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A PROPOSED FRAMEWORK FOR EFFICIENT DELIVERY OF SEISMIC RESTRAINT DESIGNS AND ITS POTENTIAL COST SAVINGS

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ABSTRACT

The National Building Code of Canada requires seismic restraint of mechanical and electrical equipment to limit movement of non-structural components in the event of a seismic event, providing for safe egress of building occupants. While the costly effects due to damage of non-structural components have been previously documented, only in recent years in the Ottawa area have the implications of proper restraint been realized by all disciplines involved in building design. With a new appreciation for the scope of seismic restraint requirements, contractors, architects and base building engineers are learning to incorporate this aspect into the design and construction process earlier. However, it still remains the responsibility of the mechanical and electrical contractors to provide seismic restraint to the equipment that they supply - a process that is often inefficient and time consuming. This paper outlines a proposed framework for streamlining the delivery of seismic restraint designs. Aspects of such a system include integration of seismic restraint considerations early in the design process, and optimization of equipment location and restraint details. In addition to detailing each of these efficiencies, this paper also attempts to quantify the potential for cost savings associated with applying these efficiencies. Implementing a framework such as the one described herein, means that minor modifications made early in the design can have considerable cost benefits to building owners by the end of a project.

Introduction

Recent seismic events have highlighted the potential for widespread damage to non-structural components that results from such occurrences. The M6.8 Northridge earthquake in 1994 led to damages estimated at $20 billion, of which approximately 77'% was attributed to damage of non-structural components (McLeod, 2004). The National Building Code of Canada (NBCC, 2005) requires seismic restraint of mechanical and electrical equipment to limit movement of non-structural components in the event of a seismic event, providing for the safe egress of building occupants, and in the case of post-disaster buildings to allow for continued operation

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after a seismic event. While this requirement has been part of the code for decades, only in recent years in the Ottawa area have the implications of proper restraint been realized by all disciplines involved in building design.

Earthquakes ranging in magnitude from M5.9 to M7.2 have been recorded in Eastern Canada, and a magnitude M6.0 earthquake is considered representative for the Ottawa area. Drawing on experience with over 375 restraint projects, this paper presents a framework for efficient delivery of seismic restraint design and installation, and aims to quantify the potential for cost savings associated with this framework.

Current Practice in Ottawa

The City of Ottawa requires that Clause 4.1.8.17 of the NBC be satisfied for all new buildings and all retrofit projects. In the past five years, engineers and contractors in the Ottawa area have gained an improved understanding of what is involved in fulfilling this code requirement from both practical project experience, and knowledge sessions conducted by local consulting firms engaged in seismic restraint engineering.

Despite the heightened awareness of this issue, in most cases the restraint of mechanical and electrical systems is considered late in the construction phase of the project, and it typically remains the responsibility of the mechanical and electrical contractors to provide this service. As a result of this situation, the contractor, owner and building occupants are all affected, as detailed in Figure 1.

Proposed Framework

Integration of seismic restraint considerations early in the design process

Key to streamlining seismic restraint delivery is to include a seismic restraint engineer on the design team from the initiation of the design process. By taking this proactive measure, the restraint engineer has the opportunity to educate the team as to the intent of restraint design, where restraint may be required, and how best to locate and layout mechanical and electrical systems to provide for efficient restraint designs. The restraint engineer can also be consulted early in the design process when atypical design situations occur, so that cost effective solutions can be achieved. While restraint considerations won't necessarily dictate how mechanical and electrical equipment is installed, the restraint engineer can at least advise the building design team about possible problem areas, along with potential solutions to minimize problems during construction. Finally, the restraint engineer can advocate for timely inclusion of restraint work in the construction schedule.

Unfortunately, the addition of a seismic restraint engineer to the building design team is not one that is familiar to projects in Eastern Canada, nor do the design fees exist to fund such position on the team. One alternative is for restraint engineers to educate fellow structural, mechanical and electrical engineers, architects and contractors in the basics of seismic restraint considerations. The project managers for both the design and construction phases must also understand and promote addressing the restraint design and installation in a timely manner.

