Original Article

The Empirical Assessment of Vibration in HVAC Systems

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Abstract

Background and purpose: Vibration caused by ventilation systems in buildings is one of the harmful physical factors that can cause harm to residents. Therefore, measuring and controlling vibration is important.

Materials and Methods: In the first step of the study, the vibration accelerometer was placed on the base of a fan where the vibrations were sent toward the duct wall. A vibration assessment of the building was conducted in the other steps to compare with guidelines. In the next step, isolation method was used to control vibration. By placing the isolator on the duct wall, the accelerometer was located on the body of the duct wall and the value of vibration was measured in a millimeter per second. All stages of the experiment were performed in the Faculty of Health of Isfahan University of Medical Sciences in 2018.

Results: The maximum vibration velocity reduction in the building was related to the frequency of 68 Hz, which reached 33 mm/s after isolation. In addition, the fan vibration at 485 Hz was equal to 2.1 m /s, which decreased to 2 mm /s after isolation.

Conclusion: Comparison of vibration after fan isolation with standard showed that this method has been effective in reducing the fan vibration resulting in the vibration to reach below the standard.

Keywords: Human Vibration; Building; HVAC Equipment

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1. Introduction

One of the harmful physical factors at a workplace is vibration generated by the environment or machines. These vibrations will be transferred to a human body in two ways, hand-arm (HAV) and whole body (WBV). The human body may be injured by these vibrations which can also be a risk factor of damage to machines and structures of buildings. Through methods of vibration transmission, the most common method is whole-body vibration that is usually the same as low frequency vibration. These vibrations can be transmitted to the person's body through sitting or standing positions. Exposure of the human body to high intensity of vibrations for a long time, which is out of the defined permissible threshold, can cause physical and physiological disorders (1, 2).

According to the Directive 2002/44/EC of the European Parliament and of the Council, Whole-Body Vibration is a mechanical vibration that, when transmitted to the body, may cause risks to the health and safety of workers. This type of vibration occurs when a part of the body can be affected by a vibrating surface (3).

The international standard organization has set the ISO-2631/1997 standard for whole-body vibration (4).

Human exposure to WBV is an important and worrying problem because it causes a number of adverse health consequences, including neck and back pain (5, 6), the development of various neuropathies, headaches, motion sickness, dizziness, potential cardiovascular disease, digestive problems, and possibly cancer (7).

Rafieepour et al. showed that whole-body vibration was an effective factor in response time and mental function of individuals that can lead to a decrease in the accuracy of work (8). Khani et al. described that increasing vibration during a visual computer test reduces reaction time and increases physiological fatigue (9). Newell and colleagues claimed that exposure to vibration can cause concentration disorder and increase reaction time (10).

Mechanical vibration and vibration-induced noise are often the main sources of complaints by residents in new buildings. Lightweight components that are used in the construction of buildings may raise the vibration of the building and its associated problems. Increased attention to the preservation of energy has resulted in many new buildings that are designed with variable air volume systems, for example, by using an HVAC system that generates vibrations in buildings.

The vibration of buildings may cause some problems for the occupants that are due to the following reasons:

i. Vibration levels received by the residents of the building are too high and are the cause for concern and alarm.

ii. Vibration energy is transmitted from mechanical vibration to the building structure and then it is radiated by way of structure-borne noise.

iii. Vibration in buildings may interfere with the proper operation of sensitive equipment (11).

The operation of Heating, Ventilation, and Air Conditioning (HVAC) systems is an important issue because people spend more than 80% of their time indoors (12). HVAC system equipment, due to its mechanical function, creates a certain amount of vibration and sound that affects the comfort and convenience of human life as well as the structural stability of the building (13). One of the main sources of sound in buildings is the mechanical equipment of ventilation systems. Parts such as fans,

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ducts or distributors, elbows, branching channels as well as fan movement are other sources of sound and vibration (14).

