# Settling of Loose-Fill Thermal Insulation—Development of a Laboratory Method for Attic Application

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## ABSTRACT

*Present developmental work on a laboratory method for determining settling of attic loose-fill thermal insulation is based on the principle that the settling shall be determined under the same conditions as in a real attic, which means that the loose-fill materials shall be affected by the same factors. The main factors that affect settling of attic insulation are intrinsic weight (mass), moisture, and vibrations.*

*The test apparatus consists of a 1 $m^3$ box containing loose-fill materials. The box stands on a framework to simulate an attic structure. Under the framework structure, a sound-tight box with loud speakers is mounted. Vibrations are produced by sound waves from the loud speakers. During the settling test, the apparatus is placed in a climate room, where humidity can be cycled to simulate moisture effects.*

*According to the experiments performed, the method seems to be promising. The results of the laboratory experiments show the same tendencies as field experiments. In the field there are significant differences in the settling of cellulosic and mineral wool materials. These differences are also documented in the laboratory experiments. The shape of the settling curves is similar for both the laboratory and field experiments.*


## INTRODUCTION

Loose-fill thermal insulation, such as mineral wool and cellulosic materials, will settle under service conditions. This means that the insulation layer will compress and the thickness of the thermal insulation will decrease. The need for a laboratory method for determining settling of loose-fill thermal insulation, such as attic insulation, has become more obvious because standardization work related to the use of this type of thermal insulation has started in different parts of the world. The International Organization for Standardization (ISO) and the European Committee for Standardization (CEN) have emphasized the great need for such a method. The method can be used for approval certificate testing and developmental work of new loose-fill materials.

In North America some efforts have been made to design a suitable test method for loose-fill thermal insulation. In Canada, studies of loose-fill materials were performed during the 1970s. These studies resulted in a method where moisture and vibrations influenced the tested loose-fill material. Tests were designed to obtain a suitable settling value for cellulosic loose-fill thermal insulation and, secondly, for development of a test method (Bomberg and Schirtliffe 1978).

In the United Kingdom, some parts of British Standard BS5803 have been used to test settling of loose-fill materials. The tests focused on vibration and moisture influence but were not aimed to design a test method for attic insulation.

At a Swedish research institute (SIB), studies of settling for loose-fill materials were performed during the 1980s. The studies resulted in long-term field data on settling of loose-fill thermal insulation used for attic applications (Svennerstedt 1990).

In these studies, laboratory tests of the influence of moisture and intrinsic weight on loose-fill materials were conducted. A preparatory laboratory test method was developed, which took into account the effect of moisture and intrinsic weight on the magnitude of settling for attic loose-fill thermal insulation (Svennerstedt 1986, 1988).

During 1990-92, a developmental project on loose-fill thermal insulation was carried out at a technological institute in Sweden (Svennerstedt 1992). The purpose of the project was to develop an accelerated laboratory method to determine the settling of loose-fill thermal insulation used in attic applications.

## LABORATORY METHOD

### Principle of Method

The settling of loose-fill thermal insulation is a long-term material property, which depends on many factors. The main factors are intrinsic weight (mass), moisture, and vibrations. Intrinsic weight affects every loose-fill material when the material is installed. Moisture from the ambient air of the attic affects insulation because of variations in the attic climate and affects cellulosic insulation more than mineral wool insulation. Vibrations in the building structure may affect cellulosic loose-fill materials less than mineral wool loose-fill materials.

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The present test method is based on the principle that the settling of loose-fill thermal insulation in attic applications should be determined under the same conditions as experienced in a real attic. This means that the loose-fill materials should be affected by the same factors as in reality. It also means that the material should be tested in a device that simulates a real attic. The test method should take into account the effects of intrinsic weight (mass), moisture, and vibrations on the magnitude of settling.

### Description of Method

The test device consists of a box containing loose-fill materials (see Figure 1). The box is open at the top. The four sides are made of aluminum, and the bottom of the box is made of plastic, which is perforated. In the bottom there is an insulation batt 150 mm thick; a fiberboard plate is positioned loosely above the batt. The box is 1000 mm wide, 1000 mm long, and 1000 mm deep.

The box is supported on a framework that simulates an attic structure. This structure is perforated and can be made of any material rigid enough to support the load of the filled test box. The framework is part of the bottom of the test device. The bottom is a sound box with five sound-tight sides and one perforated open side. Four loud speakers are installed in the bottom of the sound box. The loud speakers are placed in the quarter points of the bottom side in order to produce uniform vibrations in the fiberboard plate.

