GETTING GOOD SOUND ENVIRONMENT IN OLD BRICK AND WOOD STRUCTURE BUILDINGS

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There were large numbers of old wood and brick structure buildings maintained in China, some of which were historical buildings, and there were strict restrictions when they were renovated. These old buildings have poor sound environment. When changed to hotels, the sound environment became serious problem. This paper investigated numbers of historical buildings maintained in normal ways in Hangzhou, and found that the sound environment were not improved. One old brick and wood structure house built 90 years ago were refurbished and changed to a hotel last year, the wood structure must be reserved as a historical building. A multi-layer floor including steel plate was used for good air-borne and impact sound insulation. Other sound insulation measures were also used. The weighted standardized level difference measured between first floor and second floor was 48-51dB. The weighted standardized impact sound pressure level was 51-55dB. The consumers were satisfied with the sound environment.
Keywords: Sound environment, wood structure, old building renovation

1. Introduction

In the process of urban renewal, the number of old building renovation projects is growing, and the adaptive reuse of historical buildings has become a method of conservation. Most historical buildings in China are wood and brick structure buildings, of which the acoustic properties are poor. This problem was not serious before because these buildings were used by a single family. When reconstructed, these old buildings cannot meet the high sound requirements of new functions. The sound insulation improvement is necessary, but the theory and practice experience in China are inadequate. There are strict restrictions of historical building renovation, which makes it more difficult to improve the acoustic property.

2. Acoustic properties of traditional wood buildings in China

Chinese traditional buildings were mainly wood structure buildings, with wood beams and columns, wood roof frame and floors. Walls acted only as envelops. In most traditional buildings, the gable walls were brick walls, but the wall facing south or the inner yards were usually made of single wood boards.

Low mass and poor sealing leaded to acoustic defects of traditional buildings, including airborne sound insulation of walls and floors, and the impact sound insulation of floors. Weight (mass per unit area) is one of the most important parameter of sound insulation. Traditional wood walls and floors were made of single board, so the low mass of wood resulted in the low airborne and impact sound insulation. Gaps were common in walls and floors made of wood boards, which were ignored in old times, thereby decreasing the sound insulation capability. In most traditional buildings, inner walls were only built to the bottom of lowest beams. There was no wall or only single broad wall above the lowest beam, so the inner walls hardly had sound insulation function.

When reforming an old wood building, the character of wood material and the traditional construction increase the difficulty of acoustic improvement. Firstly, the necessary mass to give good acoustic performance may impose too much load so that adding mass is not a suitable way. The second problem is sealing. Unlike regular concrete beams and columns, wood beams and columns are usually of round section, and some are curved, thus increasing the difficulty of sealing. Besides, the wood roof frame of traditional buildings are complex so that wall integrity is destroyed.

In Hangzhou, some traditional wood buildings were refurbished in the last few years, including reinforcing the structure, replacing outworn components, and repainting the walls using the original construction, but without any treatments of acoustic improvement. Then they were used as stores, hotel, restaurants and offices.

In order to learn more about acoustic performance of traditional wood buildings, a measurement survey has been carried out on 7 of those refurbished old buildings. The measurements were airborne sound insulation of outer walls and floors, and impact sound insulation of floors. The results are shown below:

Table 1 Weighted standardized level difference of 7 refurbished buildings

Building number	Components	Construction	$D_{nT,w}$(dB)
1	Floor	Wood frame	27
	Wall	Wood wall with 3 wood doors	21
2	Wall	Wood wall with 16 wood doors	21
3	Floor	Wood frame(with surface floor and ceiling)	44
	Wall	120mm brick wall with 1 glass window and 1 wood door	20
4	Floor	Wood frame(with ceiling)	35
	Wall	Wood wall with 1 wood door	20
5	Floor	Wood frame	22
	Wall	wood wall with 1 glass window	24
6	Floor	Wood frame	23
	Wall	wood wall + 2.57mm gap + glass, with 3 wood door	28
7	Floor	Wood frame	20
	Wall	Wood wall with 3 wood doors	16

According to the results, these refurbished old wood buildings did not perform well in airborne sound insulation. The weighted standardized level differences of wood walls were all under 30dB. The wall in building No.7, consisting of 3 wood doors, was the worst one, namely only 16dB. The wood frame floors also had a bad airborne sound insulation property, and most of their weighted standardized level differences were blow 35dB. The airborne sound insulation of floors in building No.3 and 4 is higher than the others because additional ceilings and floor layers were built when refurbished.

