The empirical assessment of human vibration propagated in building and HVAC systems

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ABSTRACT

Researchers in vibration have shown that disorders of a heart-cardiovascular circle appeared by vibration exposure. In the first step of doing work, the vibration accelerometer put on the base of a fan where the vibrations send toward the duct wall. Vibration assessment of building is done in the other steps to compare with guidelines. The vibration rates in these areas should not be more than recommended values of ASHRAE for buildings. The methods tried including the isolator and balancing duct. By placing the isolator on the duct wall, the accelerometer locates on the body of duct wall and the value of vibration measured in a millimeter per seconds. A Peak reduction of vibration velocity in building has been appeared at frequency of 68.5Hz by a value of 33mm/s after applying isolation.

For other parts of the vibration rate of the frequency's band, the taken results prove a proper cut of vibration paces. There were exceptions in the cut of vibration rate for frequencies, including 627.2 and 636Hz, but the increased amounts are excusable. Thus, applying the methods of control may be acceptable, but it could not cover few parts of vibration frequency band spreading in building.

Keywords: human vibration, building, HVAC equipment

1. INTRODUCTION

One of the harmful physical consequences 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 and whole body. The human body may be injured by these vibrations which can also be a risk factor of damage to machines and structures of buildings (1).

Through methods of vibration transmission, the most common method is whole-body vibration that is usually the same as low frequencies. 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 will cause physical and physiological disorders (2).

From 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, causing risks to the health and safety of workers. This type of vibration occurs when part of the body can be affected by a vibrating surface (3).

Vibration is an oscillatory motion that occurs in the combination of frequencies. Some people in some particular frequencies are more sensitive than others. The direction of the vibrations is an important factor which affects the susceptibility of certain individuals to the number of frequencies (4).

International standard organization has set the ISO-2631/1997 standard for whole-body vibration (5).

If the vibrations which are transmitting to the individual part of the body exceeded the recommended standard, this will increases the Risk of complications and side effects, including musculoskeletal disorders (6).

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 which are designed with variable-air volume systems. For example, using HVAC system, that generates vibrations in buildings.

Vibration of buildings may cause some problems for the occupant which 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 is radiated by way of structure borne noise.

iii. Vibration in buildings may interfere with proper operation of sensitive equipment (7).

Accordingly; studies in the field of vibration have shown that disorders of heart - cardiovascular system, respiratory, digestive, nervous, Female reproductive system (6),impact on reducing gastric movements (as one of the adverse effects of vibration)are other disorders caused by vibration (8).

There is a direct relationship between whole-body vibration and low back pain (9).

Bodil in 2006 showed a significant relationship between exposure to vibration and the risk of myocardial infarction (10).

In 1978, Poulton conducted a research on the psychological effects of vibration with a frequency of five Hz, and the report showed that high levels of vibration increase excitability and thus affect the long-term performance in tasks that require more alertness (11).

In 1966, Holland, considered the heart rate, during the cognitive tests, at six-hour exposure to vibration from frequency of 1 to six Hz and intensity of 1/2 and 1/6 meter squared per second. He demonstrated that exposure to vibration and increase of vibration intensity cause an increase in the mean heart rate (12), However; Wikström and colleagues (1994) reviewed studies on the effect of vibration on the human body and showed that vibration did not affect heart rate (13).

Newell and colleagues claimed that exposure to vibration will cause concentration disorder and excessive reaction time (14).

Based on the above mentioned issues and the importance of building vibrations due to duct and variable-air volume systems in healthy individuals, this study aims to measure the vibrations of residents in buildings and the effectiveness of performed vibration control.

2. MATERIAL AND METHODS

2.1 Building Vibration

This method is designed to measure the value of vibration velocity generated by a fan propagated to ventilation ducts that are used in buildings.

In this case, the vibration accelerometer has been made by DYTRAN Company (15) with a sensitivity of 10mV/G, frequency response of 1-5000 Hz with ±%5 and 0.66-10000 Hz with ±%15 has applied in accordance to ISO 8041 and ISO 10816-1, 2005 (16, 17). Frequency analyzer is selected from China BSWA Company with data-acquisition card hardware from USA National Instrument Company for sampling the frequencies. MATLAB software was used for processing and simulating of vibration signals propagated on the duct wall.