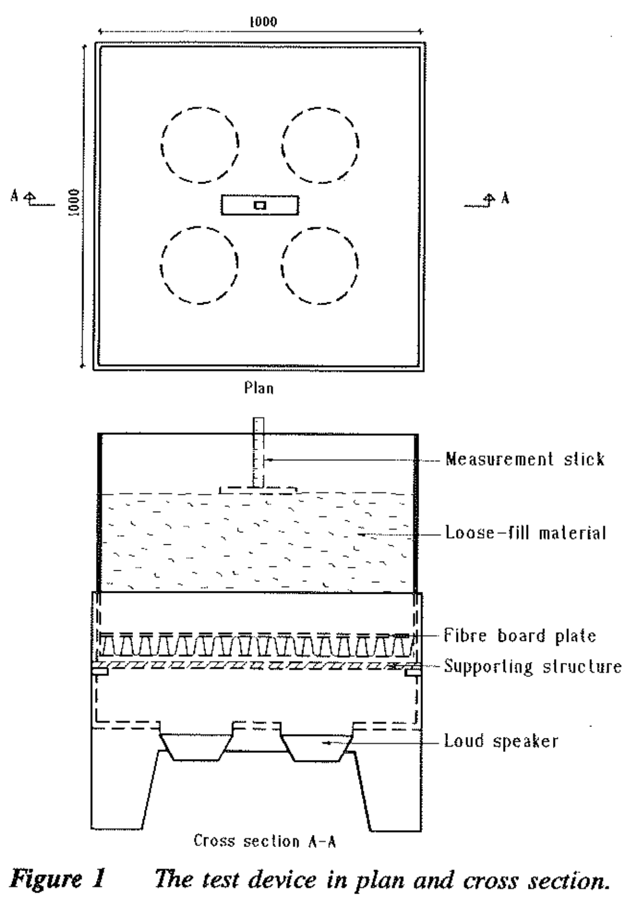


*Figure 1 The test device in plan and cross section.*

Two measuring sticks (graded in mm) are positioned on top of the tested material. The measuring stick and the support plate are made of a material (e.g., cellulose plastic) sufficiently light in weight that their combined weight will not affect the material being tested.

The test apparatus is placed in a climate room where the loose-fill material can be exposed to varying levels of humidity. For a cyclical test, at least two levels should be tested, one with low and one with high relative humidity. In the laboratory experiments, the relative humidity level was chosen to be 50% RH for periods of low moisture and 90% RH for periods of high moisture. The temperature in the climate room should be around 23°C.

The vibration can be held at a low constant acceleration level during the whole test period. Based on a literature study of vibration effects on attic structures, the low, constant acceleration level chosen was to 0.1 $m/s^2$ (Svennerstedt 1988). Within each climate period, some "shocks" with a high acceleration level (2.0 $m/s^2$) can be performed.

The length of each experiment was varied in order to find an optimal test period. Figure 2 shows a test period.

## LABORATORY EXPERIMENTS

Within the scope of the developmental project, experiments with the new laboratory method have been completed. Both cellulosic and mineral wool materials have been tested at different thicknesses. The apparatus was placed in a climate room (see Figure 3) so that humidity could be varied. During most of the experiments, the vibration level was held constant. The testing time was also varied.

In the following, two tests—one with cellulosic material and one with rockwool material—will be described and the results will be discussed.

### Cellulose

This test was performed with the apparatus filled with loose-fill cellulosic insulation as test material. The insulation was made of cut recycled newspaper and was treated with chemicals of aluminum compounds. The cellulosic material was loosened with a commercial blowing machine before it was hand loaded into the testing device to a

