Research on the Key Technology of the Heat Insulation and Sound Insulation of the Ultra-low Energy-consumption Green Floating Floor

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Abstract. At present, since global energy is becoming increasingly tight, it is imperative to develop green buildings and promote green technology. At the same time, it can also be integrated into the atmosphere of joint construction of green "Belt and Road " and the construction of Green Silk Road to make the green infrastructure build a harmonious and livable habitat for humanity. In terms of key technology of heat-insulation and sound insulation of the ultra-low energy-consumption green floating floor, analyzing and studying from status of research and development at home and abroad, sound insulation design of building, the design of the surface layer floating structure, technical characteristics of heat insulation and sound insulation of floating floor and moisturizing and sound insulation technology of floating floor, the advantages of ultra-low energy consumption green floating floor insulation are obtained finally.

1. Preface
In many high-rise buildings in our country, the impact noise from household floor of upstairs and downstairs has seriously affected the living quality of the vast number of residents. At present, under the development situation of co-building "Belt and Road", it is imperative to develop green buildings. The ground heat insulation of traditional buildings is based on lightweight insulating mortar or lightweight insulating concrete as the main aggregate to form the ground floor of the building by replacing fine aggregate concrete and protective mortar. During construction, lightweight mortar or concrete is directly placed on the floor. After vibration and maintenance, the floor heat insulation and sound insulation system of the building is formed. For this kind of system, its sound insulation performance is poor and strength and heat insulation properties are difficult to satisfy requirements for ground surface strength, heat conductivity of household floor and sound insulation and sound absorption performance in the design and acceptance code at the same time. And because its uncontrollable material ratio and its unstable quality, it is difficult to guarantee the quality of field engineering.

Heat insulation and sound insulation system of floating floor paves material with heat-insulating and sound insulation function on structural floor and then pouring the floor insulation and sound insulation system formed by protective layer of fine aggregate concrete on heat preservation and sound insulation material. Vertical insulation material is set up among heat preservation, sound insulation material, protective layer of fine aggregate concrete and wall. “Floating” means that the floor layer is separated from structural floor and wall as shown in figure 1. The heat insulation and sound insulation system of floating floor is applied to heat insulation and sound insulation of household floors in general industrial
and civil buildings. It is an effective popularization technology which can replace the traditional lightweight screed or ground heat insulation system of concrete building at present.

Fig. 1 Schematic diagram of floating floor

2. Present situation and development trend of research and development at home and abroad

2.1 Present situation of research abroad
With the growing tension of global energy, countries all over the world, especially developed countries in Europe and the United States, pay full attention to building energy saving technology. The architectural design and construction and the development and application of heat insulation materials of new building are researched by many countries. The development and application of building heat insulation and sound insulation materials have been paid increasing attention by countries in the world. New heat insulation materials continue to emerge in large numbers. Amorphous slurry heat insulation material has become an indispensable parts of building heat insulation material. The research and application of slurry heat insulation materials were started earlier in Europe and the United States and other developed countries where had matured technology and achieved a lot in research and application.

In 1995, Craik studied the weakening mechanism of solid sound transmission on installing elastic cushions between floor and wall. It is found that the sound transfer coefficient between the floor and the wall can be greatly reduced by the cushion so as to improve sound insulation effect. In particular, it has a good isolation effect on the transmission of flexural wave. The floating floor is composed of slabs, keels, cavities and viscoelastic layers. Research on Viscoelastic Materials is mainly applies strain energy method and viscoelastic method. The strain energy method is to measure the characteristics of the material by experimental method and to calculate and analyze by establishing corresponding calculation model.

Adams and Bacon modeled for fiber reinforced composites and put forward damping model of this kind of composite material. Since then, many scholars have also proved the correctness of the model.

In 2007, A. Schiavi et al, studied on sound insulation effect of floating floor in medium and high frequency 125-2000Hz. Simultaneously, K. Kim et al., studied the sound insulation effect of low frequency (63) HZ floating floor. It was found that if the stiffness coefficient of the cushion layer used in the floating floor was smaller, the sound insulation effect of the floor as a whole would be better and the effect of the sound bridge on the keel would be weaker. Tongjun Cho applied FEA finite element method and SEA Statistical Energy Analysis method to carry out numerical simulation on impact sound of floating floor at low frequency, which had been verified by experiments.

