DOCUMENTATION OF URBAN DESIGN AND OUTDOOR NOISE BEST PRACTICES FOR AIR-SOURCE HEAT PUMPS

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Prepared for City of Vancouver Green Building Team
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This GCS project was conducted under the mentorship of City staff. The opinions and recommendations in this report, and any errors, are those of the author, and do not necessarily reflect the views of the City of Vancouver or The University of British Columbia.

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1. EXECUTIVE SUMMARY

Background

The City of Vancouver's current direction towards greater energy efficiency standards, combined with continuous advancements in green energy technology, will likely result in the greater adoption of air-source heat pumps as an alternative source of space conditioning and domestic hot water production. As Vancouver continues to densify, the competition for suitable mechanical space will become even more limited and the possibility for noise conflicts even greater. This research project therefore explores some of these challenges and presents potential solutions to these issues.

Report Methodology and Structure

This report was primarily informed by an analysis of the current City of Vancouver noise by-law, heat pump guidelines and regulations, as well as mechanical noise mitigation strategies. This approach was complemented by a series of 12 interviews with key stakeholders, which provided contextual knowledge of real world design issues and solutions. This report contains three independent chapters (Sections 5-7) that each addresses a different audience.

Recommendations to the City of Vancouver

Section 5 outlines a series of amendments to the current noise by-law that could help protect residents from potential mechanical noise intrusions, as well as improvements to the by-law framework that could provide greater clarity for development and design industry professionals. This section also includes some zoning by-law amendments to help facilitate the successful installation of air-source heat pumps.

Homeowner Guide

Section 6 provides guidance for homeowners pursuing the installation of an air-source heat pump. A one-page homeowner guide can be found in Appendix B that aims to answer some of the most essential noise related questions.

Development Process Considerations

Section 7 is intended to provide a basic overview of the various mechanical noise mitigation strategies and considerations. A one-page internal bulletin for development planners can be found in Appendix E.

2. INTRODUCTION

2.1 Greenest City Scholars

The Greenest City Scholars program is a partnership between the University of British Columbia and the City of Vancouver. Through UBC's Sustainability Initiative, graduate students are given the opportunity to collaborate on applied research projects that support the long-term goals identified within Vancouver's *Greenest City 2020 Action Plan* (GCAP). As part of the City of Vancouver's Sustainability Group, the Green Building Team submitted a project to explore the different urban design and noise considerations of air-source heat pumps.

2.2 Supporting Plans and Policies

This project aims to support the facilitation of heat pump installation within new construction projects, while minimizing any potential noise conflicts that may result from greater adoption of this technology.

2.2.1 Goal 3 - Green Buildings

Under the Greenest City 2020 Action Plan, Goal 3 (*Lead the world in green building design and construction*) identifies the need to continue improving the environmental performance of buildings. This goal has provided direction for the *Zero Emissions Building Plan (ZEBP)*, which requires all new buildings to be carbon-neutral by 2020. The first path for GHG emissions reductions within the ZEBP promotes the increased efficiency of buildings. Heat pumps are able to reduce emissions by providing a reliable source of space heating and cooling, and domestic hot water. Air-source heat pumps are efficient at converting ambient outdoor heat for indoor conditioning and hot water production.

2.2.2 Renewable City Strategy

Heat pump technology equally supports the *Renewable City Strategy* given that heat pumps are a viable alternative to the use of natural gas. The City of Vancouver's renewable electricity portfolio is currently around 97%[i], allowing heat pumps to be considered a renewable source of energy.

2.3 Potential for Noise Conflict – Density

As Vancouver evolves as a city, it will need to accommodate an increasing number of residents. This will likely result in the densification of both existing neighbourhoods and undeveloped sites. In the context of single- and multiple-family detached dwellings, an increase in density has the potential to increase noise conflicts between neighbouring residents. Specifically in Vancouver, which has a large proportion of low rise buildings with narrow side yards, combined with an increased prevalence of laneway homes, the competition for suitable locations for heat pumps becomes even more limited. In mid- and high-rise building applications, the competition for rooftop space is also increasing, as well as the possibility for newly introduced development to impact existing residents. This project therefore explores what the potential issues and solutions are within these contexts, as well as how to best approach these various trade-offs.

3. RESEARCH DESIGN

3.1 Objectives

Through the Greenest City Scholar project agreement, several tasks were initially identified:

- Compile an educational summary of issues and best practices in noise control and urban design for new buildings using air-source heat pumps
- Develop a user-friendly compilation of the applicable noise bylaw requirements, a summary of the various real-world design under different project conditions, and an evaluation of the performance of those responses for noise control and urban design
- Draft recommendations to regulators, designers, or others for ways that heat pumps can be better facilitated in new buildings.

3.2 Methodology

The methodology for this project consisted of two approaches. In order to understand the current context in which heat pump systems are designed, installed, and operated, a compilation of current by-laws, policies, and industry best practices was developed. This approach was complemented by a series of interviews with key topic stakeholders, which provided a better understanding of real-world design considerations and solutions. From these two sources of information, draft recommendations and deliverables were developed in response to the various opportunities identified.

3.2.1 Context Analysis

In order to have a baseline understanding of the context in which heat pump systems are implemented in Vancouver, a set of fundamental questions first need to be addressed. They consisted of the following:

- What are the current regulations that guide heat pump installations?
- Are there any standards, policies, or tools that help facilitate noise mitigation with respect to heat pumps?

- Which heat pump units are the quietest and what are their noise reduction features?
- What is the current noise by-law and how is it measured?

The scope of these questions focused largely on the City of Vancouver, but was also informed by surrounding municipalities, and some international examples that could be considered best practices.

3.2.2 Key Informant Interviews

A total of 12 key informant interviews were conducted in June 2017. These included a range of expertise and perspectives, including mechanical and acoustical engineering consultants, City of Vancouver Real Estate and Facilities Management employees, and green mechanical equipment suppliers. These interviews were then transcribed and the information provided was used to further inform deliverables and recommendations.

3.3 Limitations

The main limitation of this endeavour was the time allocated to the project. In order to be the most efficient in producing this final report, time and effort were focused on content rather than layout and design. Further, other deliverables were identified as more effective in helping noise mitigation of air-source heat pumps (Sections 6 and 7, specifically). A secondary limitation was the willingness for external consultants to participate fully in the exercise. Although some individuals were quite generous with their time, not all were willing or able to respond to email and phone call enquiries.

Finally, the interviewing process presented a wide range of interesting themes and topics that were determined to be outside the scope of this project. These included: the role of aesthetics in new construction projects, the variability of human experience and sensitivity, as well as potential unintended consequences as a result of development projects. Although these discussions formed part of context of this report, they are not discussed in detail.

3.4 Report Structure

This report is structured with separate sections that have different intended audiences: Section 5 provides recommendations to the City of Vancouver, Section 6 is a guideline for homeowners considering installing an air-source heat pump, and Section 7 outlines relevant background information for development planners (Section 7). Given that each section may be read as an independent document, there may be some overlap or repetitive information if read in succession.

4. CONTEXT ANALYSIS

4.1 Current Noise Control By-law 6555

Air-source heat pumps are categorized under the Mechanical Equipment section of the City of Vancouver Noise Control By-law 6555. Within the by-law, noise is measured in units of A-weighted decibels (dBA) which weights sound pressure levels using the "A" weighting network. The A-frequency band is argued to better represent the relative loudness perceived by the human ear given that it eliminates lower and higher audio frequencies that are imperceptible to average humans.[ii] Decibel units are evaluated using a logarithmic scale, meaning that each increase in 10 dB is a perceived as relative doubling of loudness.[iii] Noise levels are measured using an approved sound meter.

