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A Practical Guide to

Noise and Vibration Control for HVAC Systems

SECOND EDITION (SI)

Mark E. Schaffer

ASHRAE®

A Practical Guide to Noise and Vibration Control for HVAC Systems

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Preface

Since the publication of the 1991 edition of this guide, building owners and managers have been paying more attention to occupant comfort, and municipal codes have become more attentive to property-to-property noise emissions. As a result, the HVAC community has become much more sensitive to the acoustical design of its products and systems. Many equipment manufacturers are producing quieter products and sometimes use the acoustical benefit as the primary marketing feature. Increased attention to product acoustical performance is evidenced by the fact that the number of HVAC acoustical testing laboratories has almost doubled since 1991. Also, increased internationalization has permitted access to low-noise HVAC products from Europe and Asia.

System designers are paying closer attention to the acoustical performance of the products and systems that they specify, and many building owners now require acoustical consultants on project design teams.

Unfortunately, not all industry changes have been for the quieter. Energy-efficient screw (rotary) compressors have been the source of many noise and vibration complaints, and the momentum to remove internal acoustical liner from ductwork, or to cover it with solid sheet metal in air-handling units and terminal boxes, has reduced the palette of noise reduction strategies that can be used in system designs. These and other factors increase the importance of *system* design in the form of more careful attention to vibration isolation and the airflow aerodynamics in air distribution systems. Therefore, the main theme of this guide has not changed over the past 20 years—that is, most HVAC system noise and vibration problems are *system* problems that are due to the improper selection, design, or installation of the components into a complete *system*. More careful attention to these factors will greatly reduce the number and severity of noise and vibration complaints.

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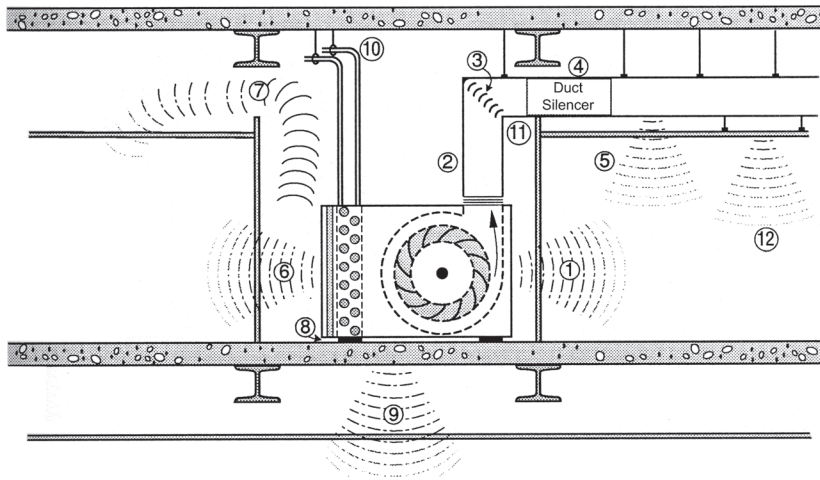
The entire membership of ASHRAE for its support of technical research in all areas of HVAC system design.

Introduction

Over the past few decades, building design teams have become more aware of the potential noise and vibration problems from HVAC systems. Mechanical engineers are specifying sound traps (duct silencers), acoustical louvers, sound-absorbing duct liners, and vibration isolators, while architects are designing mechanical room walls and slabs with high sound transmission class (STC) ratings. Despite the addition of these noise and vibration control features in more and more building designs, complaints of excessive HVAC system noise and vibration are still common. Investigations into these complaints by acoustical professionals have found that, in many cases, the correct equipment and materials were used, but they were not properly integrated into a *quiet system*, or some seemingly insignificant detail was omitted that negated the expected acoustical benefit.

A TYPICAL APPROACH

Figure A shows a typical air-handling unit (AHU) mechanical room in which some of the most common system-related acoustical faults are noted. Of the 12 faults noted, very few have to do with the specific equipment or materials used. Most of the faults are *system* related; that is, the individual components are not designed and installed as if they were part of a whole system. Airflow through the AHU/ductwork layout shown in the figure would generate excessive turbulence, noise, and rumble. The small mechanical room would have restricted airflow in places, resulting in locally turbulent airflow and unexpected noise and rumble in the tenant space. The vibration isolators would not perform as expected because they are resting on a flexible floor structure. The designers of this hypothetical system did not consider all of the *system (interactive)* effects of the various components and how they would control the amount of noise and vibration that enters the building's occupied spaces.