Today, the determination of vibration problems in lightweight structures has expanded due to advances in building materials and construction methods. These structures can cause residents to complain about vibrations. There are two methods of vibration control including active control and passive control as effective tools for controlling vibrations received by humans (15). One of the methods of passive vibration control is the use of vibration isolator that rubber plates, metal springs, cork, and felt are used as the most widely used isolator (14).

Based on the above-mentioned issues and the importance of building vibrations due to duct and variable-air volume systems, the purpose of this study was to measure the vibrations received by residents in buildings and evaluate the effectiveness of performed vibration control.

2. *Materials and Methods*

This study was designed to measure the value of vibration velocity generated by a fan in the ventilation ducts of buildings. In this regard, the vibration accelerometer from DYTRAN Company with a sensitivity of 10mV/G, the frequency response of 1-5000 Hz with ±%5 and 0.66-10000 Hz with ±%15 was applied in accordance to ISO 8041 and ISO 10816-1(16, 17). A frequency analyzer from China BSWA Company with data-acquisition card hardware from USA National Instrument Company was used for sampling the frequencies. In addition, MATLAB Software was used for processing and simulating vibration signals propagated on the duct wall. All stages of the experiment were performed in the Faculty of Health of Isfahan University of Medical Sciences in 2018.

In the first step, the vibration accelerometer was put on the base of a fan where transmitted vibration was toward the duct wall. The vibration velocities in these areas should not be more than recommended values of ASHRAE for buildings. Table 1 shows the given maximum allowable RMS velocity levels of vibration for fans. In the second step, measurement was done on the structure of ventilation ducts in which the amount of vibrations caused by duct walls has been measured in terms of speed quantities. The values were measured in one-third octave band frequency by an accelerometer. One-control methods were also used to reduce the amount of vibrations received by the inhabitants of the buildings. The method included the use of the isolator. For isolation, four-compressed rubber isolators with density of 1507 kg/m3 which were in the form of spring rubber and placed under the fan chassis were used. In this way, one side of the insulators was connected to the fan and the other side of it was connected to the channel structure.

After placing the isolator, the accelerometer was installed on the body of the duct wall and the value of vibration velocity was measured in a mm/s. In order to compare the results of the vibration with permitted vibration defined for building structure by ASHRAE, a comparison was made for the measurement results before and after using the isolator, including fan and duct wall with ASHRAE standard graph. The device that was used to estimate the degree of allowable vibrations was placed on the structure of the building in the closest area to vibrating tools or in places where there were people or equipment sensitive to vibration.

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Table 1. Maximum allowable RMS velocity levels (7)

Equipment	Allowable rms Velocity, mm/s
Pumps	3.3
Centrifugal compressors	3.3
Fans (vent sets, centrifugal, axial)	2.3

Occupant vibration criteria are based on guidelines recommended in ANSI Standard S3.29 and ISO Standard 2631-2. In fact, manufacturers have identified acceptable values for the critical equipment. MATLAB Software and Data-Acquisition Card were used to analyze the obtained data of the measurements.