The City of Vancouver is geographically classified into zones that have different sound level limits depending on the dominant land use or activity within that area. The majority of residential neighbourhoods are categorized as "quiet zones" that have both daytime and nighttime limits. Within a quiet zone, the maximum allowable noise between 7:00am-10:00pm is **55 dB** and **45 dB** between 10:00pm-7:00am. For reference, 45 dB is comparable to sound of bird calls or the noise level within a library[iv], while 55 dB is similar to the sound of a dishwasher in the next room.[v]

This noise is measured from a point of reception, which is defined in the by-law as:

> *(a) a point in a lane or street, adjacent to but outside of the property occupied by the recipient of the noise or sound, that represents the shortest distance between that property and the source of the noise; or (b) where no lane, street, or other public property exists between the recipient and the source, any point outside the property line of the real property from which the noise or sound emanates; (d) in any case at least 1.2 m above the surface of the ground.*[vi]

Under this definition, the location where a by-law enforcement officer can measure the noise level is effectively limited to the property line between two adjacent residences. Further, if the noise is produced within an intermediate, activity, or event zone and is received within a quiet zone, the lower limits of the quiet zone will apply.

Sound is characterized as either continuous, meaning any sound occurring for a duration of more than three minutes, or occurring continually, sporadically, or erratically but totalling more than three minutes in any 15 minute period of time, or as non-continuous, which includes any sound outside of the former definition. Within any zone (activity, intermediate, or quiet), non-continuous sound cannot exceed 75 dB during the daytime and 70 dB during the nighttime.

4.2 Background on Air-Source Heat Pump Noise

Air-source heat pumps have two main sources of noise: condenser fans and compressors. Compressors are internal to the unit, pumping refrigerant through the heat pump system's loop. The sound produced by a compressor is a low frequency noise, which may disturb neighbouring residents if not properly attenuated. Inexpensive or older heat pump units will often have compressors within the condensing fan shaft, which amplifies sound. Fortunately, newer units more often include sound mitigation strategies as standard. One example is sound insulation placed around the compressor using sound-deadening foam or blankets.

Another important consideration is the potential for vibration transfer from a heat pump unit to a neighbouring residence. Depending on the size and location of a unit, this may have a negative impact on residents if not properly attenuated. Potential interventions include installing a sound absorbing base, such as a rubber mat, or in larger applications, sound absorbing shocks at the foot of the unit. This isolation mounting reduces the likelihood of vibration transfer through the building envelope or nearby windows.

Condenser fans produce a mid to higher frequency noise that is highly directional. Heat pumps can have either a vertical or horizontal discharge of air. Vertical discharge results in a noise propagation that broadcasts upward from the top of unit, while horizontal discharge units produce noise that travels outward parallel to the ground that the unit is on. It is important to understand the direction of this noise in order to effectively mitigate potential impacts on residents. The ability to hear noise is generally understood in terms of line of sight: if you are able to see a nearby sound emitting source, you are likely able to hear it. This is further nuanced with the ability for sound to reflect from hard surfaces. In order to fully understand the potential for noise conflict, the design team must follow the propagation of sound waves from source to various potential points of reception.

The advancement of variable speed technology has helped reduce the noise of both compressors and condenser fans. Variable speed motors allow for precise load matching, less cycling on and off, and low amp gradual compressor motor start-up.[vii] By not having to run the unit at full speed during light-load conditions, variable speed motors both improve the efficiency of a heat pump and reduce the overall noise that the unit produces. Further, variable speed motors allow for less abrupt start-ups, reducing the disruptive high pitch noise associated with older compressors and banging noise associated with fans.

4.3 Current Heat Pump Regulations

The installation of heat pumps in Vancouver is currently informed by the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) guidelines, as well as manufacturer instructions. It is not currently necessary to have a building permit to install a heat pump in single-family applications. New construction projects require a development permit, which is subject to the development review board and urban design panel, which evaluate the overall design of a building, although there are currently no clear guidelines for heat pump siting and potential noise impacts. This is addressed in section 7.

As an alternative example for single-family homes, the United Kingdom's Microgeneration Certification Scheme (MCS) Standard regulates both the installation of a range of home energy generation equipment, as well as provides standard requirements for equipment performance. In order for a homeowner to install a heat pump system, their unit needs to be installed by a certified professional that has completed the required compliance certificate process. Table 2 of the MCS Standard for heat pumps (included in Appendix A) outlines a series of calculations that must be completed before a unit will be approved by a local planning department. These calculations include: the A-weighted sound power level of the unit, directivity of the heat pump's noise, the distance between the heat pump and the assessment position, as well as any sound attenuation achieved from installed barriers. Once these calculations are complete, the theoretical sound power level must be below 42.0 dB in order for the heat pump to comply with permitted development.

The City of Nanaimo also regulates the siting of any heat pump to be located in the rear yard of single-detached houses or duplexes. The unit must be located at least 3 metres from the rear property line and 4.5 metres from both side yard lot lines.[viii] If the homeowner is unable to install their unit within the approved area, they may apply for variance to the Zoning Bylaw either through a development variance permit (DVP) or through the Board of Variance (BOV).

The City of Maple Ridge provides another example of a compliance framework that regulates the location of heat pump units. Maple Ridge does not allow heat pumps to be installed in the side yard between houses.[ix] The preferred location is the centre of the front or rear yard of the dwelling the unit serves. Homeowners must apply for a permit for their heat pump, including a site plan that indicates the proposed location of the heat pump, along with an electrical permit application.

5. RECOMMENDATIONS TO CITY OF VANCOUVER

5.1 Noise By-law Update

From discussions with acoustical consultants, as well as when compared to other municipal noise by-law frameworks, the City of Vancouver's current noise regulations for mechanical equipment could be improved through additional language that provides more guidance with respect to noise. In order to protect residents and provide clarity for building industry professionals, there are several amendments to the noise by-law that could help reduce the likelihood of noise conflicts.

5.1.1 Point of Reception

The current City of Vancouver noise by-law considers the "point of reception" to be at the property line at a height of 1.2 metres, which is roughly the height of a person. The City of Victoria provides a further stipulation within their by-law that allows enforcement officers to measure noise at a location that "best represents the location at which the noise or sound, emanating from another property, is received and the resulting disturbance experienced."[x] This implies that noise disturbances may be measured either on neighbouring balconies or at windows above ground level, which provides an additional layer of protection for residents.

"Most often we'll get called in when there's already a complaint and nine times out of ten it's a heat pump that's located right on the property line that's directly below a second storey bedroom, for example. So the owner may not be in compliance with the noise bylaw depending at what height on the property line a bylaw officer takes a reading; Additionally if there is a solid fence between the heat pump and the measurement position the barrier will actually help at that point but it's not going to help at all at the second level bedroom if there is a direct line of sight above the solid fence."

- Local Acoustical Engineering Consultant

This could help address some potential complaints of sound emissions from heat pumps that propagate to second- and upper-floor balconies or windows. Under the current by-law framework, noise measured at the property line is often produced directly behind an existing fence, which may not best represent the experience of residents within their homes. The City of Vancouver should consider adopting a similar approach, while providing an additional mechanism that would require the by-law officer to measure noise in a consistent fashion. This could involve multiple readings taken on the same property and then the highest one being enforced, or taking a reading where the occupant feels they are the most affected.