	Restraint neglected	Restraint considered late in construction phase of project
Condition	- Specifications neglect or are vague with respect to seismic restraint of mechanical and electrical equipment - Full scope and intent of seismic restraint is not fully appreciated by the constructor or owner.	
Effect on installation	- Restraints installed late in the construction process, leaving less time for remediation of unique restraint conditions, & correction of deficiencies, or - Equipment is not reviewed for seismic restraint requirements. Restraints	
Effect on schedule	Building occupancy delayed	
Effect on occupants	- Occupation of building is delayed, or - Exposed to inconvenience of construction after occupancy of building	
Effect on contractor and owner	- Increased costs due to extended construction period - Increased costs due to installation/remediation after finishes installed - No opportunity for coordination of restraint design/installation with building design team, result in potentially inefficient restraint design	

Figure 1. Potential impact resulting from delayed consideration of seismic restraint for OFCs.

Projects involving installation of new mechanical and electrical equipment in existing buildings are typically smaller and of shorter duration than new building construction. Due to the short project schedule and complexity associated with working around existing conditions, it is crucial that the design team consider restraint requirements early in the design, and allow for custom restraint details in both schedule and budget.

In essence, what is needed is a shift in perspective of the design and construction teams. Seismic restraint of mechanical and electrical equipment is not an element left to be addressed by the contractor at the end of a project, but rather another element of design that involves input from the entire design team.

Specifications

Also critical to an efficient seismic restraint process is the availability of an accurate, explicit set of specifications. Some mechanical and electrical specifications simply require the satisfaction of the NBCC, without specific mention of seismic restraint for that equipment. In this case, if the contractor isn't familiar with the building code, there is the risk that seismic restraint will be overlooked, or left until the end of the project when a building official brings it to the attention of the contractor.

Other specifications go a step further and require that Clause 4.1.8.17 of the NBCC must be satisfied. While this is preferred over the former approach, it leaves room for interpretation by restraint engineers, contractors and building officials. The NBCC is less specific than its American counterparts (ASCE 7-05 [2006], SMACNA [2008], ASHRAE [1999]) in that it requires restraint of all mechanical and electrical equipment. However, application of engineering judgment, assessment of the risk associated with a component as outlined in CAN/CSA S832 (2006), and consultation with established American guidelines may allow the restraint engineer to exempt certain components from restraint requirements. The risk in this situation is that the building official will require strict adherence to the specifications and the NBCC, and disallow these exemptions. On a larger scale, each restraint engineer may have a different interpretation of the NBCC, leading to a varying scope for restraint from project to project. This leaves contractors and owners with a muddled perspective of requirements, and makes it difficult for the contractor to budget for the restraint work involved.

Better practice is to engage a restraint engineer early in the design process who will interpret the NBCC, and explicitly state in the specifications the equipment, pipe, duct and cable tray that require restraint. In this way, a consistent restraint approach is applied across all disciplines, the contractor can more accurately price the seismic restraint work, and confusion over scope of work late in the construction schedule is mitigated.

Specific Design and Installation Efficiencies

At the design and installation phases, the strategies described herein can be implemented to provide for efficient installation of restraint details. In applying these strategies, additional costs associated with extra site visits, remedial restraint details and possible construction delay are avoided. This section describes common restraint installation inefficiencies and proposes alternative "best practice" restraint designs.

Location of equipment

Base mounted equipment

The standard detail for base mounted equipment is to provide anchorage at the four corners of the unit. In many cases, the unit is anchored to structure with clip angles, which are provided on the four faces of the unit (Figure 2).

Location relative to wall

Best practice occurs when the unit is located with enough clearance from nearby walls to allow for access on all sides of the unit. A common inefficiency occurs where the unit is located directly adjacent a wall, providing no access for clip installation on one side (Figure 2). With access from four sides the standard restraint design is applied, with eight clip angles, and two 1/4-inch diameter wedge anchors at each support. Where access is from three sides only, six clip angles are used, but the anchor size becomes 3/8-inch with a deeper embedment. If the site condition is discovered after issuance of the restraint design, then a remedial design must be performed resulting in an additional design fee.