1. AHU panel vibration "couples" to the lightweight, flexible gypsum wall just a few centimeters away. This coupling lets low frequency noise pass easily through the wall.
2. The counterclockwise rotation of the fan's discharge airstream is forced to change its spin direction at the downstream elbow. The turbulence generatred at the change can produce unstable flow with a very high, fluctuating pressure drop, thereby resulting in fan instability that is heard as rumble.
3. Problem 2 is aggravated if the elbow's turning vances do not have long trailing edges to straighten the airflow and control the turbulence.
4. The duct silencer is too close to the elbow. This compounds the turbulence problem.
5. Rectangular ductwork and duct silencers do not control the rumble produced by turbulent airflow.
6. The AHU's air inlet is too close to the wall. This causes two acoustical problems: unstable fan operation leading to surge and rumble, and direct exposure of the inlet noise to the mechanical room wall.
7. The lack of a duct silencer in a mechanical room return air opening allows fan noise to travel into the ceiling cavity, then through the lightweight acoustical ceiling into the occupied space.
8. The unit is resting on thin cork/neoprene isolation pads that are too stiff to adequately isolate the fan vibration.
9. The poorly isolated unit is resting on a relatively flexible floor slab without sufficient structural support. This arrangement allows unit vibration to enter the slab.
10. The chilled water piping is rigidly attached to the slab above, thereby letting unit vibration enter the slab.
11. Ductwall vibration in the duct silencer (or any other part of the trunk duct system) touching the drywall partition can cause the partition to act as a sounding board and radiate low frequency noise into the occupied space.
12. Suspending ceiling from supply duct causes ceiling to be a sound radiator.

Figure A Example of an air-handling unit room with several acoustical problems.

A BETTER APPROACH

Correcting a noise or vibration problem usually costs much more than preventing one. The real costs include not only the direct payments to the retrofitting contractor but also the time required to coordinate the investigation and retrofit and the loss of goodwill from the complaining tenants. Therefore, in most cases the slight extra cost for prevention (usually about 1% to 2% of the total HVAC system cost) is money well spent.

Specifying quiet equipment and adding noise control materials to an HVAC system design are necessary initial steps of the design process. Calculations during the initial steps can be used to estimate the sound levels in a room or to select noise control materials to achieve a design goal. Comparing equipment sound data for competing products can help in the selection of quiet equipment. However, design decisions based on such work lose their value if the equipment and materials are not integrated into a properly designed *system* or if certain system detailing is ignored.

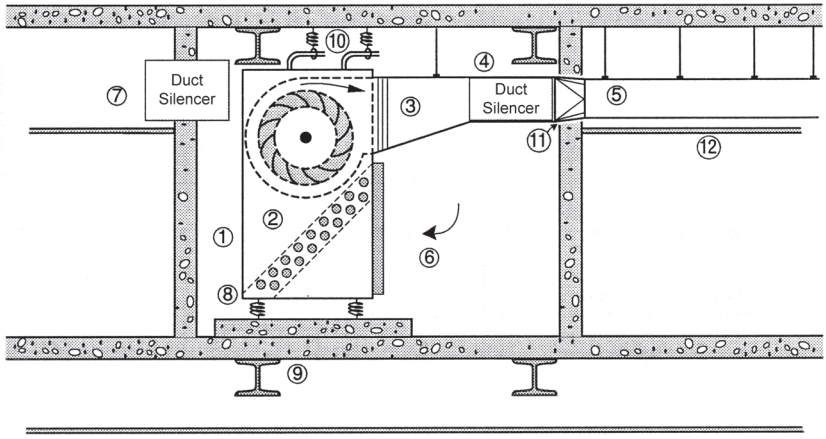
Figure B shows one version of a typical AHU room in which basic construction materials are integrated into a quiet system. The AHU and ductwork are selected and laid out for the best aerodynamics possible (this also reduces pressure drop and, therefore, fan horsepower). The AHU room is large enough for good aerodynamics in the room and for adequate clearance between the unit and the walls. The supporting structure has been stiffened with a housekeeping pad and beam to permit better vibration isolation.