5.1.2 Correction Factors

Although measuring the sound level of a noise disturbance is a fundamental step is assessing a complaint, the *character* of that sound is also an important consideration. Within the City of Victoria's noise by-law, there is a section that provides guidance for applying additional decibel weightings to measured sound, depending on the characteristic of the noise present. If the measured sound is determined to be impulsive, tonal, or intermittent, the following correction factors are applied:

Impulsiveness

(a) a +5 dB correction if the sound under consideration is impulsive in character;

Tonality

(b) a +5 dB correction if the sound under consideration is tonal (i.e., it contains one or more pure tone components);

(c) in order for the tonality correction to apply, measurement is required to determine the presence of tonality, the level in the one-third octave band containing the tone, or the arithmetic average of the levels in a pair of bands containing the tone, must exceed the arithmetic average of the two adjacent bands

(i) by 3 dB or more for tones in the 500 Hz. to 16 kHz. bands,

(ii) by 5 dB or more for tones in the 160 to 400 Hz. bands,

(iii) and by 10 dB or more for tones in the 31.5 to 125 Hz. bands;

Intermittency

(d) a +5 dB correction if the sound under consideration is persistently intermittent;

Multiple Corrections

(e) a correction equal to the sum of the corrections applicable under paragraphs (a) to (d) for each of the characteristics, described in those paragraphs, that the sound possesses to a maximum of 10 dB.

This level of detail is particularly important when evaluating noise disturbances related to air-source heat pumps. Depending on the age, size, and components of a heat pump, the unit may produce loud and abrupt noises when either the condenser fan or compressor engages. Further, if the compressor is not properly attenuated, the low frequency noise that it emits could disturb nearby residents. If the City of Vancouver were to adopt a similar section of correction factors, citizens would be further protected under the noise by-law.

5.1.3 3dB Buffer and Background Noise

It is important to establish ambient or background noise levels before attempting to determine the sound level of a source, given that it would be impossible to enforce a sound level limit that is lower than what already exists. In other jurisdictions, such as Burnaby, the noise by-law requires at least a 3 dB difference between an existing noise source (measured at the appropriate position and during the relevant period of time wherever possible) and another emitting source.[xi] This is relevant in any situation where a heat pump or other piece of mechanical equipment is already producing noise and an additional unit is installed nearby.

"One thing we always have trouble with is the noise bylaw requirement at night (i.e. 45 dBA); If you design to 45 dBA, but the existing background noise level is also 45 dBA (for example) the final number is 48 dBA. So in that case you're exceeding the bylaw on the measurement day but in fact you met the bylaw because you only had to meet 45. The Burnaby Noise Bylaw says that the noise level has to be at least 3 dB above the bylaw requirement before they'll even make a measurement. So it gets out of that problem of meeting the bylaw technically even though the site measurement may show that you're in excess. This assumes that the ambient noise is 45 dBA or lower."

- Local Acoustical Engineering Consultant

In order to be effective at evaluating appropriate noise levels, the City of Vancouver should consider mandating regular background noise measurements for new construction sites, particularly in large scale developments where there is a greater potential for noise disturbance. The noise by-law should also be amended to include a 3 dB buffer for enforcement, similar to the one in place in Burnaby.

5.1.4 Enforcement

Similar to energy efficiency requirements, there could be two potential paths for enforcing noise limits of air-source heat pumps. The first being a prescriptive approach, similar to that of the UK MCS Standard, which requires the calculation of a theoretical noise level to be submitted before approval of installation of a unit. The other option could be performance-based; where an installed heat pump system would need to be measured using an approved sound meter once the building is operational. In either case, there should be clear direction for architects, engineers, developers and building owners to follow.

5.2 Zoning Exemptions

Another regulatory pathway in which the City of Vancouver could facilitate the successful design and installation of heat pump units is through building height exemptions of rooftop heat pump units. Under *Section 10* of the City of Vancouver Zoning By-law, paragraph **10.11** provides guidelines for relaxation of limitation on building height for roof-mounted energy technologies such as solar panels or wind turbines.[xii] One local mechanical engineer stakeholder explained:

"In terms of acoustics in the building, I think a big part depends on where these units are located and that has to do with what the City allows the developer or the building owners to do. In some cases the City has limits on building height and it may not be possible to locate an air-to-water heat pump on the roof. In such cases the unit likely has to be installed indoors, however, the best location for an air-to-water heat pump, it's typically on the roof."

Arguably, air-source heat pumps should also be considered green mechanical equipment given that they convert electrical energy (97% renewable in Vancouver) into space conditioning and hot water. Since the roof is often the best location in terms of noise mitigation, there is even greater incentive to ensure that design teams are not limited in where they can locate heat pump systems.

5.3 Vancouver By-law Updates

Although it may not be necessary at the current level of heat pump adoption, the Vancouver Building Code By-law (VBBL) could include a section that would regulate the siting and installation of heat pumps. This could provide greater detail than ASHRAE guidelines or manufacturer instructions, including specific instructions for siting, equipment selection, and noise mitigation strategies. Further, the Vancouver Standards of Maintenance By-law 5462 could potentially mandate the regular maintenance of equipment in larger applications, where the potential noise disturbance from unbalanced, broken, or loose components of heat pumps could emit unnecessarily loud noise.

"You'll often see units with heat pumps and the coil is totally plugged with dirt. Well that's using double or triple the energy to generate the same amount of heating or cooling as it normally does because they haven't been maintained. But that's people's individual choice. Poor maintenance leads to higher noise."

- Local Mechanical Consultant

5.4 Further Study

Moving forward, the City of Vancouver should commission a study to compile the current noise ratings of manufacturers and publish them through a user-friendly platform. Although not all manufacturers of heat pump units currently publish their sound ratings, having a comprehensive list made publically available should provide incentive for all manufacturers to contribute a detailed set of decibel ratings, given that homeowners and building developers will likely use such a platform for equipment selection. This would also help homeowners choose units that are readily available and better understand where their heat pump should be located in order to meet the noise by-law.

Another useful study would involve testing the actual acoustic performance of noise mitigation strategies under common real world scenarios. This would require an acoustical consultant to perform measurements of a variety of sound attenuation strategies, including acoustic rated barriers, typical fencing or landscaped hedges, as well as other more complex mechanical approaches such as silencers and louvers.

The City of Vancouver could also provide incentive funding for creative projects to both celebrate and enhance the aesthetics of mechanical equipment. Some related examples include the University of British Columbia student art project that constructed a wood frame and bench structure for a temporary energy centre on campus[xiii] or the City of Vancouver's current initiative to cover utility boxes with vinyl wrap art.[xiv]

UBC Energy Transformation Centre Art Project.

Vancouver Utility Box Covered in Vinyl Art (Source: Sherwood411 via Flickr)

Finally, the City of Vancouver could adopt a similar online noise calculator to the one available through fairair, a website that provides an estimate of the maximum sound power level of your unit given it's distance to the property line, barriers in place, and nearby reflective surfaces.[xv] Homeowners are able to input their own specific values into the calculator and make a more informed decision when buying an air conditioning unit.

6. HOMEOWNER GUIDE

6.1 Purpose

This section is intended to help individual homeowners through the process of selecting and installing an air-source heat pump. By reviewing this information early on, homeowners can better understand the different considerations for reducing potential future noise conflicts. A central component of this guide is a one-page informational graphic that was developed to answer some of the most basic questions that homeowners may have (see Appendix B). The main goal of this infographic was to make it as accessible and easy to understand as possible. Given that it is only one page, only the most relevant and useful information was included. The following section provides greater detail and guidance for homeowners.