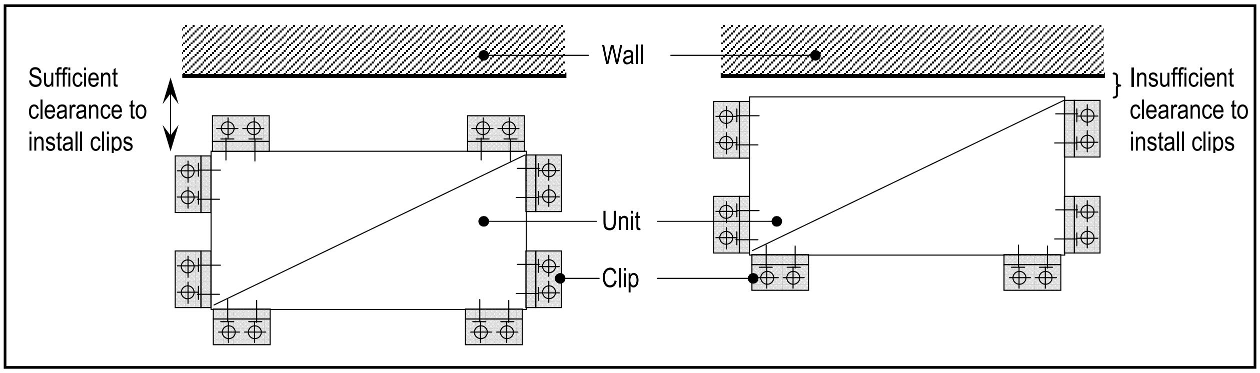

Figure 2. Installation options for base mounted units

Location relative to housekeeping pad

Best practice is to design the housekeeping pad and install the unit so that there is at least six inches of clear distance around the unit. A common inefficiency occurs when a unit is installed with insufficient anchor edge distance to the free edge of the housekeeping pad. Wedge anchors require a minimum edge distance to allow for a sufficient amount of concrete to be engaged for uplift and shear resistance. Where insufficient edge distance is provided, more complex, costly connections are required. Adhesive anchors may be required, or in more critical cases, bent plates that span over the housekeeping pad down to the main structural floor may be necessary. Where this condition is discovered after issuance of the restraint design, an additional design fee may apply.

Base mounted equipment: vertical tanks

Vertical tanks are often tall with a relatively narrow base, resulting in considerable seismic uplift forces. The standard detail for tanks is clip angles around the base of the unit, and a strap around the tank connecting to a backup structural wall. Best practice is to locate the unit adjacent to a structural wall so that the strap may be anchored to that wall. A common inefficiency is to locate the unit away from a structural wall. To address the overturning force, an HSS post and baseplate are constructed and installed adjacent the tank, to which the strap is anchored. (Figure 3). The standard strap-to-wall detail requires less materials and labour to install. In addition, the detail takes up less space in the mechanical room.

Wall mounted equipment

While wall-mounted units are typically smaller in size and weight, they still require restraint when they weigh 20lb or more, based on references to ASCE 7-05. The standard detail is to provide anchorage directly back to the backup wall. Best practice is to locate units at structural walls, such as a concrete or reinforced masonry block wall. A common inefficiency is to install a large, heavy unit to a metal stud partition wall, or unreinforced masonry wall. Metal stud partition and unreinforced masonry walls must be reviewed by the building engineer of record for the lateral forces applied to them. Where heavy wall-mounted units are installed to non-structural walls, redesign or retrofit of the walls will be required, resulting in additional materials, labour and design fees.