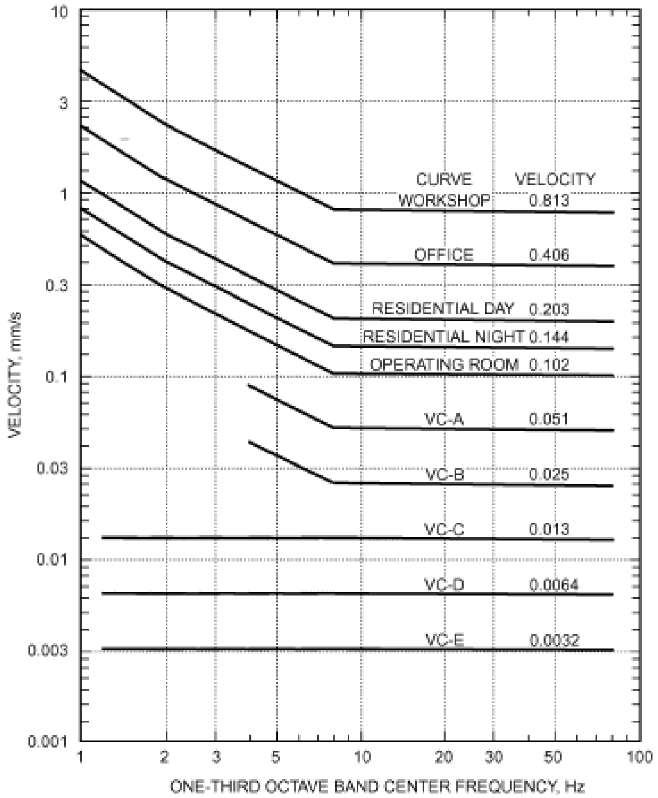

Fig 1. Building structure vibration criteria (7)

Figure 1 indicates building vibration criteria for vibration measured on building structure, meaning that vibration levels measured on duct structures should be in or below the "Good" region. Vibration levels in the "Fair" or "Slightly Rough" regions may indicate potential problems requiring maintenance. HVAC systems with the vibration levels in these regions should be monitored to ensure that no problem occurs. Vibration levels in the "Rough" and "Very Rough" regions indicate a serious problem; hence immediate action should be taken to identify and correct the problem.

3. *Results*

Based on Table 1, the allowable vibration RMS velocity of a fan should not be more than 2.3 mm/s. As seen in Figure 2, the peak of 2.1 m/s of vibration velocity was seen in a frequency of 485 Hz. All data in this figure were related to before using the isolators.

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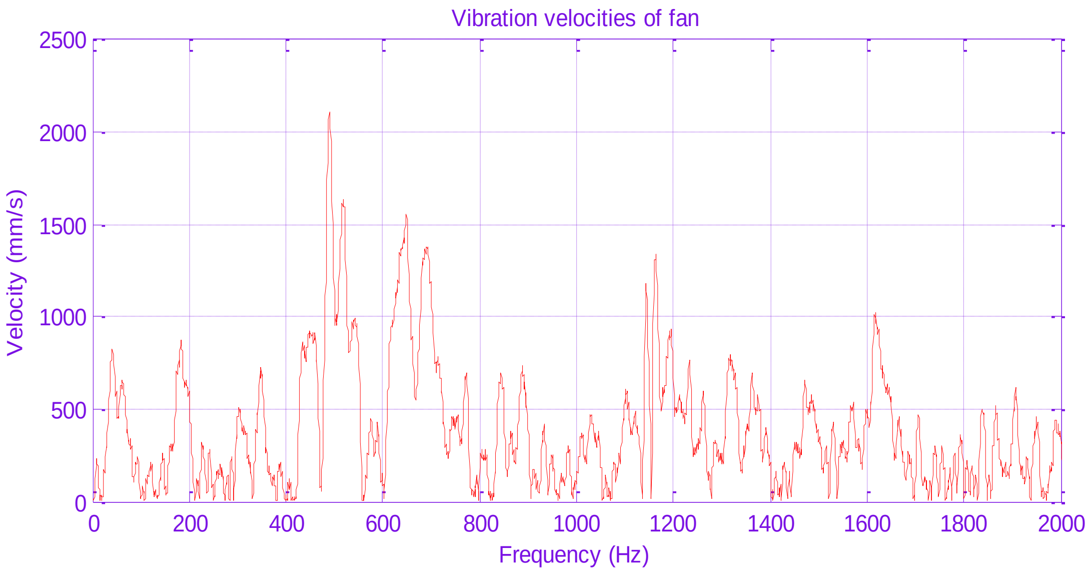

