certain extent by applying different amounts of noise absorbent, and the maximum effect that can be expected is in the order of 20dB.

**5. Ventilation**

Especially for long tunnels and half-covered roads, it is important to introduce a ventilation function to control the gas concentration in the roadway space and to preserve the ambient air quality.

This section describes an experiment that was carried out in order to verify the ventilation function of louvers installed at the open ceiling part of intermittent tunnels.

5.1 Shape of louver blades for experiment

A scale-model experiment has been carried out to verify the ventilation effect by louver installation. Figure 11 shows the louver shapes used in this experiment, which resemble louver shapes actually in use in Japanese highways (except Case 2). Figure 12 shows the scale models of these louver cases.

When comparing the noise reduction performance of the louver cases for this ventilation experiment, Case 2 and Case 3 have a similar performance, even though Case 3 has less noise absorbent per unit area than Case 2. This can be explained by the better performance of noise absorbent with increased thickness, applied in Case 3.

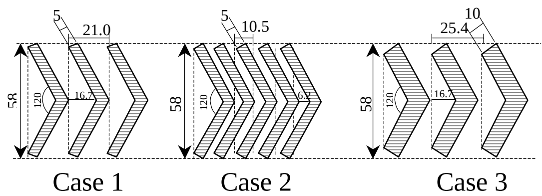



Figure 11 Louver cases for ventilation experiment

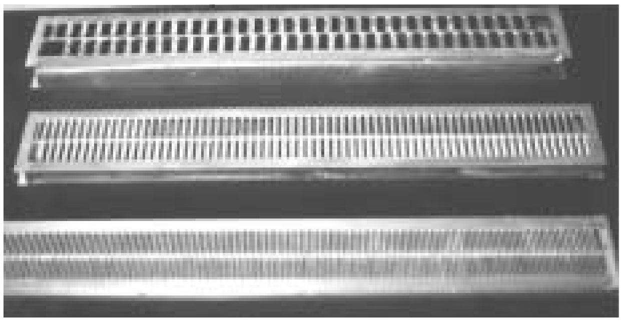


Figure 12 Scale models of louver cases

5.2 Experiment method

The scale models of the louver cases have been mounted at the open ceiling part between two scale model tunnels. This 1:200 scale model is placed on a tunnel ventilation test facility (Figure 13) that consists of two running belts with scale-model vehicles, and equipment to supply, sample and analyze $CO_2$ tracer gas (in total 22 measurement points at the louver section). Scale model vehicles are fixed to running belts in accordance with the objected traffic conditions (2 traffic lanes, velocity 40km/h, volume 3260 veh./h, head-to-head distance 12.3m, large vehicle mix rate 13%). Figure 14 shows the louver model on the test facility. The experiment was carried out by running the vehicles and releasing tracer gas at the entrances of upstream and downstream tunnel. The concentration of gas is analyzed and the flow velocity is calculated. With these results, the respiration rate at the open ceiling part is predicted in order to verify the ventilation effect of louvers.

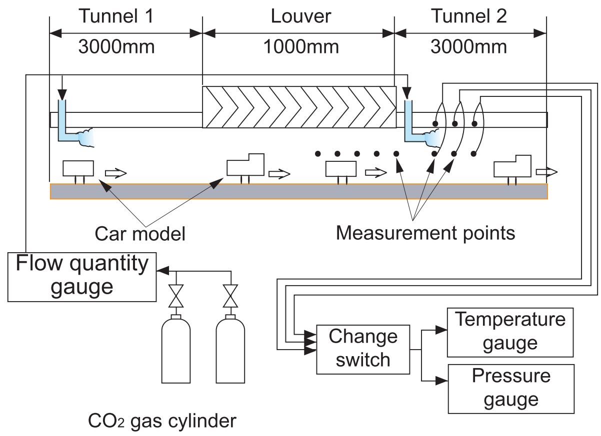



Figure 13 Experiment layout

Figure 14 Louver model on experiment apparatus

5.3 Prediction of unit respiration rate for uni-directional tunnel

Tracer gas $CO_2$ is released at a fixed point from the upstream side of each tunnel, and measured over the whole section of the tunnel after the tracer gas has mixed sufficiently with the tunnel air. The flow rate in the upstream tunnel ($Q_{r1}$) and downstream tunnel ($Q_{r2}$) is calculated with Equation (1), from the mass balance and flow rate balance (Figure 15).

$$Q_{r1} = q_{CO2}\frac{(C_{CO2}-C_{e1})}{(C_{r1}-C_{e1})},\ Q_{r2} = q_{CO2}\frac{(C_{CO2}-C_{e2})}{(C_{r2}-C_{e2})} \quad (1)$$