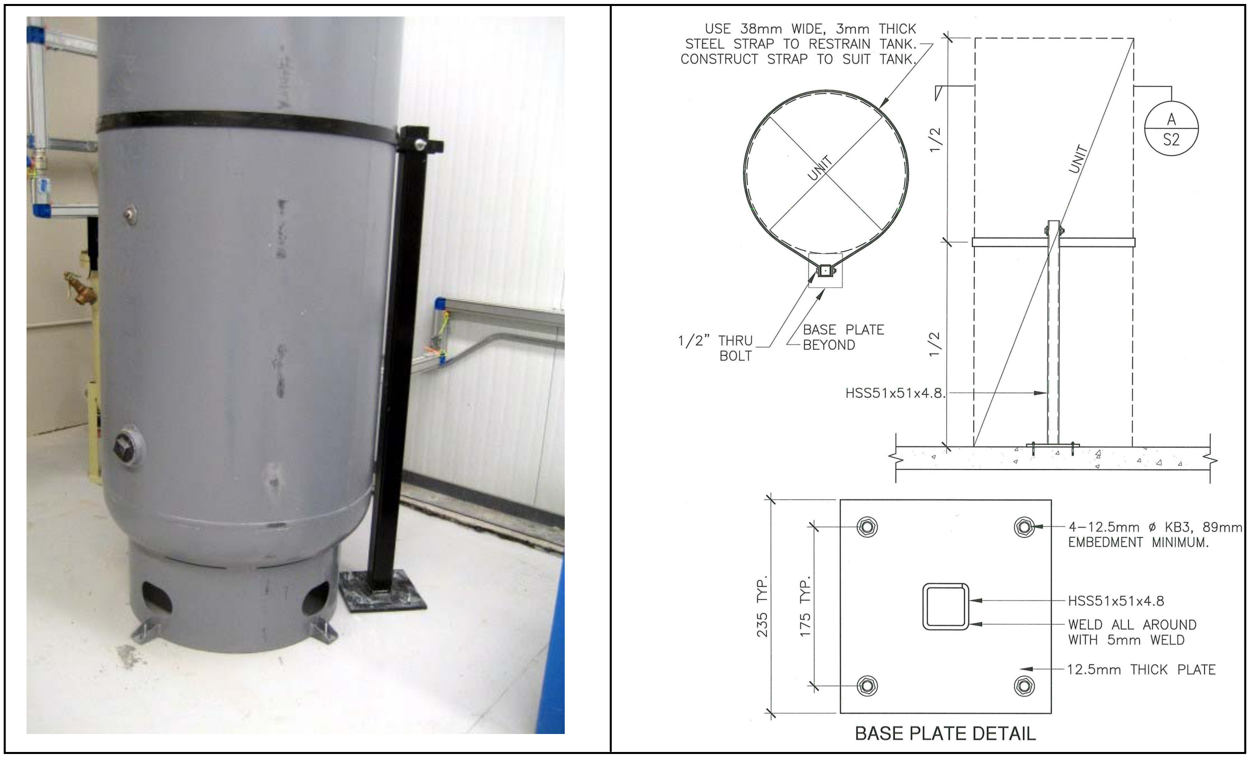

Figure 3. HSS post detail for vertical tanks

Suspended units

Suspended equipment is typically restrained with cables installed at a 45º angle from the horizontal at all four corners of the unit. The main aim of restraint is to prevent swaying of the unit, and limit bending stresses in the hanger rods. Structural steel angles clamped to the hanger rods are required to resist the resulting compression force in the rod. Where heavy equipment is to be restrained, best practice is to install large diameter hanger rods, and minimize the hanger rod length. Alternatively, heavy equipment could be base mounted. Long hanger rods have a greater potential for buckling when compression is applied to them in a seismic event. To prevent buckling, larger steel angles with stiffener clamps at a tight spacing are necessary (Figure 4). With clamps required at four corners of each unit, the material and labour costs increase quickly.

Suspended distribution equipment

Suspended distribution equipment (pipe, duct, cable trays) is restrained with cables transverse (maximum spacing 40 feet) and longitudinal (maximum spacing 80 feet) to the equipment. Structural steel angles clamped to the hanger rods are required to resist the resulting compression force in the rod at the restraint locations. Best practice is to relocate equipment to less congested areas where possible. For example, if a school hallway has a large volume of duct, pipe and cable tray running through its ceiling space, consider relocating the pipe to adjacent classroom spaces. Alternatively where congestion will make cables difficult to install, provide a steel HSS frame with a moment connection to the structure every 40 feet for trapezed equipment. In congested areas such as hallways, space does not allow for cables to be installed on the equipment, requiring the use of strut restraints, and custom treatment of unique restraint conditions. Distribution equipment may be installed with excessively long hanger rods as detailed previously.