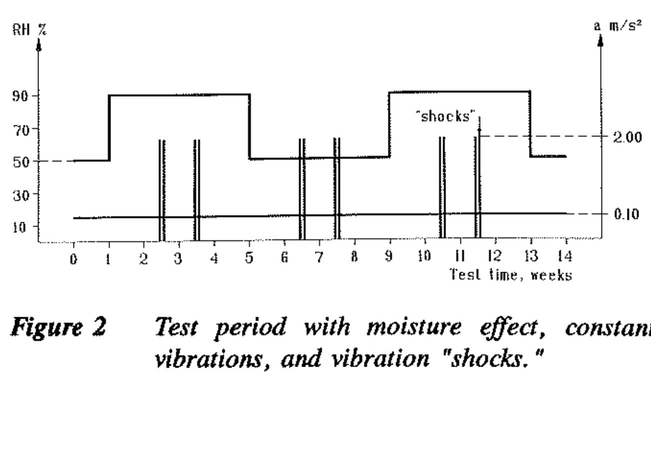


*Figure 2 Test period with moisture effect, constant vibrations, and vibration "shocks."*

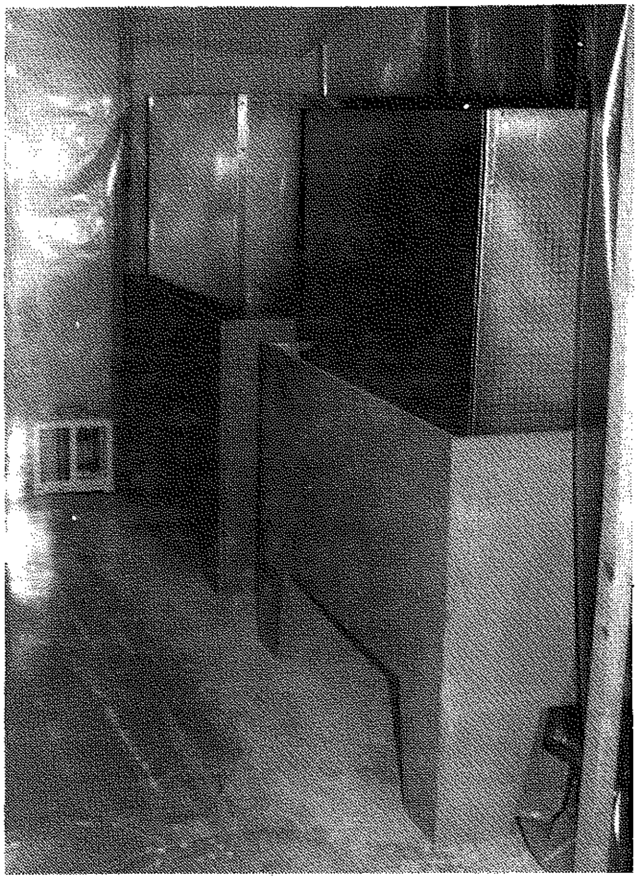

*Figure 3* *Photo of the testing device inside the climate room.*

thickness of 290 mm. The average density of the hand-filled test material was 33.3 kg/m$^3$.

The test period was 56 days (eight weeks). During the test period, the vibration level was held constant at an acceleration level of 0.1 m/s$^2$. The vibrations were produced by sound waves with a frequency of $f=31.5$ Hz and a sound level of 52.2 dB(A)). No vibration "shocks" were used to influence the material in this experiment. The humidity of the climate room varied according to the conditions, which are shown in Figure 4. The temperature of the room varied between 21°C and 27°C during the experiment.

The results were read on two height scales at least twice a week. The height scales had a low weight, and the pressure against the loose-fill material was estimated at about 8 N/m$^2$. Figure 5 shows the results of the experiment calculated in percentage of initial thickness.

The settling of the cellulosic material in the experiment was about 13% and almost 40 mm in absolute values. The initial settling was about 3.5%. During the first period of high moisture level, the settling increased about 5% from 5.5% to 10.5%. After one week of high moisture level, there was a break in the curve and the settling increase was slower.

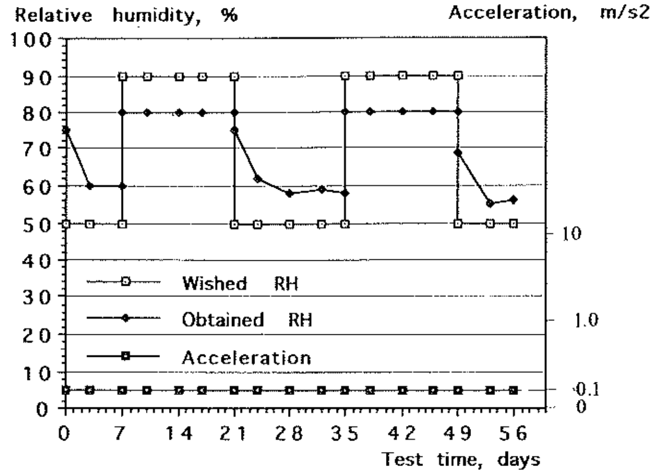


*Figure 4* *Humidity and vibration levels during the test period of the experiment.*

During the two-week dry period, there was a small increase of settling (from 11% to 12%). During the second period of high moisture level, the cellulosic material was rather steady. During the last dry period, the settling increased again.