2.2 Present situation of research at home
In 1993, Ma Tieding studied the acoustic performance of standard sound source of improved impact sound. And through theoretical analysis and field test, he studied vibration equation of elastic rectangular thin plate, the changing trend of fee vibration of plate as well as acoustic radiation characteristics. Based
on mode superposition method, Huangxi studied the acoustic radiation of plates with two opposite edges simply supported and other two free in theory and derived that acoustic control based on radiation mode at low frequency can control sound radiation of plates with two opposite edges simply supported and other two free. There are many theoretical studies on the ability of Viscoelastic materials to greatly reduce the sound transmission of structures but that theoretical study of the viscoelastic material in the field of architectural acoustics is relatively small. Ren Zhigang, Lu Zhe' an and Lou Menglin put forward the frequency and loss factor of composite sandwich structure are calculated by modal strain energy method and compound eigenvalue iteration method combined with finite element soft NASTRAN to obtain the loss factor of the complex structure. Gongjing carried out theoretical analysis and numerical calculation of acoustic radiation characteristics of Viscoelastic composite damping sandwich plates by finite element dynamic equation and dynamic equation of Elastic-Viscoelastic Composite structure. These studies provide a reference for the study of sound insulation mechanism of floating floor.

In our country, floating floors are often used to reduce the impact sound of floors. Many scholars have studied the construction and application of floating floor. A qualitative and theoretical analysis of the sound insulation mechanism of floating floor was studied by Tanhua who discussed about paving method and influencing factors of cushion layer and others. It is found that the isolation effect of cushion layer solid wood flooring floor against impact sound is the best. There are few literatures on the theory of sound insulation mechanism of floating floor in China. However, there are many studies on the sound insulation mechanism of double-layer or multi-layer structures. These studies provide a reference for the systematic analysis of sound insulation mechanism of floating floor.

3. Analysis on the design of sound insulation of building
In modern building construction, floor sound insulation is a significant building quality index. However, at present, the problem of floor impact sound in modern buildings is so prominent that it impacts on people’s daily life. The sound source of the impact sound mainly consist of noise generated by the operation of the machine and equipment and noise generated by human activities. Any of the noise is transmitted through the floor of the building. Therefore, a certain sound insulation design method can be adopted to enhance the sound insulation performance of the floor so as to reduce indoor noise. According to the sound insulation design standard of the existing residential building board in China, the weighted standardized impact sound level of the floor shall not be greater than 75dB. Therefore, this standard should be followed in the sound insulation design of buildings.

4. Design of surface floating structure
The surface layer floating structure is formed according to the sound principle of the impact sound of partition residential floor. The transmission of floor impact sound is mainly caused by the vibration and noise of the floor produced by the impact of the object on the floor. And it transmits along the rigid joint surface of the building structure. The floating structure of the surface layer can effectively prevent the vibration and noise from transmission in the floor structure to improve sound insulation performance of the floor of the residential building.

By adding a cushion layer to the reinforced concrete floor and completing paving of cushion on the floor, the floor can be isolated from the surface, the solid sound transmission can be alleviated, and then the sound insulation performance of the floor can be enhanced. The floating ground has two kinds of structures: cast-in-place and prefabricated overhead. Different construction methods have various material configuration modes of cushion layer. This structure can reduce the impact sound level below the floor and in the adjacent room. Therefore, it is more suitable for floor structure design of residential, hotel and classroom buildings.
5. Analysis on technical features of heat insulation and sound insulation of floating floor

5.1 Influencing factors of sound insulation performance
Laying an elastic damping cushion on the structural floor and making concrete floor with 40mm thick can improve the sound insulation performance of the floor. The weighted impact sound pressure level is less than 75dB, or even less than 60dB. The actual sound insulation test can be verified by the theoretical basis. The impact sound of the floor is improved by the performance of the system. It can be calculated by the following formula 1:

\[
\Delta L \approx 40 \log \left( \frac{f}{f_0} \right) \frac{f_0}{f}
\]

Of which,

\[ f_0 = \frac{1}{2\pi} \sqrt{\frac{2E}{dm}} \]

\( \Delta L \) --SNR Improvement of impact sound (dB);
\( f_0 \) --Resonance frequency of the system (Hz);
\( f \) --Noise frequency (Hz);
\( E \)--Elastic Modulus of cushion Materials (kg/cm²);
\( d \)--Elastic Modulus of cushion Materials (cm);
\( m \)--Mass per unit area of surface material (kg/cm²).