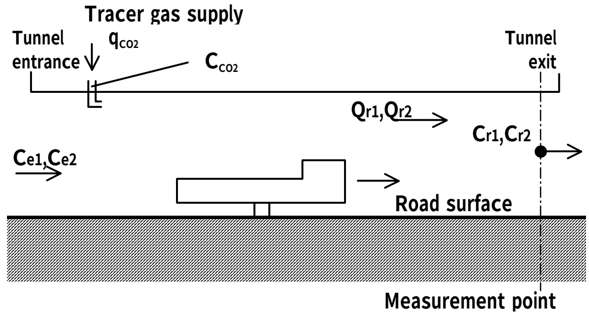



Figure 15 Gas concentration measurement

Using the flow rates ($Q_{r1}$, $Q_{r2}$) and Equation (2), the flow velocity in both tunnels ($V_{r1}$, $V_{r2}$) is obtained.

$$V_{r1} = \frac{Q_{r1}}{A_r},\ V_{r2} = \frac{Q_{r2}}{A_r} \quad (2)$$

As shown in Figure 16, the concentration $C_1$ at the exit of the upstream tunnel gradually decreases in the section with open ceiling part, and converges to a value $C_2$ at the entrance of the downstream tunnel and maintains at a constant level after that.

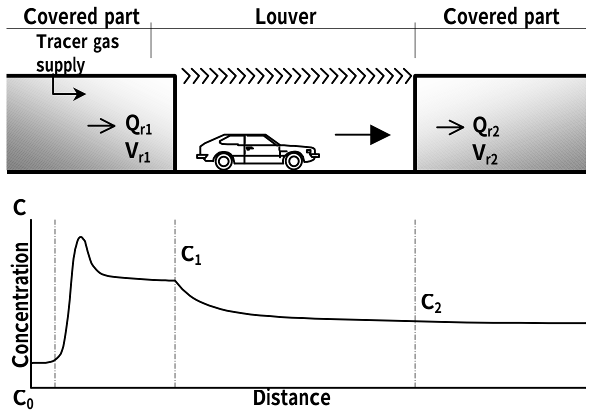



Figure 16 $CO_2$ concentration distribution (roadway space)

In this case, the unit respiration rate q at the open ceiling part with louvers can be calculated with Equation (3).

$$q = \left(\frac{A_r V_r}{A_s}\right)\ln\left(\frac{C_2}{C_1}\right) \quad (3)$$

where, $V_r = \frac{V_{r1}+V_{r2}}{2}$

By dividing the unit respiration rate by the mean flow velocity ($V_r$) in the roadway space, the dimensionless respiration rate $q_n$, which is the respiration rate per unit flow velocity, is calculated as given in Equation (4).

$$q_n = \frac{q}{V_r} \quad (4)$$

Figure 17 shows the visualization of flow through the louver to the outside, by releasing CO2 vapor of dry ice to the air flow at inlet to tunnel, and by using a laser sheet light. No smoke is seen at the end part of the louver (right side of figure), which means that outside fresh air is inhaled into the tunnel at this part of the louver.

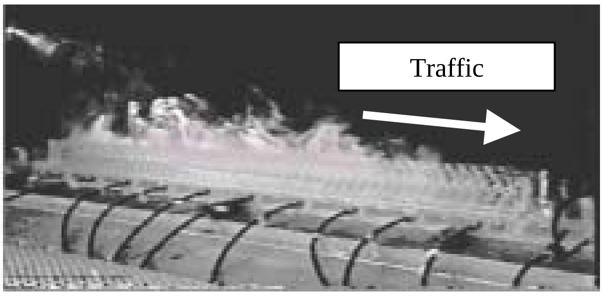



Figure 17 Flow visualization of ventilation

5.4 Experiment results

Figure 18 shows the experiment results.

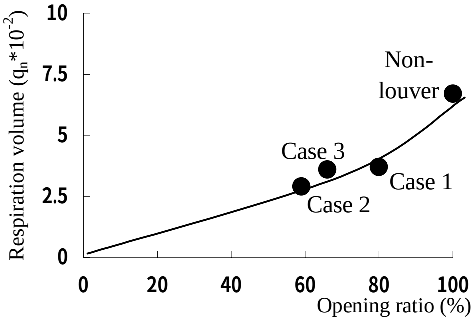



Figure 18 Experiment results

As shown in Figure 18, the ventilation function depends on the pitch of the louver blades. The louver case with the highest noise reduction performance (Case 3) has a ventilation function that is 40% less than the case without louver. On the other hand, there is only small difference in ventilation function for different blade pitch and thickness.

## 6. Visual environment

The M.F. louvers as shown in Figure 6 and 11 have overlapping blades, meaning that sunlight cannot enter the roadway space directly. Therefore, these louver types can be installed perpendicular to the road direction, regardless of the road direction and the geographical position of the road.