Samples from the loose-fill cellulosic material showed an average moisture ratio of 11.0 weight-% before the test period and about 12.0 weight-% after the test period.

Figure 6 shows average settling data from field tests on attics with the same cellulosic material as tested in the laboratory. The field data were obtained from 16 measuring points in four test attic areas during a seven-year period. The average initial thickness of the test layers was 297 mm. The initial densities of the cellulosic materials installed varied between 43 and 34 kg/m$^3$ (Svennerstedt, 1986).

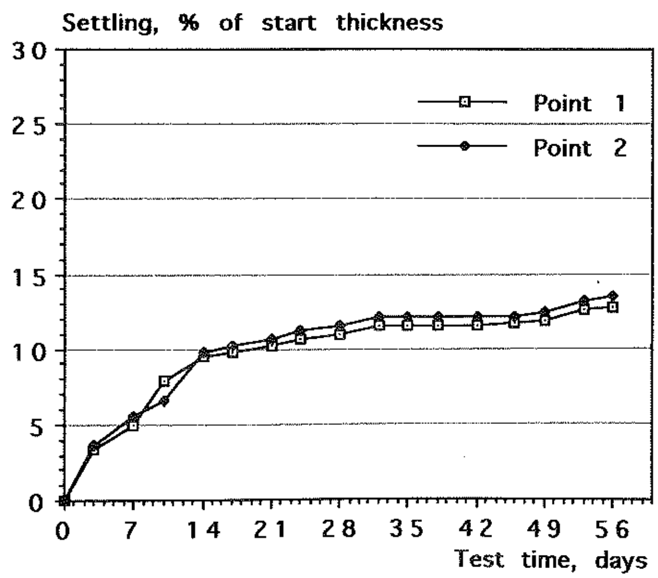


*Figure 5* *Settling results of the experiment for cellulosic material in percentage of initial thickness.*

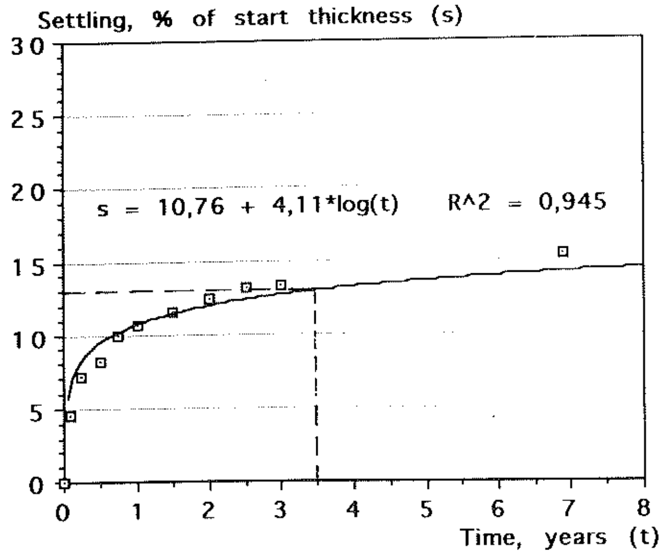


*Figure 6* *Average field data for settling of cellulosic materials.*

The average field data have been fitted by regression analysis to a logarithmic curve. The best-fitting logarithmic function was s= 10.76 + 4.11 * log(t), where s= settling and t= time in practice and is shown in Figure 6.

Settling data for cellulosic material from the laboratory test can be compared with settling data from field tests with the same loose-fill material. When $s_{lab}$=13%, the time in practice according to the log-function in Figure 6 will be $t_{prac}$=3.5 years. This time in practice can also be compared with the testing time, which was five weeks.

## Rockwool

This experiment was performed with the laboratory device filled with rockwool loose-fill thermal insulation. The rockwool material was loosened by a commercial blowing machine before it was hand filled to a thickness of 375 mm. The average initial density of the hand-filled test material was 30.3 kg/m$^3$.