SUMMARY OF THIS GUIDE

This guide presents information that will help engineers, architects, contractors, and others with little acoustical experience to develop project designs that avoid the kinds of problems shown in Figure A. Chapter 1 includes general noise control design guidelines to be addressed during the various design phases and includes some information on the architectural and structural aspects of HVAC system design. Chapter 2 addresses the selection and use of airside system components. Chapter 3 looks at the selection and use of waterside and central plant equipment.

Packaged and unitary equipment are addressed in Chapter 4. Guidelines for selecting and using vibration isolation systems are included in Chapter 5. Sample specifications for acoustical materials and the acoustical performance of HVAC equipment are given in Chapter 6, along with some examples of poorly written specifications. Reviewing submittals and making site inspections are addressed in Chapter 7. Chapter 8 gives suggestions for troubleshooting HVAC noise and vibration complaints.

The appendices present background information, including some basics of HVAC system acoustics, the use of criteria and manufacturer's published sound data, and how to make sound level measurements. Appendices with definitions of acoustical terminology, abbreviations, and addresses of relevant agencies and associations are also included.



1. Keeping a minimum 600 mm clearance reduces coupling between AHU and wall. Masonry wall provides excellent low frequency sound isolation.
2. Use of a horizontal discharge AHU eliminates the need for a turbulence-producing airflow.
3. Gradual transition at AHU outlet minimizes turbulence.
4. Duct silencer is far enough away from AHU outlet to avoid excessive regenerated noise and turbulence.
5. Circular ductwork controls the transmission of low frequency noise and rumble into the occupied space.
6. The large clearance at the AHU inlet keeps the unit away from the wall and avoids excessive inlet turbulence.
7. The return air duct silencer controls AHU noise via the return air path.
8. The unit is resting on high-deflection, steel spring vibration isolators.
9. The floor assembly supporting the unit has a housekeeping pad and at least one major beam under the unit. Additional stiffness and mass help to control the transmission of unit vibration into the slab.
10. The chilled water pipes are suspended by vibration isolation hangers.
11. The supply trunk duct does not touch the wall. A 13 mm gap surrounding the duct is filled with a non-hardening sealant.
12. Ceiling not suspended from supply duct.

Figure B Example of an air-handling unit room with optimal acoustical features.

1

General Design Guidelines

Virtually every survey on office comfort finds that, after temperature problems, excessive HVAC system noise levels are responsible for more complaints than any other aspect of the office environment. Some of the many causes of the excessive noise can be traced to one of more of the following:

- Incorrect design of the HVAC systems and their equipment area walls and slabs
- Cost-cutting without regard for the noise and vibration implications
- Improper installation
- Improper start-up or commissioning
- Ignoring the selection and/or installation guidelines published by HVAC equipment and noise/vibration control product manufacturers

To minimize the possibility that design decisions could cause noise or vibration problems, a project's design team must consider the acoustical impacts of all design decisions, whether they are part of the schematic, design development, construction documents, value engineering, or construction administration phases of a project. The team members should also follow the selection and installation guidelines that are published by most equipment and noise/vibration control product manufacturers.

All too often the area of HVAC acoustical design is limited to the addition of duct silencers, duct lining, plenum lining, and vibration isolators at the end of the Construction Documents (Working Drawings) phase, after the mechanical engineer has virtually completed the HVAC system design and long after the structural system has been designed. These "add-on" acoustical treatments may control the

noise and vibration, but if they are not properly integrated into the system, they can reduce the system's performance and energy efficiency. If selected or installed improperly, they can even *cause* noise or vibration problems. Therefore, noise and vibration control design should begin during the project's Schematic Design phase and continue throughout the entire design process. This is even more critical if the use of fibrous materials, such as fiberglass and mineral wool, is not permitted.

Some "add-on" acoustical treatments may be required no matter how well a system is designed, but the use of some, such as duct liner and duct silencers, can sometimes be minimized if the HVAC system is designed with noise and vibration control in mind from the start.

The more noise and vibration control you *DESIGN IN*, the less you have to *ADD ON*.

The design phase of a new facility occurs in sub-phases with titles such as Pre-schematic Design, Schematic Design (SD), Design Development (DD), and Construction Documents (CD). The placement and sizing of mechanical equipment rooms and duct shafts are typically set during the Schematic Design phase. Therefore, many critical decisions for HVAC system noise and vibration control are needed in this early design phase. More detailed noise and vibration control decisions can wait until the DD and CD phases.