2.2 Vibration Velocity Measurement

In the first step, the vibration accelerometer was put on the base of a fan where the vibrations are transmitted toward the duct wall. The vibration velocities in these areas should not be more than recommended values of ASHRAE for buildings. The table 1 gives maximum allowable RMS velocity levels of vibration for fans. In the second step, a 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 are measured in one-third octave band frequency by an accelerometer. Two control methods have been used to reduce the amount of vibrations received by the inhabitants of the buildings.

The methods include the use of the isolator and the balance (fixed) duct. After placing the isolator, the accelerometer is installed on the body of duct wall and the amount of vibration is measured in a millimeter per seconds. The measurement should be repeated after balancing duct. In order to compare the results of the vibration with permitted vibration defined for building structure by ASHRAE, a comparison is made for the measurement results before and after using the isolator and balancing the system, including fan and ducts with ASHREA standard graph that shows accepted values for vibrational structure of the building.
This device which is used to estimate the degree of allowable vibrations, is placed on the structure of the building in the closest area to vibrating tools or in places where there are people or equipment sensitive to vibration

Table 1- Maximum Allowable RMS Velocity Levels

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

2.3 Building Vibration Criteria

Occupant vibration criteria are based on guidelines recommended in ANSI Standard S3.29 and ISO Standard 2631-2. In fact, acceptable values for the critical equipment have been identified by manufacturer.

Table 2 - Human comfort and equipment vibration criteria

Human Comfort	**Time of Day**	**8 to 80 Hz Curve[a], mm/s**
Workshops	All	0.813
Office areas	All[b]	0.406
Residential (good environmental standards)	0700-2200[b]	0.203
	2200-0700[b]	0.144
Hospital operating rooms and critical work areas	All	0.102
Equipment requirement	**Curve[a]**	
Adequate for computer equipment, probe test equipment, and microscopes less than 40×	0.203	
Bench microscopes up to 100× magnification; laboratory robots	0.102	
Bench microscopes up to 400× magnification; optical and other precision balances; coordinate measuring machines; metrology laboratories; optical comparators; microelectronics manufacturing equipment; proximity and projection aligners, etc.	0.051	
Microsurgery, eye surgery, neurosurgery; bench micro-scopes at magnification greater than 400×; optical equipment on isolation tables; microelectronic manufacturing equipment, such as inspection and lithography equipment (including steppers) to 3 mm line widths[c]	0.025	
Electron microscopes up to 30 000× magnification; micro-tomes; magnetic resonance imagers; microelectronics manufacturing equipment, such as lithography and inspection equipment to 1 mm detail size[c]	0.013	
Electron microscopes at magnification greater than 30 000×; mass spectrometers; cell implant equipment; microelectronics manufacturing equipment, such as aligners, steppers, and other critical equipment for photo-lithography with line widths of 1/2 µm; includes electron beam systems[c]	0.0054	
Unisolated laser and optical research systems; microelectronics manufacturing equipment, such as aligners, steppers, and other critical equipment for photolithography with line widths of 1/4 µm; includes electron beam systems[c]	0.0032	

[a]See Figure 1 for corresponding curves.

[b]In areas where individuals are sensitive to vibration, use Residential Day curve.

[c]Classes of [c]microelectronics manufacturing equipment.

. Maximum levels of vibration velocities as RMS are defined by ASHRAE in a case of vibrating using equipment. Table one is showing these maximum allowable velocities to compare to real measured values of vibration generated in situ. The human comfort criteria to prevent the man from injuries of mechanical vibration is showing by table 2.

The obtained results of the measurements are analyzed by MATLAB software and Data-Acquisition Card.

The figure one 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; immediate action should be taken to identify and correct the problem.