Fig 2. The primary vibration velocity of fan

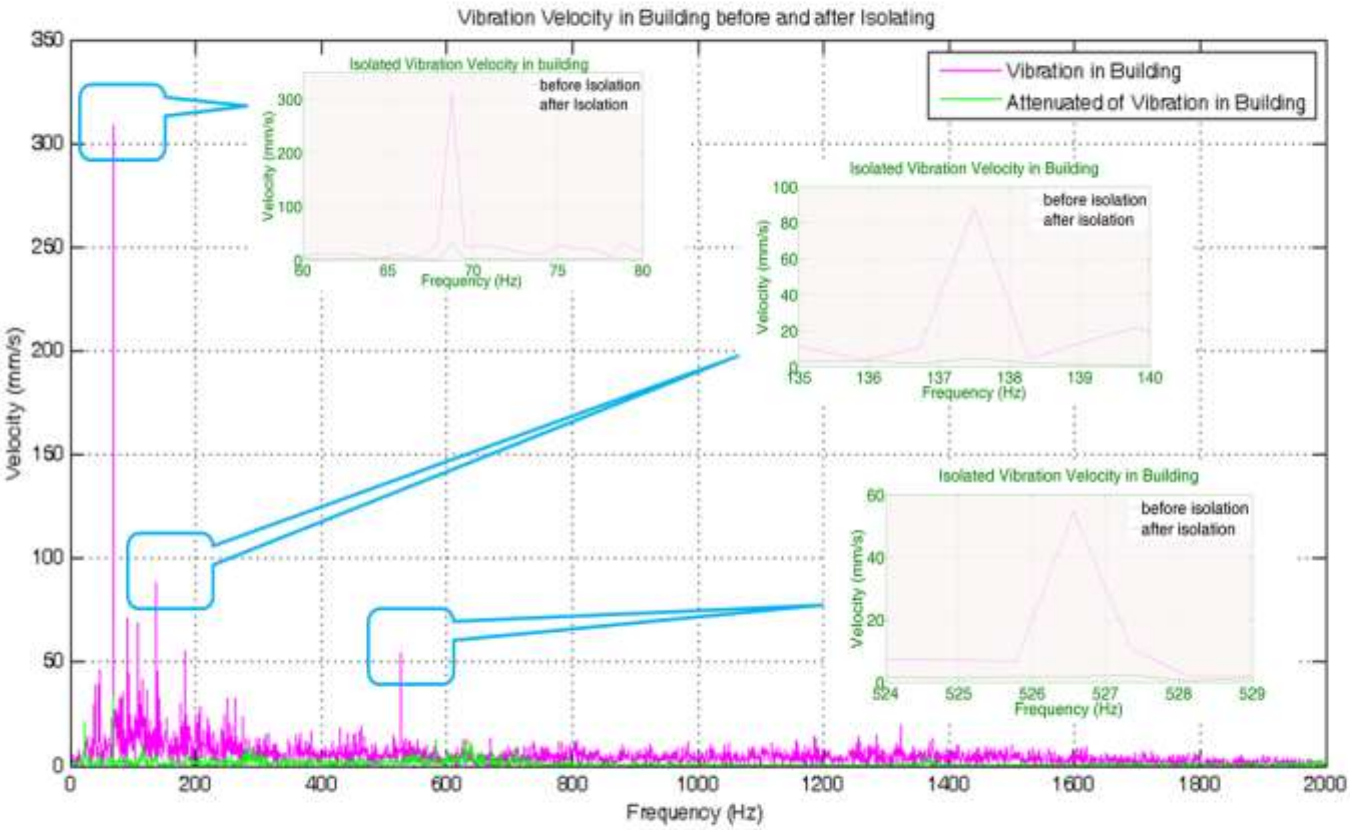

Fig 3. vibration velocity in building before and after isolation

For a better comparison, the vibration velocity in building before and after isolation is shown in Figure 3. It is seen that the peak of vibration velocities in buildings was at a frequency of 68. 5Hz which was reduced to 33mm/s after using the isolation. For other parts of the vibration velocity in the frequency band, the obtained results

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demonstrated a proper reduction of vibration velocities. There were exceptions in the reduction of vibration velocity for frequencies including 627.2 and 636Hz, but the increased amounts were excusable.

