

# Understanding Acoustics for Dynamic Building Enclosures With Wind-Driven Kinetic Façade Systems

By Jim Leslie  
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*Figure 1 – Wind-driven kinetic façade systems create an ever-changing exterior. Translucent flapper panels, such as on Pittsburgh Children’s Museum’s “Articulated Cloud,” allow natural light to enter the interior, while reducing unwanted solar heat gain and glare. The museum’s façade system was collaboratively designed and built by artist Ned Kahn, architects Koning Eizenberg, and façade manufacturer EXTECH. All photos courtesy of EXTECH.*

**W**ind-driven kinetic façade systems often are constructed of hundreds or thousands of moving parts to provide the intentional dynamic effect for a building enclosure or structure. Responding to air currents, the flapper panel design creates the look of rolling waves across the wall. Designed to attract attention, these systems typically are installed on buildings in dense, urban areas. Along with creating visual interest with their movement, all kinetic installations can produce some level of ambient sound under higher wind conditions (Figure 1).

Manufacturers can engineer and fabricate kinetic façade systems with spacers between the flappers to reduce the collateral noise. While aluminum is the most popular material for flappers, other options include perforated materials, stainless steel, polycarbonate, polytetrafluoroethylene (PTFE), acrylic, and even polyvinylidene fluoride (PVDF) films (Figure 2). The construction material, suspension system, and flapper geometry can be adjusted to ensure that the level, tone, and timbre of the resulting sound is acceptable.

The volume and quality of sound generated by a kinetic façade installation should be considered as early as possible in the design and specification process. Sound levels can be verified with full-scale mock-ups to ensure that the wind-driven façade systems are within acceptable levels.

#### MEASURING SOUND

- A decibel (dB) is a unit of measurement for sound.
- A-weighted decibels (dBA) are an expression of the sound pressure level scale, or relative loudness of sounds in air, as perceived by conscious, healthy human ears.

Be aware that dB and dBA measurements are logarithmic rather than linear. This has implications for interpreting perceived loudness and comparing levels and perceived loudness differences. For every 10 dBA change in the sound pressure level,

the perceived loudness changes by a factor of two. For instance, a 10-dBA increase in level will sound twice as loud to the average listener, and a 10-dBA decrease will sound half as loud. A 20-dBA change thus corresponds to an increase/decrease in loudness by a factor of four—four times louder or one-quarter as loud. A 3-dBA change is the smallest change perceptible to a listener with normal/average hearing.

#### NOISE ORDINANCES

Many municipalities have ordinances that prohibit unnecessary, excessive, and annoying noises. These noises include those emanating from within buildings, and also can include sounds generated by constructing or operating the structures themselves.

For example, the Minneapolis city ordinance states: “Excessive noise degrades the environment to a degree that [it]:

- Is harmful to the health, welfare, and safety of its inhabitants
- Interferes with the comfortable enjoyment of life and property
- Interferes with the well-being, tranquility, and privacy of the home
- Causes and/or aggravates health problems”

In Minneapolis, “Regulating noise should and does take into account the time, place, and manner of such noise.” In practice, this becomes complicated, because different times and noise levels are permitted, depending on the source of the sound



*Figure 2 - While aluminum is the most popular material for flappers in wind-driven kinetic façade systems, other options include perforated materials, stainless steel, polycarbonate, PTFE, acrylic, and even PVDF films.*



Figure 3 – Treasure Island Center’s wind-driven kinetic façade system installed on the building’s top exterior corner visually attracts visitors’ attention in a busy part of downtown St. Paul, Minnesota.

and the noise-generating activity’s purpose.

Commonly, city ordinances’ sound levels and frequencies are different for daytime and nighttime hours. This generally includes guidance on acceptable distances from residences and approved daytime hours for operating lawnmowers, landscaping equipment, power tools, loud motorized vehicles, or construction equipment; performing garbage collection; or allowing amplified music.

As another example, the noise ordinance for Los Angeles categorizes the city into four major zones and, depending on the typical activity level in each zone, assumes an ambient 7 a.m. to 10 p.m. daytime noise level of 50-65 dBA for sounds within a residence or within 500 feet of a residence. The acceptable nighttime ambient level is reduced by approximately 5-10 dBA between 10 p.m. and 7 a.m.<sup>1</sup>

Furthermore, the Los Angeles ordinance states that noise in any place of public entertainment at a sound level greater than 95 dBA is unlawful unless there is signage placed outside and near each public entrance, stating: “Warning: Sound levels within may cause hearing impairment.”

Local noise ordinances also may provide rules and exceptions for hospitals, schools, places of worship, and commercial business districts. In addition, state and federal guidelines may take priority for emergency

work or for regulated industries, vehicles, and properties such as train whistles and airports.