One crucial SD phase milestone is the completion of the structural system design. Delaying the acoustical design until after the structural system design is essentially complete sometimes leaves the design team with little flexibility in selecting and locating cost-effective noise and vibration control treatments. Troubleshooting investigations into HVAC system acoustical problems often find that the locations of shear walls, beams, columns, and cross-bracing make effective retrofit solutions either very expensive or, in some cases, impossible. Good acoustical design decisions made in cooperation with the structural engineer can avoid this kind of problem and minimize the cost of noise and vibration control treatments.

Proper acoustical design requires broad cooperation in the areas of architecture, structural engineering, mechanical engineering, electrical engineering, and acoustics. To that end, the design team should begin by working together in the areas of (1) system type determination, (2) preliminary equipment selection, (3) mechanical room and duct shaft sizing, and (4) space planning.

SYSTEM TYPE DETERMINATION

Each type of HVAC system has its own set of layout and operating features that determine which noise and vibration control measures are most cost-effective. Therefore, the choice of one system type over another should not be made without considering the cost of controlling noise and vibration. For example, a built-up rooftop penthouse HVAC system would generate almost all of its noise and vibration in the penthouse and would, therefore, require most attention there to prevent complaints from the occupants below the equipment rooms and near the duct shafts. On the other hand, a system using water-source heat pump units distributed throughout the building's ceiling plenums would require much less concern for noise and vibration control at the central plant but much more care in the selection, placement, and installation of the dozens of noise and vibration sources (the heat pump units) that are scattered throughout the building. It is, therefore, essential that the acoustical properties of all potential system types be considered before finalizing the selection.

PRELIMINARY EQUIPMENT SELECTION

After determining the type of system, the mechanical engineer should make preliminary equipment selections as soon as possible to allow for a preliminary noise analysis and to determine the probable sizes of the mechanical equipment rooms and duct shafts. The primary acoustical guideline is to select the quietest equipment possible, which usually means selecting the most efficient equipment (i.e., the lowest kilowatt rating at the maximum operating duty point). Since the original publication of this guide, virtually all of the major equipment manufacturers have updated their equipment selection procedures to include acoustical data that have been determined in accordance with internationally recognized testing procedures. Therefore, obtaining the acoustical information necessary for comparing equipment alternatives is much easier than it was in the past.

MECHANICAL ROOM SIZING

Economic pressure to maximize a building's usable/rentable space has resulted in less space being available for the HVAC systems and other building services. This reduction in equipment room size often forces the mechanical engineer to either select small, inefficient equipment or to shoehorn properly sized equipment into a restricted space. A similar problem occurs at duct shafts, which often contain either undersized ducts with excessive air velocities or properly sized ducts that are too close to the shaft walls. All such cases can lead to excessive noise. To minimize the possibility of this problem, mechanical rooms and duct shafts should be sized as follows:

1. All HVAC equipment rooms should have a floor area large enough to allow a clearance of at least 610 mm around all equipment. Building codes and equipment maintenance requirements may necessitate larger clearances in some cases.
2. Ductwork should be sized for the proper air velocity (see the section titled "Duct System Components" in Chapter 2) and shafts should be sized to provide sufficient clearances around the ducts (see Figure 1-1 for guidelines).

SPACE PLANNING

The primary acoustical goal of space planning is to locate the noisy equipment as far as possible from the building's noise and vibration-sensitive areas. For HVAC system design, this is most important in the location of chiller rooms, fan/AHU rooms, cooling towers, and rooftop package units.

A common space-planning problem involves the placement of an AHU room in the core area on a typical floor of a multistory office building. The best core area plans surround the AHU room with buffer zones such as toilet and storage rooms, as well as elevator, stair, and duct shafts as shown in Figure 1-2.

Effective space planning can also help minimize the construction costs of mechanical room walls and slabs. For instance, if a mechanical equipment room is adjacent to a non-sensitive room, then the construction of the common wall is not