Impact sound measurements were carried out on the floor in building No.5 according to ISO 140, and the result is shown in Figure 1. Unlike concrete floor, the sound level is high at low frequency. The weighted standardized impact sound pressure level was 61dB. But the impact sound was still loud by subjective perception.

It can be concluded that traditional wood buildings have a bad acoustic property, and routine methods of building refurbishment do not make differences in airborne sound insulation. Neither the national standard for sound insulation of civil buildings nor the technical code for partitions with timber framework in China was met.

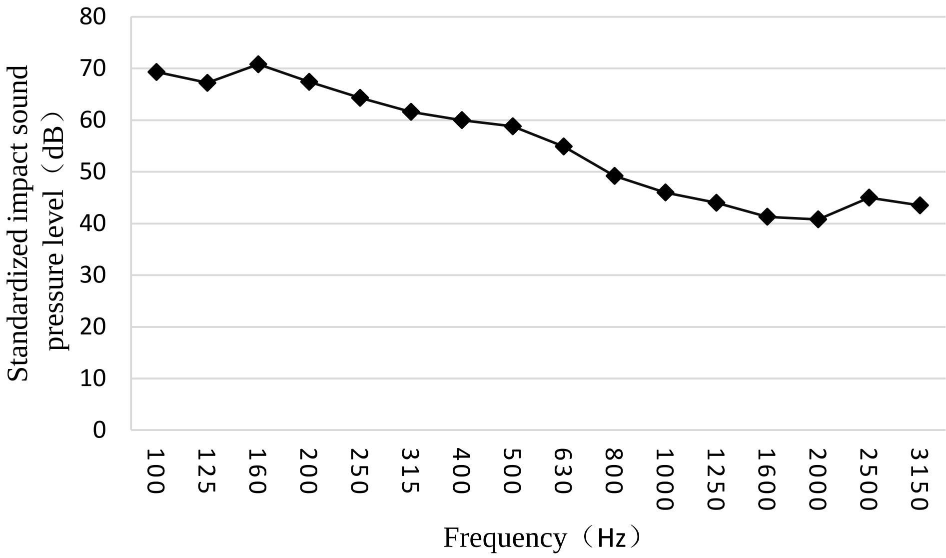


Figure 1 Standardized impact sound pressure level of building No.5

3. Requirement of historical building conservation

Some traditional wood buildings are historical buildings and must obey the conservation restrictions when they were reformed. This is another consideration of acoustic design.

In general, the conservation regulations of historical buildings in China follow the international charters like *Athens Charter for the Restoration of Historical Monuments* and *international Charter for the Conservation and Restoration of Monuments and Sites (Venice Charter)*.

Especially for wood buildings, *Principles for the Preservation of Historical Timber Structures* (1999) put forward principles of interventions and repair. The intervention of a historical timber structure should be minimum. If necessary, any proposed intervention should for preference follow traditional means, and be reversible if technically possible, or at least not prejudice or impede future preservation work.

Historical buildings are divided into 3 grades in China depending on their cultural values, and the conservation rules are different according to the grades. The conservation rule for precious historical and cultural heritage is so strict that they are not suitable for adaptive reuse. Among the conserved old historical buildings, most were built in the modern times. For those buildings, the *2015 Principles for the Conservation of Heritage Sites in China* says, the features of material, architecture and structure should not be changed when repaired.

To improve the sound insulation of wood buildings, interventions and changes are inevitable. When it comes to the acoustic design of historical wood buildings, the measures should for preference:

- Minimize the destructions to existing members, additional components could be better than completely replacing;
- Follow the traditional structure, and the main parts be made of the same material if new constructions necessarily replace the original ones to achieve the acoustic goal;
- Integrate harmoniously with the whole, and be distinguishable from the existing ones.