Therefore, the key to improve the sound insulation of the floor impact sound lies in the smaller modulus of elasticity and the high-density surface layer material so that the design and study of heat insulation materials with suitable elastic modulus, heat conductivity and compressive strength can solve the problem of poor heat insulation and poor sound insulation performance of reinforced concrete floor at the same time.

5.1.1. Modulus of elasticity of cushion
The modulus of elasticity of various cushion is quite different. Its elastic modulus should not be too small. High-elasticity electronic cross-linked foamed polyethylene material with 5mm thickness can obtain ideal sound insulation performance of impact while EPS board needs 15mm~20mm. For composite multilayered materials, at least 1 layer of material with low elastic modulus (high elasticity) should be used as cushion layer. When the elastic material is selected, the maximum load shall not cause the deformation to exceed the elastic range and the self-weight of the upper surface and the use of the floor shall be taken into consideration. Overload will make the elastic material lose elasticity, thus worsen the sound insulation performance. Based on GB50009-2012 code for load of building structures and the ultimate state of bearing capacity, the calculated value of 40mm~50mm concrete surface load is 4.7kN/㎡~5.0kN/㎡, to determine if there is a possibility of overload and if the strain at 5.0kPa is in a recoverable elastic range from compression stress-strain curve of product.

5.1.2. Surface thickness
A thin surface will increase the sound (source) of indoor impact ground impact and make impact improvement value of sound insulation be small so that the surface should not be too light and thin. The surface layer should be C25 fine aggregate concrete with at least 40mm thick. The thickness can basically meet the requirements of surface density. In fact, the increase in the thickness of the surface layer is limited by the indoor clear height and the cost.

5.1.3. Thickness of cushion layer
The elasticity of the system as a whole increases with the increase of the thickness of the cushion layer. The improvement value of impact sound also increases with the thickness of the cushion layer. However,
that increase of the thickness of the cushion layer is also limited by the condition of indoor net height, cost and so on.

5.1.4. Acoustic bridge blocking
For bare board of reinforced concrete floor, because of the rigid connection with the surrounding wall, the solid sound vibration generated by the impact transmit along the surrounding walls, beams, column structures, and components to radiate sound energy downstairs and around the room. Vertical cushion and other isolation measures should be adopted in floating floor system when designing structural transfer of surface layer and wall, cable and water heating pipe passing through floor. And attention should be paid to the treatment of skirting board; Attention should also be paid to avoiding slurry leakage in the pouring construction of surface concrete to block the to block the bridge.

5.2 Influencing factors of thermal insulation performance
The coefficient of heat transfer of the household floor is inversely proportional to the thermal resistance of the insulating layer. The greater the thermal resistance, the smaller the coefficient of heat transfer pf the floor, the better the heat preservation performance. The calculation formula of thermal resistance of the insulation layer is shown in the formula (2).

\[ R = \frac{\delta}{\lambda} \]  

In the form:

- \( R \)——Thermal resistance of insulation layer(㎡ꞏK/W);
- \( \delta \)——Thickness of insulation layer(m);
- \( \lambda \)——Thermal conductivity of Thermal Insulation Materials [W/(mꞏK)].

It can be seen from the formula that the lower the thermal conductivity of the insulation material is, the thicker the insulation layer is, and the better the thermal insulation performance of the floor is. According to the calculation, when the thermal conductivity of the thermal insulation material is near 0.03W/ (m ꞏ K) ~ 0.04W/ (m ꞏ K), the thickness of 15mm~20mm can meet the requirement of 65% energy saving rate of household floor.

5.2.1. Compression deformation
In practical use, under the self-weight of the surface layer and other floor loads, the thermal insulation material will produce compression deformation, reduce the thickness and increase thermal conductivity, which different from the state of freedom. According to 40mm ~ 50mm the limit state of normal use, the calculation value of quasi-permanent combined load on fine aggregate concrete surface layer is about 2.0kN/m² ~ 2.3kN/m². When considering the actual thickness of the insulation layer, the strain at the compression pressure-strain curve 2.3kPa can be used to estimate the actual thickness of the product.

For insulation layers with large elastic modulus, such as EPS plates, its modulus of elasticity in compression is 5 MPA, and the deformation corresponding to 2.3 KPA is about 4.6% so that it is possible to ignore the change in the thermal conductivity. However, the high-elasticity material, which is used as the heat-insulating layer and the cassion layer, should be taken into consideration.