6.2 Important Questions

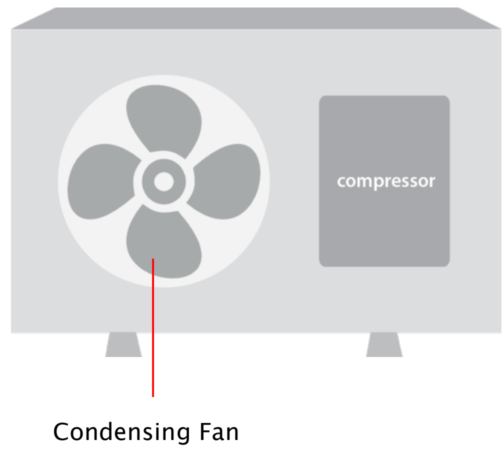
Before starting the process of installing a heat pump, there are several key factors that should be considered. It is important to understand that most potential noise conflicts can be avoided through careful design that is pursued early on. It is both difficult and expensive to retrofit a heat pump system that has already been installed. Both sound attenuation strategies and the relocation of equipment is time consuming and costly. The following questions are intended to equip homeowners with a better understanding of the selection and installation process.

What is the noise by-law?

The City of Vancouver Noise By-law 6555 limits the allowable sound levels across the city. The majority of residential neighbourhoods are considered Quiet Zones, where noise shall not exceed **55 dB** between 7:00am – 10:00pm and **45 dB** between 10:00pm – 7:00am. For reference, 45 dB is comparable to the sound of bird calls or the noise level within a library[xvi], while 55 dB is similar to the sound of a dishwasher in the next room.[xvii] Under the current by-law, noise is measured at the property line at a height of 1.2 metres. If possible, you should measure the current background noise of your property before installing a heat pump system. In louder environments, such as near transportation routes or commercial and industrial areas, a high background noise level allows for less stringent sound levels required of your heat pump unit. For example, if the background noise in your area is 60 dB, you will not be limited to models that are in the 40-50 dB range. Oppositely, in quiet residential neighbourhoods, you will need to be extra careful when selecting equipment given that any introduced noise will likely be intrusive. Theoretically, if you live in a quiet suburban area with a background level of 35 dB, and you install a 45 dB heat pump, that will be perceived as twice as loud, given that each incremental increase of 10 dB is a perceived doubling of loudness.

Where does heat pump noise come from?

Heat pumps have several different sources of noise with different sound characteristics. The compressor, which is internal to the unit, pumps refrigerant through the heat pump system's loop. The sound produced by a compressor is a low frequency noise, which may disturb neighbouring residents if not properly attenuated. Newer and more advanced heat pump units will have compressors that are wrapped in blankets or foam, behind sound attenuation panels.



Condenser fans produce a mid to higher frequency noise that is highly directional. Heat pumps can have either a vertical or horizontal discharge shaft. Vertical discharge results in a noise propagation that broadcasts upward from the top of unit, while horizontal discharge units produce noise that travels outward parallel to the ground that the unit is on (see above diagram). It is important to understand the direction of this noise in order to effectively mitigate potential impacts on residents. The ability to hear noise is generally understood in terms of line of sight: if you are able to see a nearby sound emitting source, you are likely able to hear it. This is further nuanced with the ability for sound to reflect from hard surfaces. In order to fully understand the potential for noise conflict, you must follow the path of sound waves from source to various points of reception.

The advancement of variable speed technology has helped reduce the noise of both compressors and condenser fans. Variable speed motors allow for precise load matching, less cycling on and off, and low amp gradual compressor motor start-up.[xviii] By not having to run the unit at full speed during light-load conditions, variable speed motors both improve the efficiency of a heat pump and reduce the overall noise that the unit produces. Further, variable speed motors allow for less abrupt start-ups, reducing the disruptive high pitch noise associated with older compressors and banging noise associated with fans.

Where should I locate my heat pump unit?

Ideally, your heat pump unit should be located in the centre of the rear yard, as far away from the property line and neighbouring windows as possible. You should be particularly attentive to neighbouring bedroom windows either on the ground or upper floors. In addition, you should site the unit away from any neighbouring outdoor living spaces, as well as any hard surfaces that could reflect sound towards your neighbour's windows. The diagrams from ANSI/AHRI Standard 275-2010 found in Appendix C demonstrate some standard minimum distances within these situations.

An effective strategy is to use any existing barriers to block your neighbour's line of sight to the equipment, such as a fence, garden shed, or hedge. It is important to locate the unit as close to the structure as possible, with the intention that the barrier will reflect noise away and upward. A property line solid fence, garden shed, or acoustic barrier can typically provide a 10 dB reduction in sound levels at the point of reception.[xix] If you do use a solid fence or acoustic enclosure as a barrier, you must allow a minimum separation for airflow – you do not want your heat pump unit to be recycling the same air.

Another important consideration is to locate the unit out of the dripline of your roof and away from any walking paths – the discharge of a heat pump unit can cause ice to form and pose a potential slipping hazard.

Which type of heat pump should I buy?

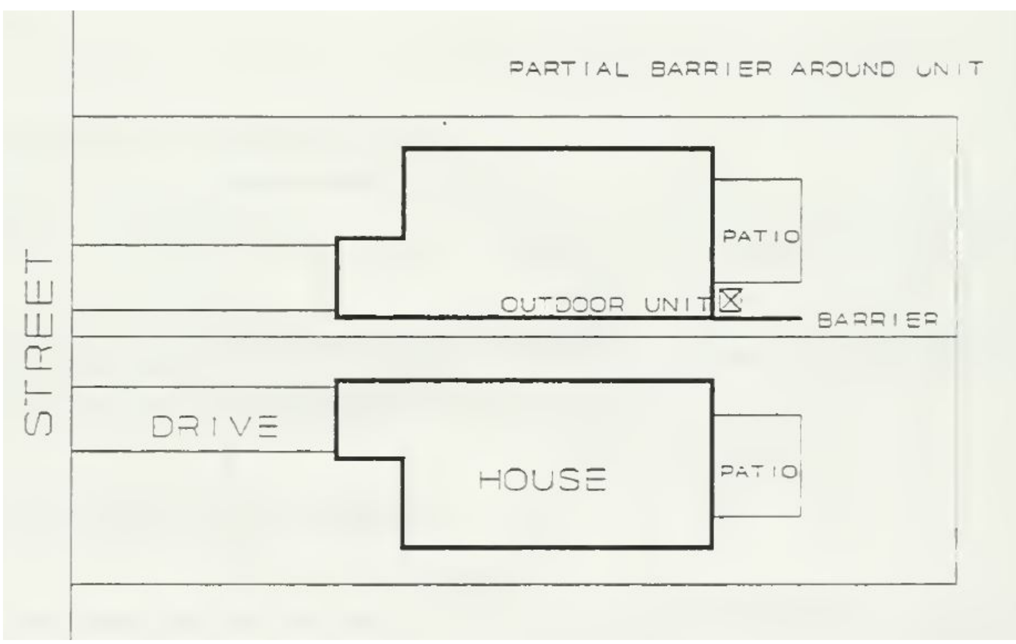
Before committing to the installation of a specific heat pump model, research the noise rating of the unit you are considering purchasing. Look for models that have the lowest decibel rating, as well as the following features:

- Variable speed fan and compressor
- Soft start and stop function
- Nighttime/low sound mode
- Insulated compressor
- Discharge muffler or "external silencer"

For single-family applications, there are currently a wide range of heat pump manufacturers and models available that produce varying levels of noise.   Currently, the most quiet heat pump unit available is the Sanden CO2 Gen3 model that is rated 37 dB at 1 metre from the unit, although it is currently limited to domestic hot water production only. Several Mitsubishi, Daikin, Samsung, and Fujitsu models are rated in the high 40 decibels, while Trane and other American manufacturers have units in the 50's decibel range. These heat pump models are generally priced according to their levels of efficiency and available features, with more advanced and quieter models being more expensive. The most important consideration is to understand the unit's noise rating in relation to the required placement of the heat pump, as well as any sound attenuation strategies needed to meet the noise by-law at your property line. Although higher-performance units may be more expensive initially, they could help avoid the need to install any barriers or enclosures.