The ratio of light transmitted through this louver type is less than 1%. This ratio can be increased by widening the spacing between the louver blades (within the allowable limits to avoid the flickering effect) and allowing some direct sunlight to enter the roadway space. On the other hand, this will mean a reduction of noise reduction function.

It is important to investigate these items in combination with the characteristics of the road structure in question.

## 7. Implementation of louvers to road structures

At the moment, about 30km half-covered road structures are in use in Japan, in which about 90,000$m^2$ M.F. louver is installed.

A recent example is the Ring Road of Nagoya, one of the largest cities in Japan located about 350km west of Tokyo. The Ring Road has a diameter of 10km around the city center, and about 5.5km on the east side consists of a half-covered road structure. The road was opened to traffic in 1992, when there were not many buildings along the road. The urbanization has continued since that time, and the number of high-rise buildings in the direct vicinity of the road has increased accordingly.

Especially the influence of noise from the half-covered road structures required improvements, as well as the visual environment in the roadway space (Figure 19), which lead to the investigation of louvers.

Based on the results of this investigation, it was decided to install louvers at the open parts in the section with half-covered road structure. Figure 20 shows the road before and after louver installation, which was completed in 1998.

The noise conditions in the vicinity of the road, as well as the visual environment in the roadway space have improved considerably, and the surrounding population as well as the road users are satisfied with the results.

Figure 21 shows a detail of the louver blades. Additional investigations have been carried out in order to decide the correct perforation and noise reduction material for the road structure in question. Figure 22 shows the louvers as seen from the roadway space.

Figure 19 Visual environment in roadway space of Nagoya Ring Road before louver installation

Figure 20 (a) Nagoya Ring Road before louver installation

Figure 20 (b) Nagoya Ring Road after louver installation

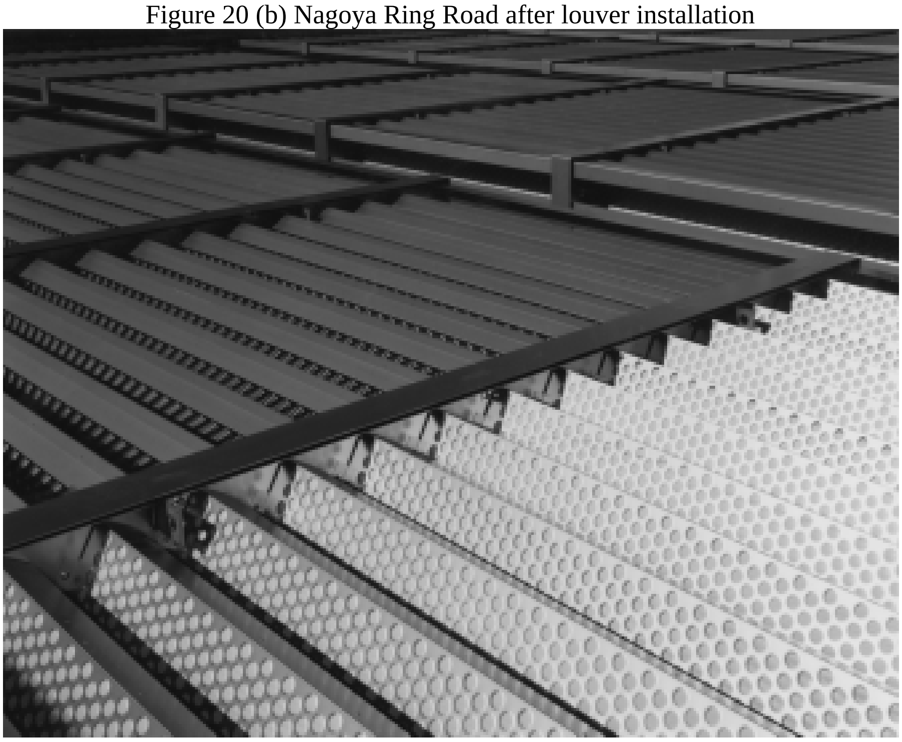


Figure 21 Detail of louver blade

Figure 22 Louver seen from the roadway space

## 8. Conclusion

A multifunctional louver has been developed for urban areas, and is in use in actual half-covered road structures and intermittent tunnel structures.

The main reasons to implement louvers are as follows:

- preserve the urban appearance
- cost reduction in terms of mechanical ventilation and lighting facilities
- environment preservation of surrounding areas, in terms of sound and ventilation air quality control

At the same time, it is necessary to continue developments in order to further improve effectiveness and cost performance.

## Literature

1) Kohei Yamamoto et.al., “Reduction of Road Traffic Noise by Louvers”, Inter-noise, 1984
2) Toshio Matsumoto et.al., “Noise Reduction by Absorptive Louvers”, Inter-noise, 1991
3) Yoshikazu Ota, “Research Report concerning Road Louvers”, 1993