According to Figure 2, the fan caused a serious problem in the area of 485 Hz frequency with a vibration velocity of more than 2.1 m /s. However, this value was about 2 mm/s after the isolation.

For a better judgment of vibration reduction and the effect of applied control methods in reducing the vibration of the building, specific frequencies with the maximum vibration velocity were extracted from Figure 3 and classified in Table 2. The results showed that the use of isolation at frequencies of 68.5, 137.5, 91.5, 107.7, 182.8, and 526.5 Hz reduced vibration by about 90% and more.

Table 2. Vibration velocity of building before and after isolation

Frequency (Hz)	Vibration Velocity in Building before isolation (mm/s)	Vibration Velocity in Building after isolation (mm/s)	Reduction percentage
68.5	300	33	89%
137.5	86.5	4.8	94.4%
91.5	69	4	94.2%
107.7	67	3.3	95%
182.8	54	0.9	98.3%
526.5	53	1.8	96.6%
636	4.1	11.2	-174%
627.2	1.7	7	-315%
669.7	13	3	76.9%

4. *Discussion*

According to the ASHRAE standard (Figure 1), the criteria of vibration velocity for the workshops and residential day and night in the frequency range of 8- 80 Hz were 0.813, 0.203, and 0.144 mm/s, respectively (7). In order to reduce the vibration of the fan and the vibration received from the buildings to the permissible limits of the ASHRAE standard, rubber isolators were used. At many frequencies studied, the amount of vibration velocity after isolation was reduced by more than 90%, which indicates the proper performance of this type of isolation. However, in order to reduce vibration within the ASHRAE range, especially at frequencies of 636, 627.2, and 669.7 Hz, it is necessary to use another suitable control method along with this type of isolation.

In agreement with the results of this study, Forouharmajd et al. described that the use of rubber isolator was efficient for small systems, such as fans in the ventilation systems. In addition, based on the static displacement, load and compression of the material, they can be used as an effective method of reducing vibration (14). Himmel showed that the use of vibration isolators for the fan could effectively reduce vibrations in buildings or other places that require a low-level vibration environment (18). This finding was in line with the results of the current study. In addition, Wang stated that rubber-like mounts as isolators can reduce vibration over a wide frequency band, and vibration absorbers or other vibration isolators may control vibration bandwidth in the presence of active or inactive vibration control (19).

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Some researchers believe that the dwellers of a building may be exposed to the high extent of a vibration or vibration-induced noise from the viewpoint of vibration velocities generated by heating, ventilation, and air-conditioning systems. At first glance, it may not seem to be very important but sometimes produced noise and vibration is a disaster for people who are living in a building equipped with these kinds of HVAC systems. In fact, inhabitants of such buildings are uncomfortable and dissatisfied by dwelling in these areas. The ASHRAE standards provide a guideline for estimating the boundaries required for a quiet life or work. In this study, the ASHRAE standard was used as a reference to reduce vibration, and it was determined that the rubber isolation was able to reduce vibration in buildings. This method has tried to decline the velocity of vibration transferred from the duct wall to the building.

In the present study, due to the time and facilities available, a limited number of laboratory conditions were examined. It seems that it is necessary to evaluate more conditions and different scenarios in future studies. In addition, in this study, only one type of fan and one type of isolator were used. Therefore, it is suggested that in future such studies to be conducted on a variety of ventilation systems as well as other isolators. Measurement and control of building vibration to work with sensitive equipment should be considered in the future.

5. Conclusion

Vibration generated from the air condition system may cause discomfort to nearby residents. The main noise and vibration resulting are caused by air turbulence at condenser fans and compressor noise and vibration during the running and on/off cycle of refrigerant. The vibration transmitted may activate the building structure and make an annoying noise to the occupants inside the building. Therefore, the use of vibration isolators as a vibration control method can greatly prevent the transmission of noise and vibration to the occupants of the building.

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Conflict of Interest

The authors declare they have no financial interests.

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