What are some active noise mitigation strategies?

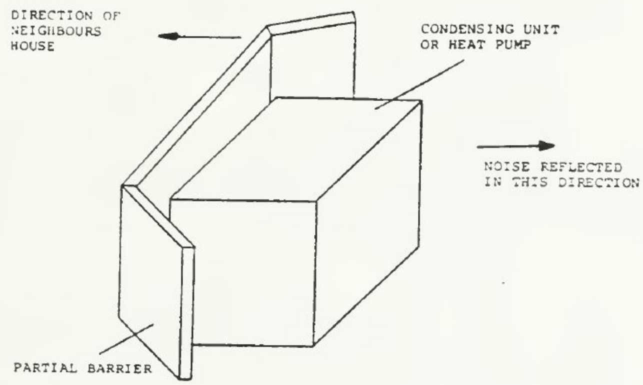
If you are limited in where you can locate your heat pump, you may need to install an acoustic fence, barrier, or enclosure. These structures could take the form of a solid or perforated wood, metal, concrete, or fibreglass barrier that is either a partial or full enclosure. The actual shape and material used will depend on the noise source and point of reception. In the example below, only a partial one sided barrier is required to block the neighbour's line of sight to the air conditioning unit.



Plan view of single-family home with partial barrier installed
(Source: Ministry of Energy and Environment Ontario)

In more sensitive areas, or with the use of noisier equipment, a more elaborate barrier may be required, such as the one below:

(iv) The following sketch shows a partial barrier which can also be used to deflect noise away from the neighbour's house. Such barrier will only be effective for horizontal discharge units. Care must be taken so that the airflow into and out of the unit is not impeded. For more details refer to section 8.2.



(Source: Ministry of Energy and Environment Ontario)

If you have a vertical discharge unit, do not construct an enclosure too close above the condensing fan shaft. Likewise, do not place a barrier too close to a horizontal discharge unit. There must be adequate flow separation between inlet air and discharge air. If installed adjacent to a ground floor suite, it would be effective to build a well and use the change in elevation as a sound attenuation barrier. Further, any barrier you construct could provide other functions such as a bench or storage space. On the following page is a bench that was constructed around a Sanden CO2 heat pump at the front of a studio in Washington State.

Source: INCLINEDESIGN.info

What else should I do?

In order for your heat pump unit to run efficiently, it needs to be installed by a certified technician and maintained over time. This implies changing or cleaning the unit's air filter according to manufacturer guidelines and keeping your coils clear of dirt and debris. In colder climates, this would also imply keeping the heat pump unit clear of snow and ice.

6.3 Online Tool

If you would like to approximate the maximum allowable sound power level of your heat pump system before purchasing a unit, the online platform developed by fairair in Australia could help provide an estimate (retrievable at http://www.fairair.com.au/calculator.noise.aspx). This online calculator will input your specific measurements, such as distance to property line, barrier factor, and reflective factor, into an acoustic equation to provide an approximate allowable maximum sound power level for your unit. Although this is only an estimate, it can help you through the process of selecting a heat pump unit based on your property's existing conditions.

7. DEVELOPMENT PROCESS CONSIDERATIONS

7.1 Context

Through discussions with key informants, it became clear that the development and design industry has the technical capacity to limit noise impacts of building mechanical equipment. Any experience with noise conflicts were largely attributed to procedural issues rather than engineering or design limitations.

"If you catch these issues early on, you can probably eliminate them."

- City of Vancouver Real Estate and Facilities Employee

"The systems and equipment are built so well now that if you do reasonable things, you should not have a problem."

- Local Mechanical Consultant

In order to ensure that new construction projects minimize the risk of potential noise impacts on residents, coordination among design teams needs to be built into the design process and development planners need to be cognoscente of sources of mechanical noise. Although it would be ideal for design teams to consider noise at all stages of a project, this is unlikely and would require a major shift in the fee structure of the design process. Therefore, in order to reduce the likelihood of heat pumps and other mechanical equipment to cause noise disturbances, this section aims to build capacity for development planners to evaluate development proposals on the basis of noise. Although the following information may be well-known within the engineering industry, this section provides a baseline understanding of all the different potential noise mitigation strategies that are available for residential and commercial heat pump applications.

7.2 Location of Equipment

The most central consideration for noise mitigation is location. Given that these are specifically air-source heat pumps, the ideal location is typically on the rooftop of a building. This relationship holds true assuming that there are no nearby residences overlooking the rooftop and that the building's structure is able to accommodate the mechanical equipment. The competition for rooftop space can also be an important factor – nearby amenity space or rooftop patios will need to be considered in the design process.

"So because it's an air-cooled system you have to have an open area so the options would be: on the building's roof; within the property but away from the building itself; or in an underground parkade. So it's just three options from a design point of view."

- Local Mechanical Consultant

"We find that 90% of the units we install are on rooftops. Without a well, simply sitting on the roof. And may or may not have an architectural enclosure around them."

- Local Sales Engineer

"The best systems really are the ones that are simple. Whenever you start introducing ducts, silencers, and louvers, the system becomes more expensive and inefficient."

- Local Mechanical Consultant

"The other thing is, on these, it's making sure it's not in someone's line of sight. Because with line of sight, if you can see it, then it's usually an issue."

- Local Mechanical Consultant

"To meet the noise by law it is best to locate the unit in the centre of the building. If you put it right at the edge, then all the noise is going to be escaping right next to the property line. The Aermec air-to-water heat pumps units are very quiet and easier to comply with acoustic requirements. In the most stringent cases we've had to install silencers over the condenser fans and acoustic enclosures around the compressors."

- Local Mechanical Consultant

The ability to hear noise is generally understood in terms of line of sight: if you are able to see a nearby sound emitting source, you are likely able to hear it. This is further nuanced with the ability for sound to reflect from hard surfaces. In order to fully understand the potential for noise issues, the design team and development planners must follow the propagation of sound waves from noise source to various potential points of reception.

"The best strategy is to think very carefully from the source of the sound outwards and how to reduce and mitigate those issues."

- City of Vancouver Building Operations Employee

An alternative location is to install a heat pump inside the parkade level of a building. This generally involves ducting inlet and outlet air from a unit to the outdoors, usually connected a rear service lane. This approach is more complex and assumes that there is enough space between the floors of the building to install ductwork. In some smaller applications, heat pump units could be installed inside a parkade, assuming that there is enough airflow so that the unit's intake does not short cycle the same exhaust air.

Example of single heat pump unit located in ground-floor parking garage.

Finally, installing a heat pump unit at grade outside a building is often the least desirable location given the tendency for noise to propagate upwards, back towards the occupants of a building. Again, none of these locations should be understood as absolute and each situation will require careful consideration all of the various nearby points of reception.

7.3 Selection of Equipment

In multi-unit residential and commercial applications with larger units, there are less available manufacturers to choose from than in the single-family market. Mechanical engineering consultants generally do not design around a single piece of equipment from a specific manufacturer, but rather use a set of specifications that are fulfilled by various suppliers. This can cause potential issues if the choice of manufacturer and model change at some point in the design or construction process. It is important to question whether the sound power level of equipment has changed throughout the process for a louder unit.

"You should find out what the actual sound data is from the unit that is being used for design and stick by it. Because a lot of times it gets buried and things get approved and you end up with a machine that's much louder – that can do the performance, but that's much louder."