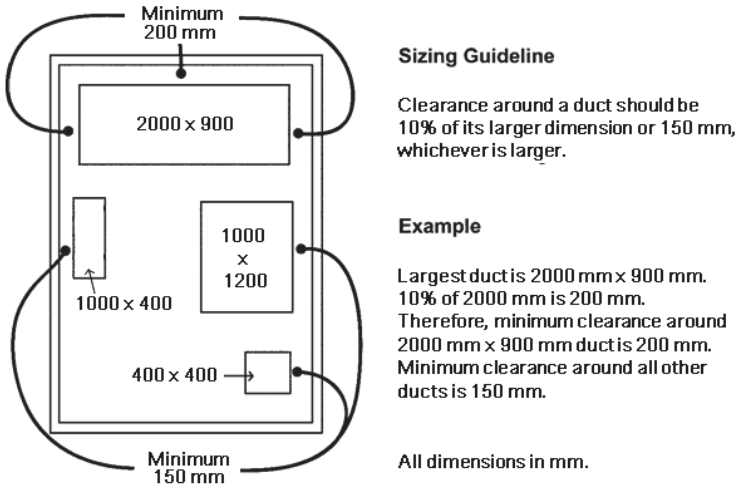


Figure 1-1 Guideline for duct chase, shaft, and enclosure sizing.

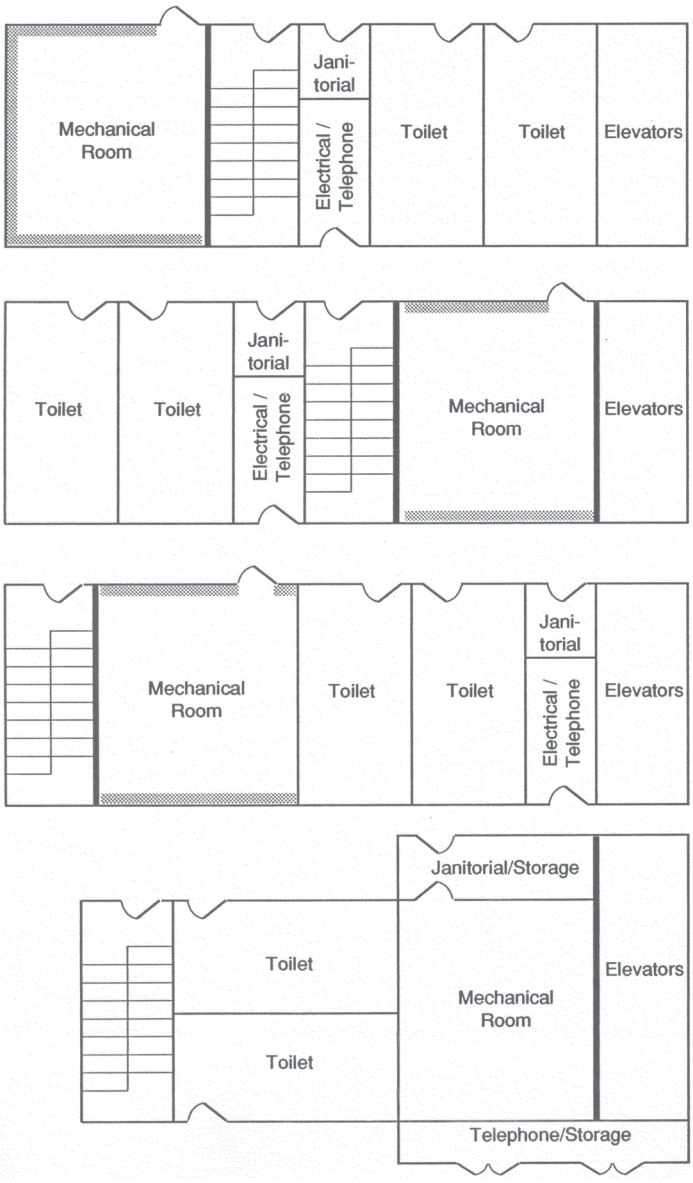


Figure 1-2 Acoustical comparison of various building core area layouts.