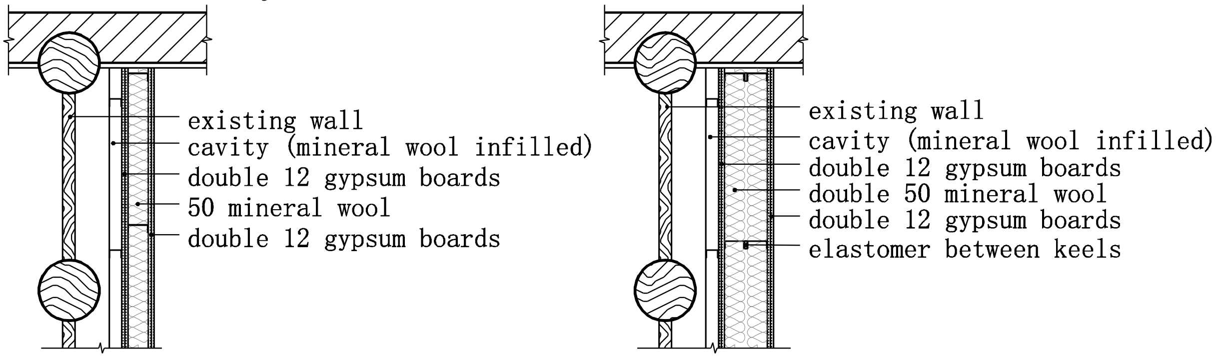
4. Acoustic measures

The goal of acoustic design is to improve the sound insulation property of old wood buildings. Particularly, this means the airborne sound insulation of walls, windows and floors, and the impact sound insulation of floors.

There were researches about acoustic property of wood buildings. Comparatively, air-borne sound insulation is easier to achieve. Double framework construction and absorbent in the cavity can increase the sound insulation values, and a suspended ceiling is appreciable for floors [1]. The impact sound insulation of wood floor is a challenge. In general sound insulation treatments of wood floors are: additional mass and sealing the gaps; adding pugging in the cavity; non-rigid suspended ceilings and floating floors [2] .The treatments can be combined to achieve a good sound insulation. Besides, increasing the mass and stiffness of floor and increasing damping between components are effective [3,4] .

4.1 Walls

Lightweight materials and constructions are mainly used in wood buildings due to load limits, so the basis weight of components is low. The sound insulation values can be achieved by making use of multi-layer construction and cavity insulation. Maintaining the existing components and building an independent additional wall for acoustic improvement can avoid damages to buildings. The additional wall should be composed of several layers and mineral wool. Flexible connection between wall frames is necessary. This construction increase the total wall thickness.



a) used for normal sound insulation b) used for high sound insulation

Figure 2 additional independent wall construction

The sealing performance is affected by roof truss for walls on the top storey. It is difficult to get a tight seal at the junctions of walls and roof, for the soffit of roof is not flat. So sound will spread through the gaps between roof and wall.

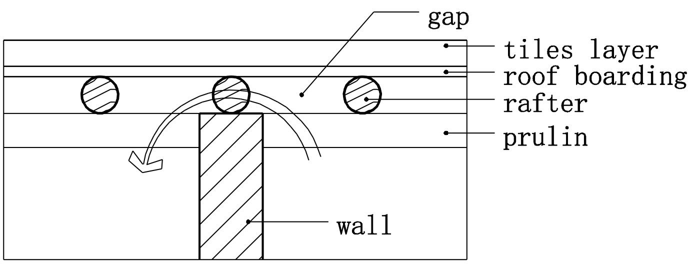


Figure 3 junction of traditional wood roof and wall

To improve the sound insulation of walls, additional walls must be built to the soffit of roof. As it is hard do sealing well, double acoustic ceilings (Figure 4) can be used. The lower ceiling with mineral wool above boards is helpful to reduce sound transmission between rooms and reduce the noise from HVAC and other mechanical facilities. The upper ceiling offers a flat surface, and avoid the gaps between roof truss and walls. Most traditional buildings have sloping roofs, so the roof space is large and beneficial for double acoustical ceiling construction and mechanical facilities.