- Local Sales Engineer

"With the whole scope of the job, it's better to go with the quietest unit you can for the job up front. It gets buried in the job because of all the changes that happen, it becomes a lower risk when dealing with that up front."

- Local Sales Engineer

There are a variety of potential add-on features to heat pump units that can make them quieter. Any additional sound attenuation features above standard are going to add cost to a project and are only used when perceived as necessary. The following are some potential features to consider for noise reduction:

Intake Louvers: adding acoustical louvers to a heat pump system can help attenuate noise by minimizing line of sight while maintaining airflow.

Discharge silencers: silencers are used to smooth the airflow of outlet air of a heat pump unit.

Fan Selection: the profile of a fan can help reduce the noise produced within a condensing shaft. Reducing fan speed can also be effective at reducing noise levels, but this will depend on the output of the unit.

Compressor wraps: wrapping the compressor in sound deadening foam or blankets will help attenuate the low frequency noise that they produce.

An example specification sheet from an air-source heat pump manufacturer can be found in Appendix D. This includes specific decibel reduction values from add-on low sound components.

The advancement of variable speed technology has helped reduce the noise of both compressors and condenser fans. Variable speed motors allow for precise load matching, less cycling on and off, and low amp gradual compressor motor start-up.[xx] By not having to run the unit at full speed during light-load conditions, variable speed motors both improve the efficiency of a heat pump and reduce the overall noise that the unit produces. Further, variable speed motors allow for less abrupt start-ups, reducing the disruptive high pitch noise associated with older compressors and banging noise associated with fans.

"Nowadays manufacturers install variable speed drives on the condenser fans to control capacity. This method also achieves two things: better head pressure control for the refrigeration component, and a more efficient fan as you use less energy when it's cooler outside and they reduce noise. So it's a win-win situation. So that's where the majority of the units are nowadays."

- Local Mechanical Consultant

Large air-source heat pumps should be installed on vibration isolation mounting in the form of a rubber mat or air shocks. This will help reduce potential vibration transfer through any nearby building envelope or window.

7.4 Noise Mitigation Strategies

Beyond choosing an appropriate location and quiet heat pump unit, there are active noise mitigation strategies that may be necessary in constrained or sensitive environments. There are a wide variety of acoustic rated barriers that can be installed around a heat pump unit. This is often the last resort as it is quite expensive in larger applications. If a barrier or enclosure is required, it should be architecturally consistent with the building. This could also be an opportunity for a creative or visually appealing installation. If a project requires this level of sound attenuation, acoustical engineers will likely be involved and should provide sound power level calculations to demonstrate how the barrier will reduce potential noise conflicts.

"Any kind of enclosure on the roof is expensive and could be an issue in terms of the building envelope – how to anchor these kinds of things. So unless it's a requirement from the City or it's a development permit requirement, most design teams try to avoid it, unless you really have problems with sound and you just have to have it."

- Local Mechanical Consultant

View of vibration isolation air shocks underneath Aermec NRP 1800 unit.

7.5 Development Planner Bulletin

As a result of this analysis, as well as through discussions with green building and development planners at the City of Vancouver, the most useful avenue for ensuring noise mitigation was determined to be a one-page internal bulletin. This bulletin outlines some questions for development planners to ask throughout the development process to help evaluate projects on the basis of mechanical noise (see Appendix E).

"There needs to be a point in the development process at which people take stock, if possible, of certain pieces of the building. Really it's the checklist: have you thought about the following – tell me that you've looked at this, looked at that. What's your response to options for reducing sound from equipment?"

- City of Vancouver Real Estate and Facilities Employee

8. CONCLUSION

Air-source heat pumps provide a viable, efficient source of space conditioning and domestic hot water production. As the City of Vancouver continues to mandate more stringent energy efficiency standards, and as green building technology continues to improve, the rate of heat pump adoption will likely increase. Before potential noise issues become a serious concern, strategies for thoughtful design and installation of heat pump systems should become standard. This project has attempted to provide guidance for a range of audiences to better understand the different consideration for noise mitigation of mechanical equipment. Moving forward, the process for designing and installing heat pump systems will hopefully be easier and result in minimal impacts on residents.

9. APPENDIX A: Example Noise Calculation Checklist (MCS Planning Standard)

STEP	INSTRUCTIONS	INSTALLER RESULTS / NOTES
1.	**From manufacturer's data, obtain the A-weighted sound power level of the heat pump. See '<u>Note 1: Sound power level</u>'. The highest sound power level specified should be used (the power in "low noise mode" should not be used).** *Example: Manufacturer's data states the sound power level of the heat pump is 55 dB(A).*	STEP 1 RESULT =
2.	**Use '<u>Note 2: Sound pressure level</u>' and '<u>Note 3: Determination of directivity</u>' below to establish the directivity 'Q' of the heat pump noise.** *Example: The heat pump is to be installed on the ground and against a single wall hence the directivity (Q) of the heat pump noise is Q4.*	STEP 2 RESULT =
3.	**Measure the distance from the heat pump to the assessment position in metres.** *Example: Distance between heat pump and assessment position is 4 metres.*	STEP 3 RESULT =
4.	**Use table in '<u>Note 4: dB distance reduction</u>' below to obtain a dB reduction.** *Example: 4metres @ Q4 = -17 dB.*	STEP 4 RESULT =
5.	**Establish whether there is a solid barrier between the heat pump and the assessment position using '<u>Note 5: Barriers between the heat pump and the assessment position</u>' and note any dB reduction.** *Example: There is a brick wall between the heat pump and the assessment position. Moving less than 25cm enables the assessment position to be seen. dB reduction = -5 dB.*	STEP 5 RESULT =
6.	**Calculate the sound pressure level (see '<u>Note 2: Sound pressure level</u>') from the heat pump at the assessment position using the following calculation:** **(STEP 1) + (STEP 4) + (STEP 5)** *Example (55) + (-17) + (-5)=55 – 17 – 5 =33 dB(A) Lp*	STEP 6 RESULT =

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7.	**Background noise level. For the purposes of the MCS Planning Standard for air source heat pumps the background noise level is assumed to be 40 dB(A) Lp. For information see '<u>Note 6: MCS Planning Standard for air source heat pumps background noise level</u>'.** *Example: Background noise level is 40 dB(A).*	STEP 7 RESULT = 40 dB(A)
8.	**Determine the difference between STEP 7 background noise level and the heat pump noise level using the following calculation:** (STEP 7) – (STEP 6) *Example: 40 dB(A) (background) – 33 dB(A) (heat pump) = 7dB(A).*	STEP 8 RESULT =
9.	**Using the table in '<u>Note 7: Decibel correction</u>' obtain an adjustment figure and then add this to whichever is the higher dB figure from <u>STEP 6</u> and <u>STEP 7. Round this number up to the nearest whole number.</u>** *Example: Adjustment figure is 0.8 dB and the higher figure is 40 dB(A).* *40 + 0.8 = 40.8 dB(A).* *Rounded up to 41 dB(A)* *Final result at this assessment position is 41 dB(A).*	FINAL RESULT=
10.	**Is the FINAL RESULT in STEP 9 equal to or lower than the permitted development noise limit of 42.0 dB(A)?** **If <u>YES</u> - the air source heat pump will comply with the permitted development noise limit for this assessment position and may be permitted development** (subject to compliance with other permitted development limitations/conditions and parts of this standard). NOTE - <u>Other assessment positions may also need to be tested.</u> **If <u>NO</u> – the air source heat pump will not be permitted development. This installation may still go ahead if planning permission is granted by the local planning authority.** *Example: 41 dB(A) is equal to or lower than 42.0*	Final result is equal to or lower than 42.0 dB(A) YES / NO (delete as appropriate)