The test period of this experiment was 81 days (about 12 weeks). During the test period, the vibration level was held constant at an acceleration level of 0.1 m/s$^2$. The vibrations were produced by sound waves with a frequency of f=31.5 Hz and a sound level of 52.2 dB(A)). No vibration "shocks" were used to influence the material in this experiment. The humidity of the climate room varied according to the conditions, which are shown in Figure 7. The temperature of the room varied between 13°C and 20.5°C during the experiment.

The results were read on two height scales at least twice a week. The height scales had a low weight, and the pressure against the loose-fill material was estimated at about 10 N/m$^2$. Figure 8 shows the results of the experiment calculated in percentage of initial thickness.

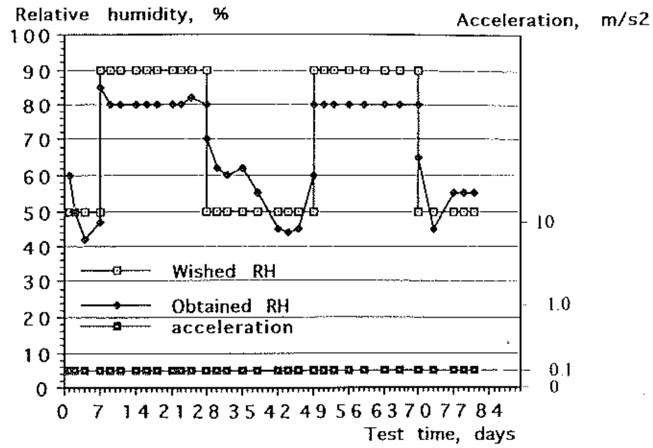


*Figure 7* *Humidity and vibration levels during the test period of the experiment.*

The settling result for the tested rockwool material was 3 mm in absolute values. This means about 0.8% calculated on the initial thickness. The rockwool material shows a low settling result from the field, and this is also documented in the present laboratory experiment.

Figure 9 shows average settling data from field tests on attics with the same rockwool material as used in the laboratory test. The field data were obtained from 16 measuring points in four test attic areas over seven years. The average initial thickness of the test layers was 331 mm. The initial densities of the rockwool material installed varied between 26 and 30 kg/m$^3$ (Svennerstedt 1986).

The settling average field data have been fitted by regression analysis to a logarithmic curve. The best-fitting logarithmic function was $s$=2.94 + 1.06 * log(t), where $s$=settling and $t$=time in practice, shown in Figure 9.

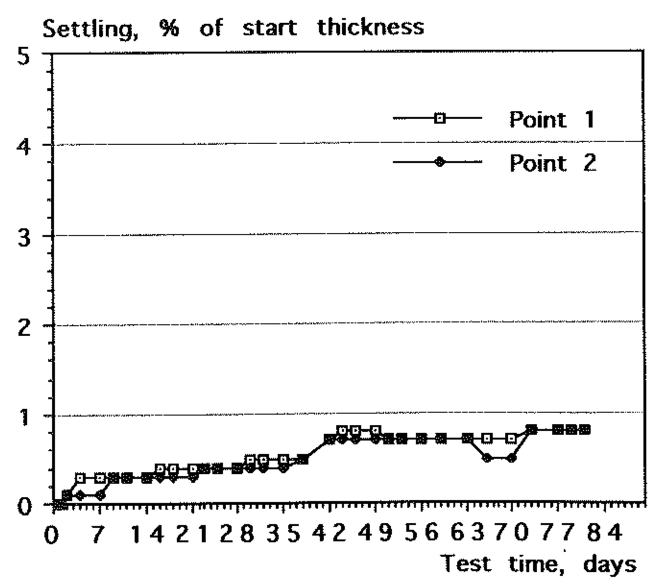


*Figure 8* *Settling results of experiment for rockwool material in percentage of initial thickness.*