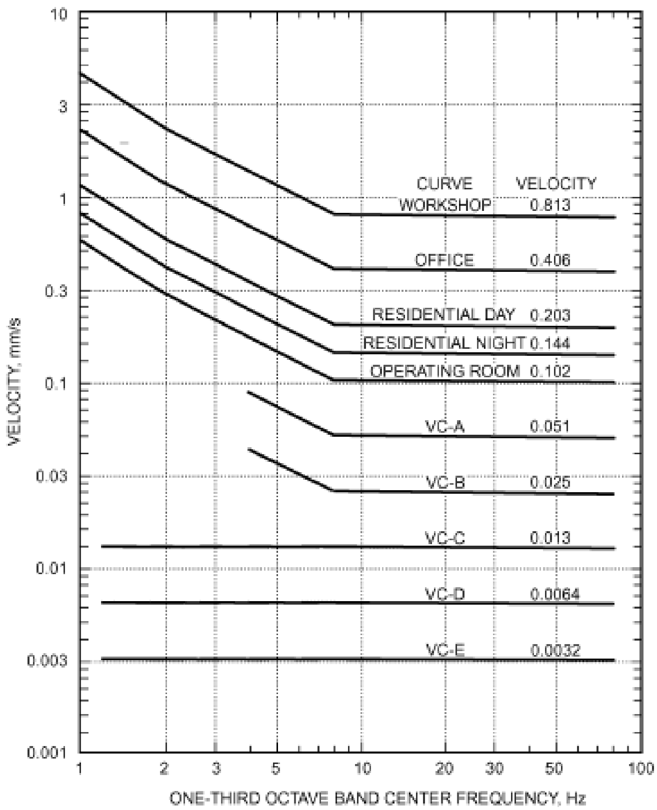

Figure 1- Building vibration criteria for vibration measured on building structure

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, a massive value of energy is generated by the fan. A peak of 2.1 m/s of vibration velocity is seen in frequencies of 485 Hz. All the data in this figure is related to before balancing and using isolators.

For a better comparison, the vibration velocity in building before and after isolation is shown in figure 3.According to figure 3, the peak of vibration velocities in building at frequency of 68. 5Hz is reduced to 33mm/s after applying isolation.

For other parts of the vibration velocity of frequency's band, the obtained results demonstrate a proper reduction of vibration velocities. There were exceptions in reduction of vibration velocity for frequencies including 627.2 and 636Hz, but the increased amounts are excusable.