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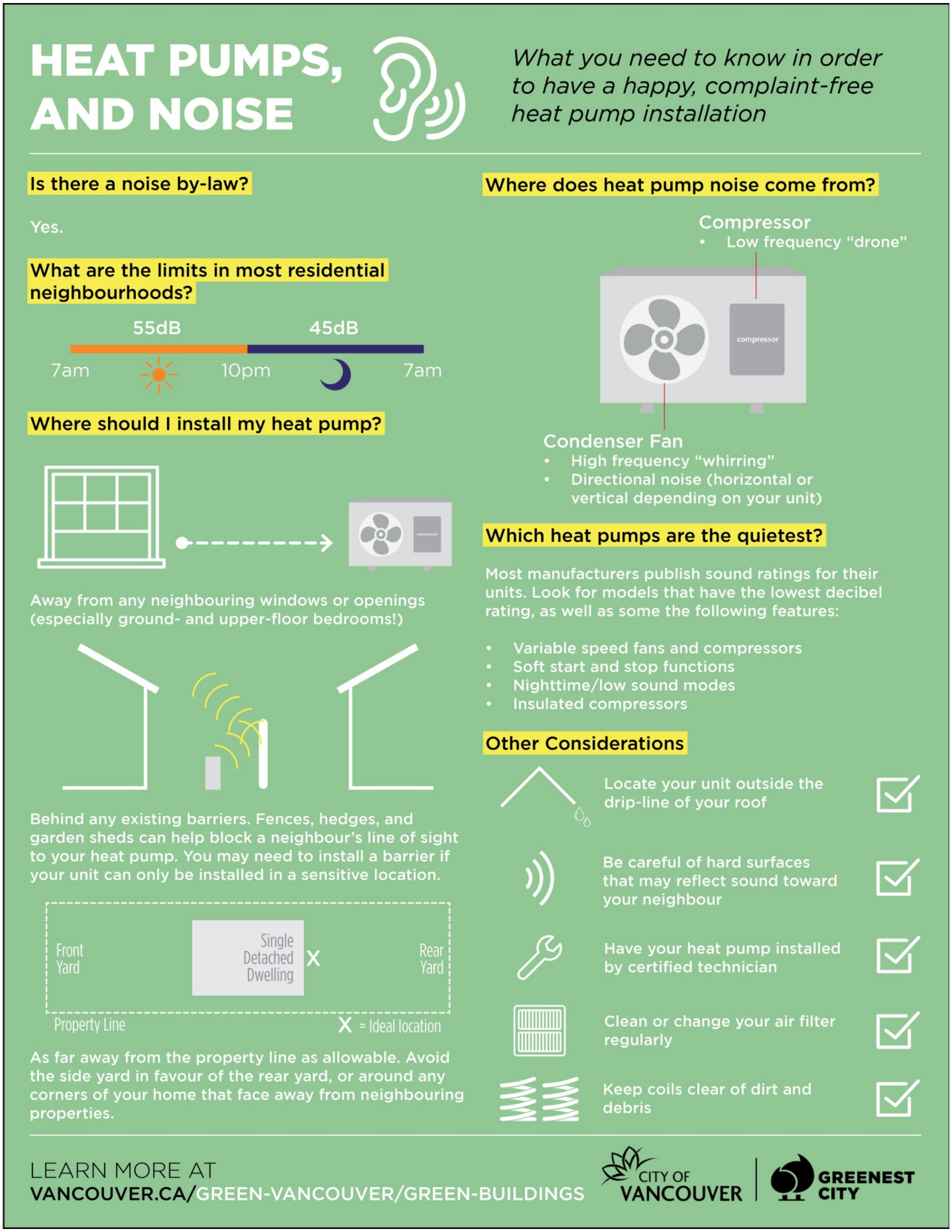
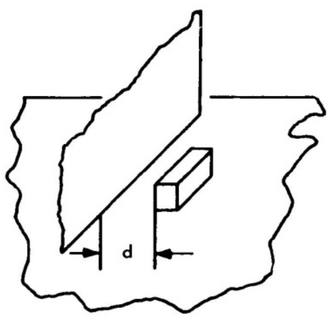
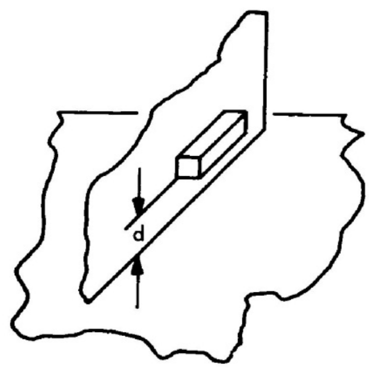
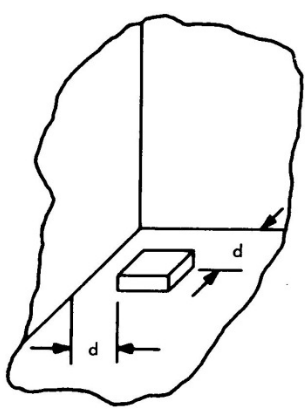
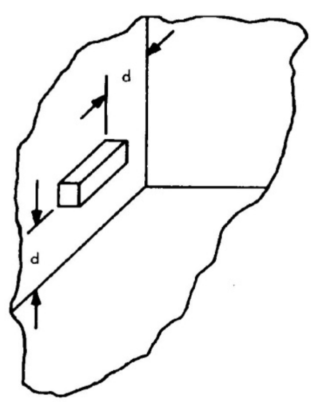
10. APPENDIX B: Homeowner Infographic for Heat Pump Noise Mitigation



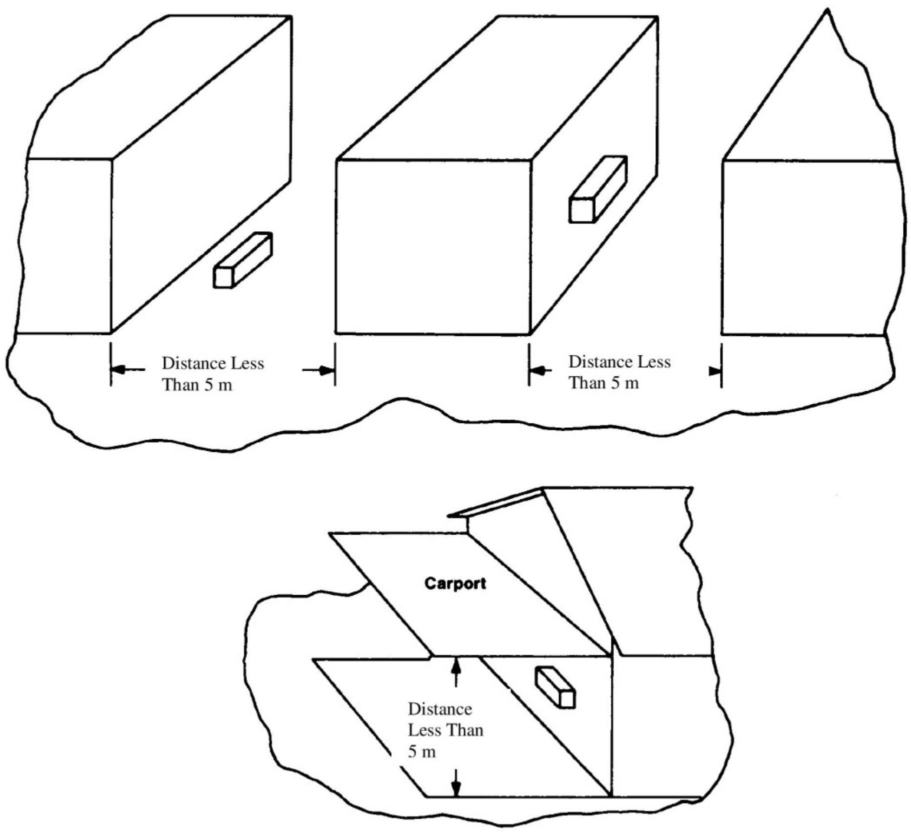
11. APPENDIX C: Example Heat Pump Placement and Noise Guidelines