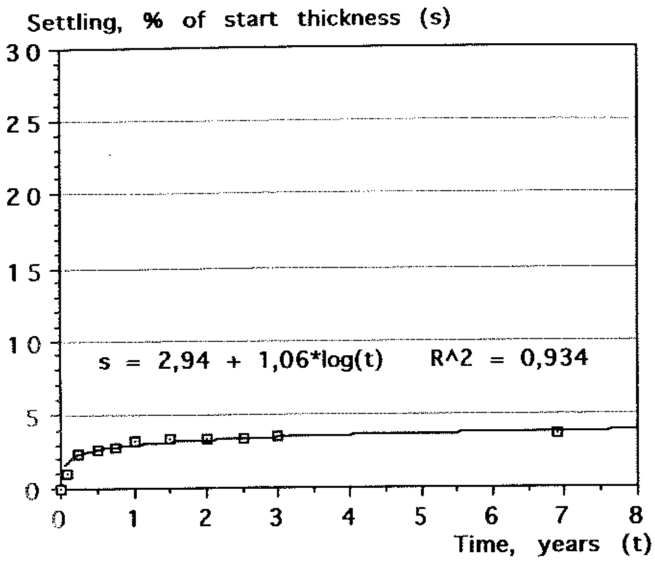


*Figure 9* *Average field data for settling of rockwool material.*

Settling data for rockwool material from the described laboratory method can be compared to settling data from field tests. When $s_{lab}$=0.8%, the time in practice according to the log-function in Figure 9 will be $t_{prac}$=0.01 years. This time in practice can also be compared to the testing time of 12 weeks.

## DISCUSSION

This laboratory method for determining the settling of attic loose-fill thermal insulation has been designed on the assumption that settling should be determined under the same conditions as in a real attic. This means that the loose-fill materials should be affected by the same factors as in reality. It also means that the material should be placed in the test device as it is in a real attic structure. The test method should take into account the effect of settling factors such as intrinsic weight (mass), moisture, and vibrations.

If the test device is placed in a climate room, the tested material can be affected by the same factors as in reality. The box of the apparatus has a volume of 1 $m^3$ so that it can be filled by machine or by hand. When the test box is filled, the mass will affect the settling of the insulation layer at once. Therefore, it is important to place and to read the height scale as soon as possible after the test box has been filled to the desired thickness.

Moisture plays an important role in the settling of cellulosic materials but does not have the same importance for mineral wool materials (Svennerstedt 1986). In this method, moisture was taken into account by the cycling of moisture in the climate room. In order to accelerate the moisture effects, both high and low humidity levels were used in the experiments. A relative humidity of 90% is suitable for high moisture effect and a relative humidity of 50% is suitable for low moisture effect.

The temperature was held constant at around 23°C in these initial experiments as a result of limitations of the climatization equipment in the climate room used. In future experiments with this method, the room temperature and the relative humidity of the climate room should be varied according to the conditions in a real attic. The method should also be developed so that a temperature gradient over the insulation layer can be added during the test.

According to earlier investigations in North America and Scandinavia, vibrations are more import for mineral wool materials than for cellulosic materials. The real vibration effect on attic structures is very low (Svennerstedt 1988). In the present method, the vibration effect is caused by sound waves, and the vibrations affect the loose-fill material at a rather low level. In the experiments, there was a constant vibration level, which corresponded to an acceleration level of 0.1 $m/s^2$. It corresponds to the vibration level from a fan standing on an attic floor. Vibration "shocks" to the attic, which occur when the front door in one-family houses is closed very quickly, can affect the settling of the loose-fill material. This method has possibilities for testing with constant vibrations and vibration "shocks."

This method can be performed with only mass and climatic influences or mass and vibration influences on the loose-fill material. The best way to test effects, however, is from all the main settling factors at the same time because that is more like reality.

At present too few experiments have been performed. With additional settling data, a better statistical prediction of the repeatability of the method can be made. More laboratory results are also needed to evaluate the most reasonable testing time.

## CONCLUSIONS

According to the experiments performed, the method seems to be promising. The results of the laboratory experiments show the same tendency as the field experiments. In the field there is a great difference in setting between cellulosic and mineral wool materials. This difference is also documented in the laboratory. The shape of the settling curve is similar both for the laboratory and field experiments.

It can be concluded that moisture affects cellulosic material much more than mineral wool material. A cycling of moisture with a relative humidity of 90% is suitable as a high moisture effect. A relative humidity of 50% is suitable as a low moisture effect. If there are limited testing resources, the temperature of the climate room should be around 23°C. Otherwise, the temperature of the climate room should be varied according to the conditions in a real attic.

According to earlier investigations, the real vibration effect on attic structures is very low. That suggests there should be a low vibration level in the laboratory method. The method allows tests with constant vibrations and vibration "shocks."

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