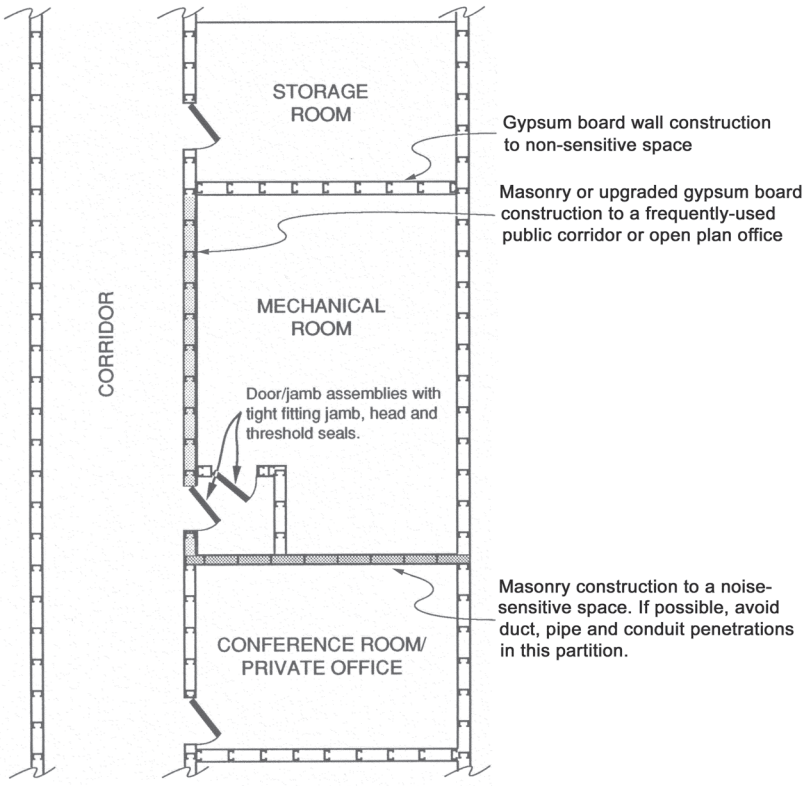


Figure 1-3 Guidelines for the preliminary selection of mechanical room walls.

critical, so lightweight gypsum board walls are typically acceptable. However, if the adjacent room is a conference room or private office, then a double-studded partition, or perhaps even a fully grouted masonry wall, may be needed. Figure 1-3 shows the concept.

After the preliminary space plans for the HVAC equipment areas has been determined, the mechanical engineer should distribute equipment layouts to the rest of the design team showing approximate weights and sizes of all equipment. A sample layout is shown in Figure 1-4. The structural engineer should use this information to select beams with maximum loaded deflections as listed in Table 1-1. The recommended deflection limits may be somewhat smaller than structural engineers would

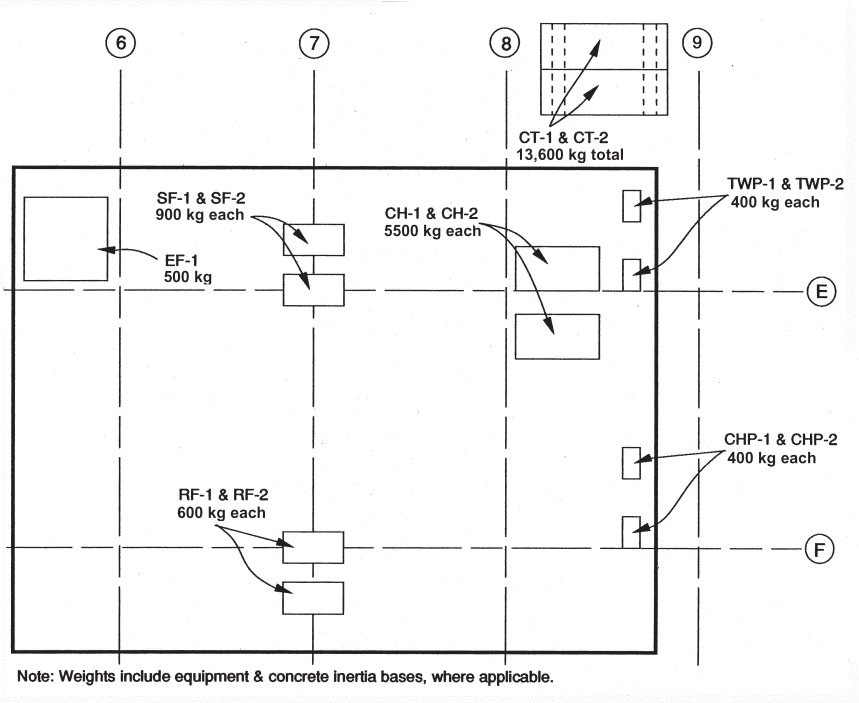


Figure 1-4 Sample mechanical penthouse equipment layout.

Table 1-1. Maximum Mid-Span Deflections for Above-Grade Structures that Support Vibration-Isolated HVAC Equipment

Equipment to be Mounted on Vibration Isolators	Maximum Structural Deflection due to Equipment Load (Composite Action for Concrete/ Metal Deck Floor Systems)
Cooling towers	8 mm
All other HVAC equipment	6 mm