Table 1. Application Factors for Estimating A-Weighted Sound Pressure Level(s)
(Equipment Location Factor)

Equipment Location Factor	Factor Value
a. Equipment on ground, roof, or on side of building wall with *no* adjacent reflective surface within 3 m (d greater than 3 m)	0 dB
b. Equipment on ground, roof, or on side of building wall with a *single* adjacent reflective surface within 3 m (d less than 3 m)  On Ground or Roof Single Reflective Surface	3 dB  On Side of Building Single Reflective Surface
c. Equipment on ground, roof, or on side of building wall within 3 m of two adjacent walls forming an inside corner (d less than 3 m to both surfaces)  On Ground or Roof Two Adjacent Reflecting Surfaces	6 dB  On Side of Building Two Adjacent Reflecting Surfaces

3

Table 1. Application Factors for Estimating A-Weighted Sound Pressure Level(s) (Equipment Location Factor) (Continued)	
Equipment Location Factor (continued)	Factor Value
d. Equipment on ground, roof, or on side of building wall and between two opposite reflecting surfaces less than 5 m apart	6 dB



12. APPENDIX D: Example Specification Sheet of Heat Pump Sound Attenuation Options

December 2015

ASP-X Low Sound Options

Start with baseline level in **BOLD**, select acoustic options and subtract numbers in *italics* to determine resulting sound pressure level at 30ft
Resulting levels are approximate; consult Multistack for more exact estimate.

Model	***Frame***	***Fan*** [11]								***Acoustic adds***					
		Multiwing	*Baseline L_p* [1]	Ziehl-Abegg FN		Ziehl-Abegg ZN (ZAplus)		Ziehl-Abegg ZN+ (ZAplus+)		Compressor Wraps [7]	Compressor Housings	Intake Louvers [8]		Discharge Silencer [9, 10]	
ASP010X	58 x 31.5 [2]	25.4/4-4/25	**63**							*0*					
ASP015X	58 x 31.5 [2]	24.3/6-6/45	**64**							*0*					
ASP020X	72 x 36	30/5-5/35	**73**	FN071	*-4*	ZN071 [6]	*-4*			*0*		ZA	*-2*	ZA	*-5*
	84 x 36 [3]	30/5-5/37.5	**69**	FN071	*-4*	ZN071 [6]	*-4*			*-1*		ZA	*-2*	ZA	*-4*
	84 x 42 [3]			FN080	*-6*	ZN080	*-6*	ZN080+	*-8*	*-1*		ZA	*-2*	ZA	*-4*
ASP030X	84 x 36	30/5-5/37.5	**73**	FN071	*-4*	ZN071 [6]	*-4*			*-1*		ZA	*-2*	ZA	*-5*
	84 x 42			FN080	*-5*	ZN080	*-6*	ZN080+	*-8*	*-1*		ZA	*-2*	ZA	*-5*
ASP060X	84 x 72	30/5-5/37.5	**72**	FN071	*-3*	ZN071 [6]	*-3*			*-1*		ZA	*-2*	ZA	*-5*
	84 x 84 SM [4]			FN080	*-5*	ZN080	*-6*	ZN080+	*-8*	*-1*		ZA	*-2*	ZA	*-5*
	84 x 84 W [5]			FN080	*-5*	ZN080	*-6*	ZN080+	*-8*		*-2*	ZA	*-2*	ZA	*-5*

Notes

1. L_p: Sound pressure level, total dBA, at 30ft
2. Putting 10X or 15X in 20X frames with 20X fans does not make them quieter with current fan and coil options
3. Includes change from 20X to 30X coils
4. Sheet metal frame
5. Welded frame, independent compressor circuits (4 compressors)
6. ZN071 is not quieter than FN071 but uses less power
7. Wraps improve sound *quality* even when they do not decrease measured dBA at 30ft
8. Not available with Multiwing fans
9. Available with ZA fans; consult Multistack for use with Multiwing fans
10. Standard height 36", other lengths available
11. For any configuration, further sound level reduction can be achieved by invoking "low sound option" in module controller. This limits fan speed.

13. APPENDIX E: Sample Internal Bulletin for Development Planners

Air-Source Heat Pump Noise Considerations

This bulletin is intended to provide a baseline understanding of the various factors that influence the potential noise impacts of air-source heat pump systems. This guideline was produced specifically for evaluating multi-unit residential and commercial development proposals that include air-source heat pump units. This guidance applies equally well to large air-conditioning equipment. Note: some smaller heat pumps and cooling equipment intended to serve a single residence can be inaudible if carefully selected and installed.

Questions to Ask

- Has noise been considered at all stages of the design process?
- Do any existing residents have a direct line of sight to the proposed heat pump unit?
- Are there any reflecting surfaces that will amplify the sound toward existing residents?
- Does this development proposal require an acoustical study?
- Have there been any changes in the heat pump unit selection (and consequent noise rating of the unit)?

Location

- If there are no residential units overlooking the roof, the unit can be located on the building's rooftop in the centre, without concern. If there are nearby residences, the roof may still be the best location with proper mitigation strategies.
- In many cases, the unit can also be installed indoors within a parkade and ducted out at grade toward a lane.
- Existing structures and walls should be utilized as much as possible to block noise transmission by line of sight.
- Fan noise is highly directional and can be attenuated when directed away from neighbouring residential units.
- If the heat pump unit is at ground level or facing existing residents, an acoustic rated barrier or enclosure should be installed.
- The unit needs to be accessible for maintenance and servicing.

Barriers/Enclosures

- Solid barriers are ideal for sound attenuation, but require a setback for airflow.
- An acoustic enclosure with louvers facing away from nearby residences is also an effective approach.
- Any proposed structure should be architecturally consistent with the building. This could also be an opportunity for a creative or visually appealing installation.

Features of Heat Pump Unit to Look For

- Encased compressor behind sound attenuated panels with sound deadening foam/blankets
- Variable speed compressors
- Variable speed fans
- Nighttime and low sound modes
- Properly mounted on a sound absorbing base or sound isolating air shocks

14. REFERENCES

[i] http://vancouver.ca/files/cov/renewable-city-strategy-booklet-2015.pdf
[ii] http://www.noisemeters.ca/help/faq/frequency-weighting.asp
[iii] http://www.sengpielaudio.com/calculator-levelchange.htm
[iv] http://www.industrialnoisecontrol.com/comparative-noise-examples.htm
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[x] https://www.victoria.ca/assets/City~Hall/Bylaws/bylaw-03-012.pdf
[xi] https://bylaws.burnaby.ca/media/Consolidated/7332C.pdf
[xii] http://bylaws.vancouver.ca/zoning/sec10.pdf
[xiii] http://energy.ubc.ca/projects/district-energy/temporary-energy-centre/
[xiv] http://www.cbc.ca/news/canada/british-columbia/city-of-vancouver-seeks-public-art-for-utility-boxes-1.3508988
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[xix] http://www.quiet.org/documents/GuidelinesAirConditioners.pdf
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