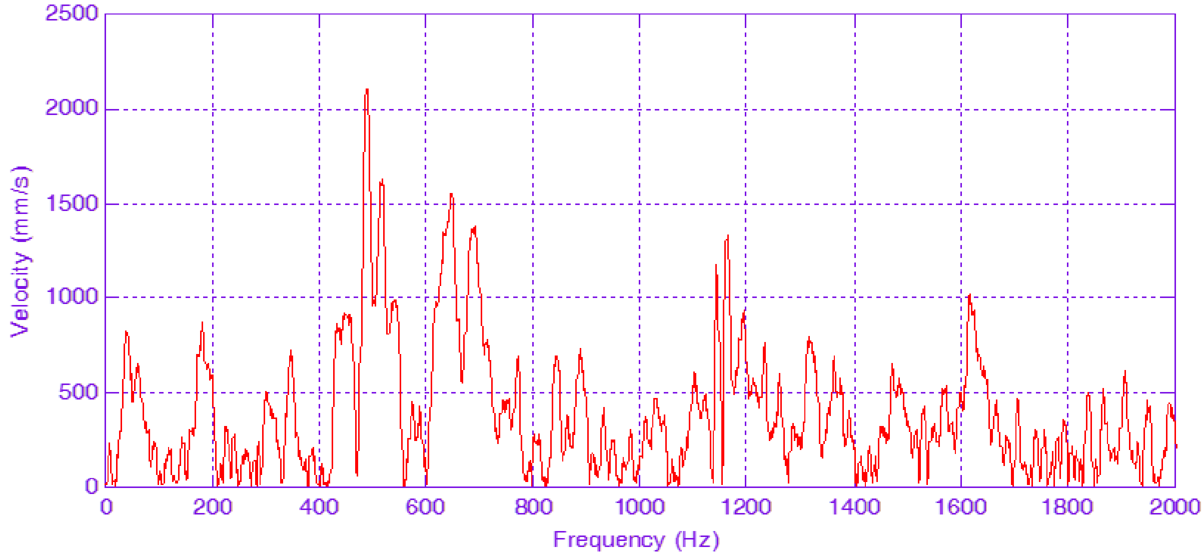

Figure 2 - The primary vibration velocity of fan

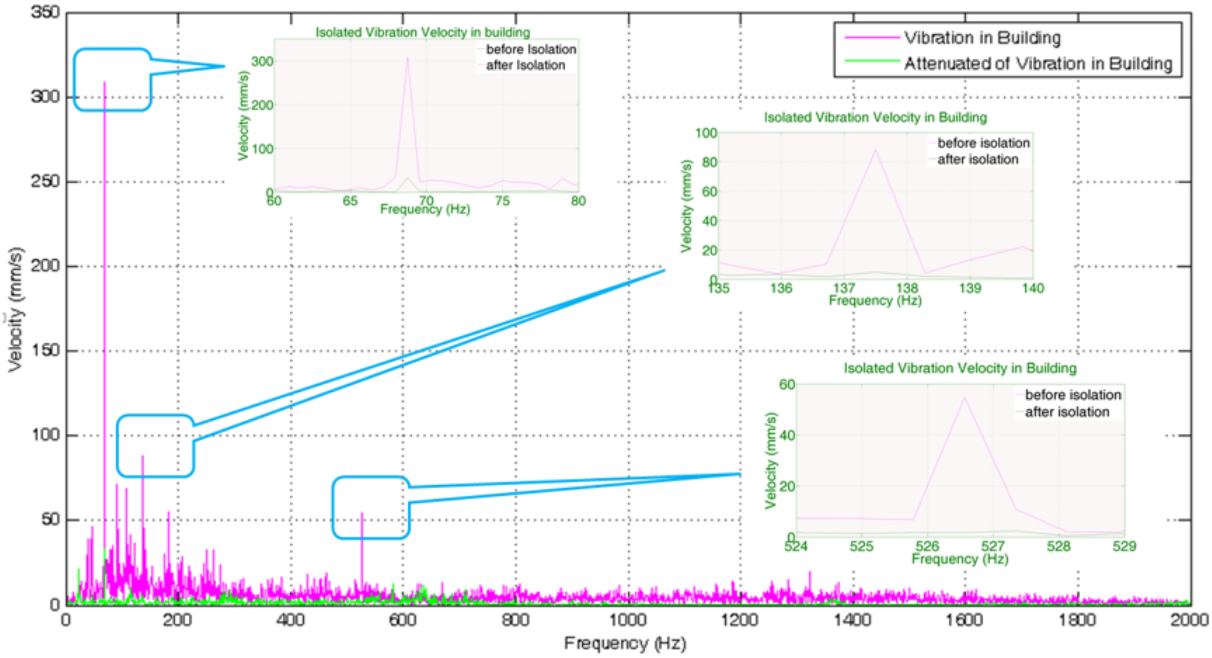

Figure 3 - Vibration velocity in building before and after isolation

According to figure 2, a serious problem has happened in the area of 485 Hz frequency with a high vibration velocity of 2.1 m/s generated by a fan. However, the value in the building after isolation is about two mm/s.

To have a better judgment about the reduction of vibration and the effects of applied control methods in vibration reduction of building, certain frequencies with a peak of vibration velocity have been extracted from the figure 3 and classified in table 3.

Table 3 - 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)**
68.5	300	33
137.5	86.5	4.8
91.5	69	4
107.7	67	3.4
182.8	54	0.9
526.5	53	1.8
636	4.1	11.2
627.2	1.7	7
669.7	13	3

4. CONCLUSIONS

Few researchers believe that dwellers of a building may be exposed to the high extent of 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 so 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 to estimate a boundary for having a quiet life or work.

According to the ASHREA standard, the permitted vibration velocity limit for the workshops is the frequency range of 8- 80 Hz is 0.813 mm/s. After applying the isolator, the vibration velocity of building has been reported 0.4 mm/s for frequency of 10 Hz that is in the allowable range for the workshops. However, the rate of vibration velocity in the other frequencies is more than the allowable limit for the ASHREA standard even after isolation.

In addition, before applying isolation, the measured values show that frequencies of 137.5 and 26.5 Hz had large amounts of vibration velocity though after applying the isolation, the vibration is reduced to 4.8 and 1.8 mm/s respectively.

Figure 3 suggests that the system has been reached to a comfort zone in terms of vibration hazards. It means that the system has simply passed rough, fair and good situations even to have a smooth area of the building.

Vibration can be isolated or reduced to a fraction of the original force with resilient mounts between the equipment and the encouraging structure, provided that the encouraging structure has sufficient stiffness and mass.

Therefore, what can be said is that legislation in thirsted has been able to reduce the vibration in building .Balancing system and its parts has tried to decline the velocity of vibration transferred from the duct wall to building. Vibration isolators must be selected not only to provide required isolation efficiency but also to compensate for floor stiffness.

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