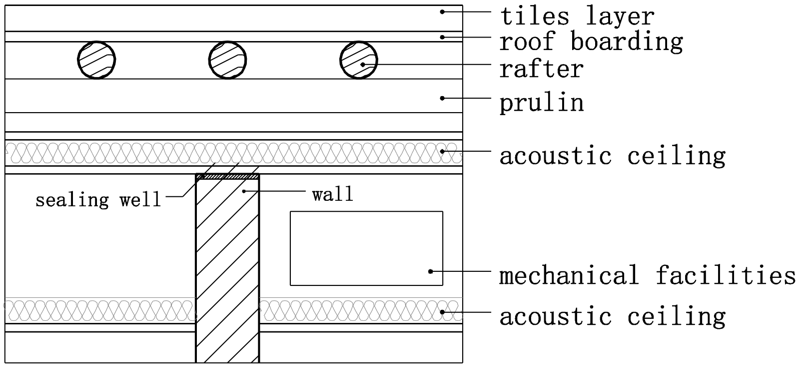


Figure 4 double ceiling construction to improve the sealing of walls

4.2 Floor

Chinese traditional floors were simple wood ribbed floors with a lath ceiling underneath (Figure 5). The floor height of traditional wood buildings was always enough for most treatments. As for historical buildings, to minimize the structural disturbance and remain the distinctive construction, non-rigid suspended ceilings and floating floors may be more appropriate for reforming historical buildings (Figure 6).

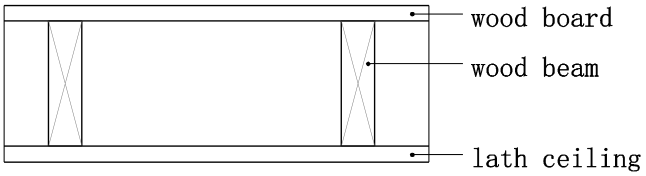


Figure 5 traditional wood floors construction

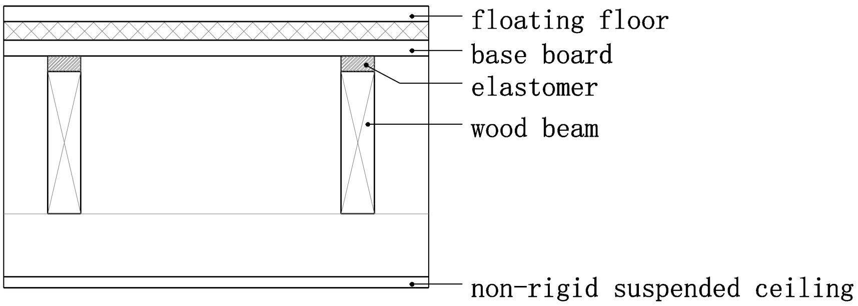


Figure 6 sound insulation floor construction

The floating floor consists of the surface floor and a resilient layer. A composite floating floor with different kind of material could increase its mass, stiffness and damping at the same time and be advantageous for sound insulation. Elastic materials like fiberglass are used as resilient layer. But for wood floor, a more efficient sound insulation, such as rubber vibration isolator, is better if the floor height allows.

A non-rigid suspended ceiling customarily is usually two layers of gypsum boards fixed with resilient channels. Extra boards and mineral wool can further improve sound insulation. It must be taken care of that the gaps between the wall is sealed and ceiling and the resiliency of ceiling is not destroyed. The major shortcoming of ceiling are that it covers the original features of floor, which is not allowed in some historical buildings.

4.3 Windows

Windows are important for envelop walls. New windows with good sound insulation are most recommended. For historical buildings, of which the original windows have to be remained, new windows can be add outside or inside the old ones. The distortion of window frame, which resulted in gaps between walls and windows, requires particular attention.

5. Case Study

Yinlu is a three-storey historical building in Hangzhou. Built in 1929, it was a so-called Chinese and Western architecture, which means that it was an integration of Chinese and Western style. This building had a wood and brick structure, with wood ribbed floors and lath ceilings, wood roof, and brick walls. The outer brick walls were 370mm thick and the inner ones were 240mm thick.

Yinlu was conserved to a boutique hotel in last year. There would be a lobby and a small meeting room on the 1st storey, and totally 4 guest suites on the 2nd and 3rd storey, so the walls and floors between suites and required high sound insulation. The airborne and impact sound insulation of wood floors and the airborne sound insulation of walls were two main problems. Acoustic measures of improving sound insulation were practiced in this project.

5.1 Floors

Considering that this was a historical building, the existing decayed wood floors had to be replaced with the same construction and material, which is the wood ribbed floor. So a floor construction with a floating floor on the original floor was chosen (Figure 7). Rubber vibration isolations were used as elastic supports of floating floor. Different boards were used in the multi-layer floor surface, such as a steel plate to increase mass and SBS boards to increase damping. The risk of rigid coupling and sound flanking were carefully considered and the junction details were designed. E.g. an elastic junction was design for mental nails, and the floor surface was detached from walls.