5.2.2. Water absorption
After absorbing water, the thermal coefficient of the insulation layer becomes larger, which is disadvantageous to the heat preservation. In addition, cushion products should control its water absorption. It will be softened after absorbing water. Excessive water absorption adversely will affect mechanical properties, thermal properties and durability of materials. However, different from roof and exterior wall insulation, the use environment of the household floor is more dry. The indoor ground with relatively stable temperature will not contact the outside rain under normal operation conditions. It is only possible to absorb water when the surface concrete is under pouring and maintaining. And the water will be gradually evaporated in the future. Therefore, there is no need to control the water absorption too strictly. It can be controlled within 15%.
6. Analysis on the technique of moisture and sound insulation of floating floor

There are three ways to realize sound insulation in the current construction structure: to set elastic surface layer, to cushion layer, or set up an elastic ceiling. The elastic surface layer comprises a sound insulation function in the surface material. The floating floor system is to lay elastic material with a certain thickness between the surface layer and the structural floor to weaken or absorb the solid sound energy transmitted by the floor, which belongs to realizing sound insulation by using cushion layer. At present, most of the common products are uniform material products, such as BGL heat insulation and sound insulation system of building building floor. The thermal insulation and sound insulation cushion for the system process graphite EPS board by cutting, extruding while graphite EPS board plays the role of heat preservation and sound insulation. There are also a small number of multi-layer composite products in the market. For instance, electronic crosslinked polyethylene sound insulation pads is cushion layer for sound insulation. A layer of fiberglass felt was glued under it to serve as an insulating layer.

Graphite modified molded polystyrene board is the main material of heat preservation and sound insulation. On the basis of the original sound insulation technology of floating floor, taking the requirements for thermal insulation of the floor into account, cushion layer products with certain thickness and low thermal conductivity are used as insulation and sound insulation layer. After special processing technology, it has superior characteristic including heat preservation, steam permeability and sound insulation. The sound insulation system is arranged on a household floor (or ground). The floor construction system is composed of base floor, thermal insulation and sound insulation, concrete protective layer (containing steel wire mesh).

It is processed and cut from graphite modified molded polystyrene board with one-sided wavy structure on the bottom surface. It effectively reduces the sound transmission of floor impact; The surface can be coated with non-woven cloth or ThermaWrap as an enhanced protective layer. It acts as construction layer with moisture-retaining and sound insulation function in the system. Corner sound insulation line, vertical sound insulation sheet, can effectively solve the problem of acoustic bridge of wall joint and heat channel. Seam tape can effectively solve the joint problem and steel wire mesh can prevent the cracking of the surface layer.

7. Conclusion

Ultra-low energy consumption moisturizing and sound insulation system of floating floor has the characteristics of remarkable sound insulation effect on the full-frequency noise frequency, with advantages including non-toxic, non-organic volatilization, vibration and noise reduction, low cost, easy to use, good effect and light weight. And the performance index is stable and has a certain primacy, interference immunity, superior technical characteristics and excellent system air sound insulation, impact sound insulation performance. It can effectively solve the problems of noise and vibration that affect the quietness and heat transmission between their homes, with remarkable economic, social and environmental benefits.

Series products of floating floor sound insulation pad are developed for residential buildings, villas, high-rise apartments, commercial and residential buildings and other buildings. The sound insulation pad of floating floor adopts innovative raw materials and production technology, which solves Shortcomings such as moisture absorption, decay, pest generation and high cost, etc. of traditional sound insulation materials such as cork board, cane fibre board, glass wool board, rock wool board. It provides the best solution for the sound insulation system of floating floor in modern buildings. The characteristics of the product and the functionality given to it in the process of product development can provide improvement effect of impact sound pressure level for floating floor to the maximum. The improvement of product weight standardization impact sound pressure level can reach up to over 20 decibels. Multi-layer composite structure and accidental breakage in the process of prevention of construction of high density surface layer affect sound insulation effect. For excellent thermal stability, it is suitable for-40 / +90°C environment. It can resist the growth of mould and fungal. It has simple construction technology, convenient installation and low comprehensive cost. Floating floor
moisturizing and sound insulation system reaches the domestic advanced level, the product applies for the national patent and the industry product production standard is to be formulated.

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