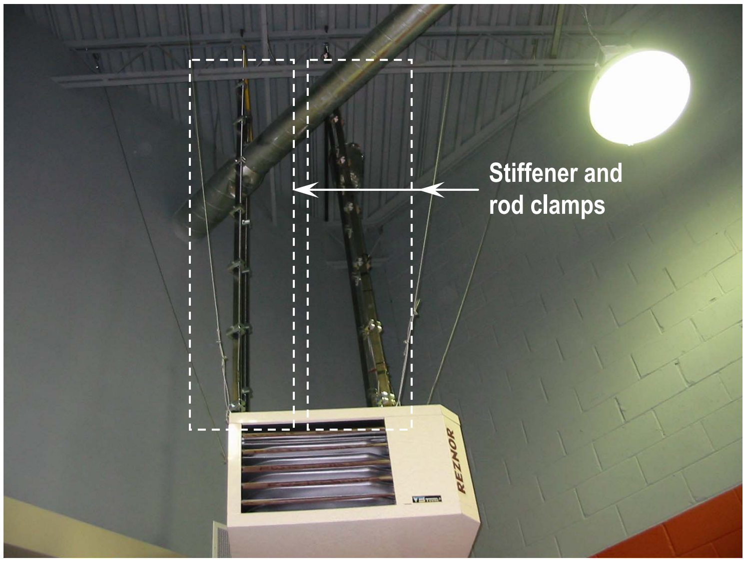

Figure 4. Suspended equipment with many clamps

If coordination of services in areas of limited space does not occur prior to installation, several inefficiencies occur. With a high degree of congestion, contractors spend more time attempting to find space for the restraints. The restraint engineer will need to review these areas carefully, identifying problem installation points and design custom restraint solutions. These factors can easily result in both increased installation cost and delay to the project.

Restraint Practices

Isolated equipment

Isolated equipment, such as cooling towers or chillers, is often associated with large mass and is located at the roof of the structure. These factors lead to large resultant seismic shear and overturning forces at the isolator connection to structure. Most isolators have a relatively small footprint; therefore best practice is to assume that an oversized baseplate, along with large concrete piers will be required. A common inefficiency occurs when the base building engineer provides relatively small piers, leaving the restraint engineer with insufficient edge distance for wedge or even adhesive anchors. As a result, costly redesign is necessary, leading to complex pier caps and anchor geometries, additional labour and material costs, as well as potential delay.

Seismic options

While restraint engineers and contractors may not be aware, restraint of equipment is often considered by equipment designers. A wide range of equipment is available with internal framing and built-in clips that allow for ease of restraint installation. Best practice is to include a statement in the specifications requiring that seismic options be ordered with equipment so that the contractor can include this option prior to ordering equipment. The cost to include such seismic options is a fraction of the cost to fabricate and install custom clips or framing at the equipment installation phase.

Potential Cost Savings

A representative elementary school from the Ottawa area is considered. The school is a newly constructed, two-storey, steel structure with 5700 m^2 (61300 sq. ft) useable space. The total construction cost is $8.9 million, of which $1.1 million is HVAC/plumbing cost, and $875,000 is electrical cost. The school is considered at an importance level of 1.3, indicating that it could be used as an emergency shelter in the event of an earthquake. The standard types of equipment to be restrained are listed in Table 1, along with potential inefficiencies. In this review, two situations are considered: (1) equipment is installed with minimal inefficiencies (90% efficient), and (2) equipment is installed with major inefficiencies (50% of units are installed inefficiently). For example, a condenser unit is to be installed at the roof. The 50% efficiency situation occurs if the roofing and mechanical contractors do not coordinate, and the roofing is installed prior to anchorage of the unit. To satisfy the requirements, the roofing must be removed, unit anchorage provided and roofing reinstalled. The 90% efficiency situation occurs where coordination between contractors does happen, allowing the work to proceed in a logical order.

Table 2 lists the costs and savings associated with design and installation of seismic restraints for sheet metal, plumbing and electrical services. Standard materials costs are assumed, with a 20% mark-up applied to contractor labour. A labour rate of $75 per hour is used.

The costs shown in Table 2 illustrate that while potential materials savings range from 18% to 61% depending on the discipline, the potential savings associated with the labour to install the restraints is around 35% across all disciplines. With the additional on-site troubleshooting, reviews and revised design, supervisory and review fees increase by around 50% on average. Also of note for this representative case is that by implementing design efficiencies from the start, a potential overall cost savings of approximately 40% of seismic restraint costs exists, which translates to a savings of approximately $6.80/$m^2$ ($0.63/sq. ft.).

In this case study, application of efficient restraint strategies represents a potential cost savings of approximately 1.5% of the HVAC/plumbing costs, and 1.25% of the electrical costs.