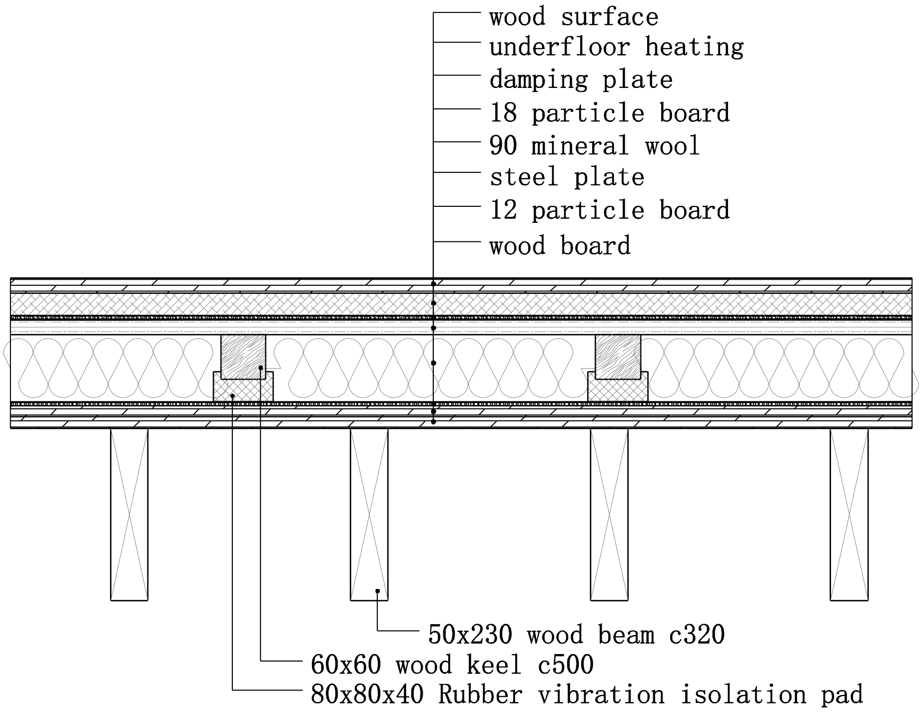


Figure 7 floating floor construction used in Yinlu

There used to be ceilings in the old building but had been destroyed, so suspending ceilings was also used to take place of the old ones. The ceiling board consisted of two layers of gypsum boards and 50mm mineral wool (Figure 8).

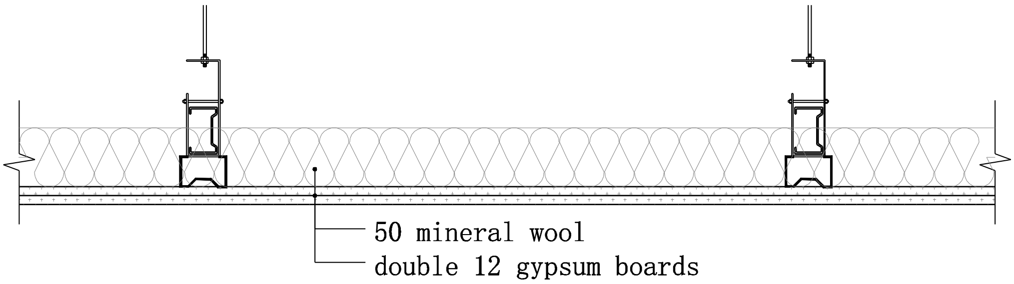


Figure 8 non-rigid suspending ceiling construction used in Yinlu

5.2 Junction of walls and roof

The walls of Yinlu building were all brick walls, massy enough to offer a good sound insulation. On 3rd storey, walls faced the problem of roof frame. Double acoustical ceilings were applied to the roof. The lower ceiling construction was the same as shown in Figure 8. The upper ceiling consisted of two layer of gypsum boards with 100mm mineral wool infilled, and was fixed to an independent frame to avoid imposing load to the roof truss (Figure 9). Junctions of HVAC system had been carefully designed to avoid sound flanking through channels etc.