Conclusion

Seismic restraint of mechanical and electrical equipment is a complex task that requires the attention of all members of the design team. A representative school case study is evaluated, illustrating that savings on the order of 40% of the restraint installation costs, or approximately

$6.80/m^2$ can be realized where efficient restraint strategies are implemented. Essential to realizing these savings is that the design team address restraint early in the project, that a restraint engineer is involved to educate the design team and contractors as to intent of restraint, and that thought is given to equipment location and layout early in the building design.

Table 1. Types of units and inefficiencies considered for costing of representative school

Discipline	**Unit**		**Installation**	**Inefficiency**	
	Type	**No.**		**Condition**	**Result**
HVAC	***Condenser***	1	Base mount	Roofing installed prior to unit anchorage	Re-roofing required at anchor points.
	Make-up air	1	Base mount	None	-
	Unit ventilator	14	Base mount with strap	Unit is not near structural wall.	HSS post required.
	Roof fan	6	Base mount	Roofing installed prior to unit anchorage	Re-roofing required at anchor points
PLUMBING	***Plumbing***	150 points	Cable restraint	Pipe installed with long hanger rods. Pipe layout not coordinated, resulting in congested areas.	Hanger rod stiffeners and clamps required. Strut restraints required.
	Boiler	2	Base mount	Unit is too close to a wall and not accessible on one side.	Larger anchors must be used on remaining sides, and re-design required
	Cabinet unit heaters	7	Wall mount	Unit is anchored to non-structural wall	Wall must be reviewed and reinforced
	Hot water tank	1	Base mount with strap	Unit is not near structural wall.	HSS post required.
	Unit heater	1	Wall mount	None	-
ELEC'L	***Cabletray***	105 points	Cable restraint	Cabletray installed with long hanger rods. Cabletray layout not coordinated, resulting in congested areas	Hanger rod stiffeners and clamps required. Strut restraints required
	Transformer	3	Base mount	Unit is too close to a wall and not accessible on one side.	Larger anchors must be used on remaining sides; re-design required
	Switchboard	1	Base mount with strap	Unit is not near structural wall.	HSS post required.
	Panels	17	Wall mount	Unit is anchored to non-structural wall	Wall must be reviewed and reinforced

Table 2. Costs and potential cost savings for design and installation of seismic restraints

Discipline	Task		90% efficiency	50% efficiency	Cost difference	Percentage savings
HVAC	***Restraint Engineer***	Design	$1,800	$2,650	$850	32%
		Site	$250	$500	$250	50%
	Project Management	Site	$750	$1,000	$250	25%
	Construction	Materials	$5,485	$14,185	$8,700	61%
		Labour	$10,890	$17,082	$6,192	36%
PLUMBING	***Restraint Engineer***	Design	$1,420	$3,120	$1,700	54%
		Site	$250	$750	$500	67%
	Project Management	Site	$750	$1,250	$500	40%
	Construction	Materials	$7,157	$8,694	$1,537	18%
		Labour	$11,867	$19,172	$7,305	38%
ELECTRICAL	***Restraint Engineer***	Design	$2,460	$5,060	$2,600	51%
		Site	$1,000	$1,000	$0	0%
	Project Management	Site	$750	$1,250	$500	40%
	Construction	Materials	$5,863	$8,611	$2,748	32%
		Labour	$9,360	$14,520	$5,160	36%
TOTAL			**$60,052**	**$98,844**	**$38,792**	**39%**

References

ASCE 7-05, 2006. *Minimum Design Loads for Buildings and Other Structures*, American Society of Civil Engineers, Reston, VA.

ASHRAE, 1999. *A Practical Guide to Seismic Restraint*, American Society of Heating, Refrigerating and Air-Conditioning Engineers Inc., Atlanta, GA.

CAN/CSA S832, 2006, *Seismic Risk Reduction of Operational Functional Components (OFCs) of Buildings,* Canadian Standards Association.

McLeod, F.A. 2004. *"The latest developments in seismic mitigation of suspended ceiling systems,"* 13th World Conference on Earthquake Engineering.

NBCC, 2005. *National Building Code of Canada*, Institute for Research in Construction, National Research Council of Canada, Ottawa, Ontario.

SMACNA, 2008. *Seismic Restraint Manual Guidelines for Mechanical Systems*, Sheet Metal and Air Conditioning Contractors' National Association Inc., Chantilly, VA.