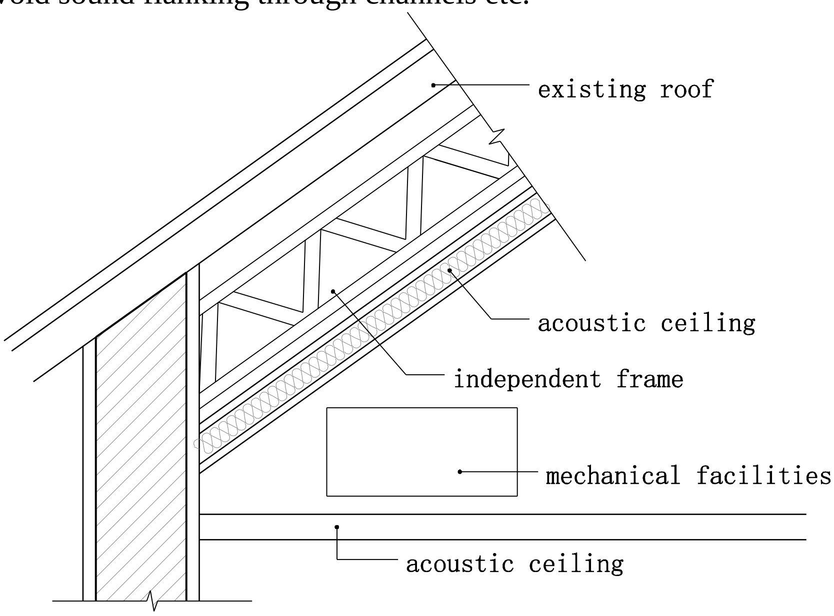


Figure 9 double ceiling used in Yinlu

5.3 Sound insulation tests

The results of airborne and impact sound insulation tests according to ISO 140 are presented in Table 2-4.

As the R_w of 240mm brick wall is about 53dB, sound transmission through wall can be regarded as insignificant. It was a favourable design to place a toilet between bedroom and living room.

Table 2 Weighted standardized level difference of inner walls on the 3rd floor

Source room	Reception room	$D_{nT,w}(C;C_{tr})$(dB)	Description
bedroom in south suite	living room in north suite	55（-3； -9）	There was a toilet between the living room and bedroom. The wall between the toilet and living room was 240mm brick wall; the wall between toilet and bedroom is light-weight wall with a glass door.
toilet in south suite	living room in north suite	48（-4； -10）	

Table 3 Weighted standardized level difference of floors on the 2nd floor

Floors	$D_{nT,w}(C;C_{tr})$ (dB)
bedroom floor in south suite	51（-5；-13）
living room floor in south suite	48（-3；-10）

The impact sound insulation of floors was measured according to ISO 140 and the Japanese standard JISA1419-2 with a heavy rubber ball. The rubber ball test was performed in third-octave bands and only sound from 50 to 630 Hz is calculated to get a single value $L_{i,Fmax,AW'}$.

Table 4 impact sound insulation of floors on the 2nd floor

Floors	$L'_{n,w}$（dB）	$L_{i,Fmax,AW'}$（dB）
bedroom floor in south suite	51	58
living room floor in south suite	55	60

The airborne and impact sound insulation of wood floors had met the national standard for sound insulation of first grade hotels. On subjective feeling, the sound of talking with normal volume could not be heard in another suite. The vibration caused by walking could hardly be perceived in the rooms blow. On the whole, the consumers were satisfied with the sound environment.

6. Summary

The sound insulation of wood components are poor and hard to improve due to its low mass and sealing difficulty. More factors have to be taken into consideration when comes to the renovation of old wood buildings, such as the original structure and constructions, and the conservation rules for historical buildings. The major structural junctions cannot be changed and the roof truss damage the tightness of walls. According to practice experience, composite constructions are best to improve sound insulation with limited additional mass. Floating floors, non-rigid suspending ceilings and resilient joists are major treatment for impact sound of floors.

In a project of conserving a wood historical building to hotel, double ceiling system was used to reduce the effect from roof truss to walls. A floating floor and non-rigid suspended ceiling were applied to the wood floor of original construction. As shown in the measurements after completed, the weighted standardized level difference of floors was 48-51dB, and the weighted standardized impact sound pressure level was 51-55dB. The result means that the hotel has met the first grade national standard sound insulation of hotel buildings

This practice shows that ideal sound performance in old wood buildings could be achieved with careful design. Other crucial parts in the improvement are proper junction details of avoiding sound flanking and rigid linking, and careful workmanship on site.

Sound insulation of windows and doors, noise control of air condition and water system, vibration isolation of mechanical and electrical products also must be considered for a good sound environment of the building, this will be not discussed in this paper.

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