Violations may be subject to fines or other punitive actions. In Los Angeles,

and similarly, in other municipalities, law enforcement may determine whether a violation has occurred based on factors including, but not limited to:

- The level of noise
- Whether the nature of the noise is usual or unusual
- Whether the origin of the noise is natural or unnatural
- The level and intensity of the background noise, if any
- The proximity of the noise to residential sleeping facilities
- The nature and zoning of the area within which the noise emanates
- The density of the inhabitation of the area within which the noise emanates
- The time of day and night the noise occurs
- The duration of the noise
- Whether the noise is recurrent, intermittent, or constant
- Whether the noise is produced by a commercial or noncommercial activity

#### ACCEPTABLE EXPOSURE

To provide a basis for state and local governments’ judgments in setting standards, the U.S. Environmental Protection Agency (EPA) identifies:



Figure 4 – Logan International Airport’s Walkway and West Garage features a wind-driven kinetic façade system with 48,000 aluminum flapper panels to screen the parking structure. Designed by architectural firm Arrowstreet Inc. in collaboration with façade manufacturer EXTECH, the garage’s dynamic wall enhances the view for the traveling public.

...a 24-hour exposure level of 70 dB as the level of environmental noise, which will prevent any measurable hearing loss over a lifetime. Likewise, levels of 55 dB outdoors and 45 dB indoors are identified as preventing activity interference and annoyance. These levels of noise are considered those which will permit spoken conversation and other activities, such as sleeping, working, and recreation, which are part of the daily human condition.<sup>2</sup>

The EPA's noise levels represent averages of acoustic energy over periods of time, such as 8 hours or 24 hours, and over long periods of time, such as years. The level of 70 dB is identified for all areas to prevent hearing loss.

Even with the EPA-stated 70-dB safe level, other U.S. regulations and guidelines vary on acceptable noise levels and duration.

- The Centers for Disease Control and Prevention agrees with the EPA and expands to say, "Noise above 70 dB over a prolonged period of time may start to damage your hearing. Loud

noise above 120 dB can cause immediate harm to your ears."<sup>3</sup>

- The Occupational Safety and Health Administration's (OSHA) permissible exposure limit is 90 dBA for all workers for an eight-hour day. The OSHA standard uses a 5-dBA exchange rate. This means that when the noise level is increased by 5 dBA, the amount of time a person can be exposed to a certain noise level to receive the same dose is cut in half.<sup>4</sup>
- The National Institute for Occupational Safety and Health (NIOSH) has recommended that all worker exposures to noise should be controlled below a level equivalent to 85 dBA for eight hours to minimize occupational noise-induced hearing loss. NIOSH also recommends a 3-dBA exchange rate, such that every increase by 3 dBA doubles the amount of the noise and halves the recommended amount of exposure time.<sup>5</sup>

#### NOISE-INDUCED HEARING LOSS

Regardless of whether the source is inside, outside, or as a result of a build-

ing structure, unwanted sounds quickly can become perceived as noise. Sustained, loud, or high frequency noises are proven to have negative consequences on human health.

The U.S. Department of Health and Human Services' National Institutes of Health (NIH) and the National Institute on Deafness and Other Communication Disorders (NIDCD) cautions, "Sounds can be harmful when they are too loud, even for a brief time, or when they are both loud and long-lasting. These sounds can damage sensitive structures in the inner ear and cause noise-induced hearing loss (NIHL)."<sup>6</sup>

Humans perceive noise by converting sound waves in the air into electrical signals that register in the brain. Sound waves enter through the outer ear and travel through the ear canal, causing the eardrum to vibrate. Three tiny bones in the middle ear convert the sound vibrations from air to fluid vibrations in the cochlea of the inner ear.

NIDCD explains that most NIHL is caused by the damage and eventual death of stereocilia—microscopic hair-like projections in the inner ear:

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| Typical sound levels (dBA) | Sound source   |
|----------------------------|--|
| 170                        | Shotgun firing   |
| 162                        | Firecracker (3 feet away)                                    |
| 150                        | Jet taking off   |
| 140                        | Threshold of pain for an average listener                    |
| 130                        | Jackhammer and operating heavy equipment                     |
| 120                        | Ambulance siren; thunderclap                                 |
| 110                        | Shouting directly in the ear; rock concerts; sporting events |
| 105-110                    | Music through headphones at maximum volume                   |
| 95-110                     | Motorcycles and dirt bikes                                   |
| 90-115                     | Approaching subway train; construction site                  |
| 85                         | Heavy city traffic; busy restaurant; hand saw                |
| 80-90                      | Food processor; blender                                      |
| 74-104                     | Movie theater  |
| 70-95                      | Coffee grinder; garbage disposal                             |
| 70                         | Freeway traffic  |
| 60-70                      | Normal conversation (3 feet away)                            |
| 60-95                      | Hair dryer; vacuum; power lawnmower                          |
| 50-75                      | Refrigerator; dishwasher; washing machine; air conditioner   |
| 50                         | Rainfall; large office                                       |
| 40                         | Library; quiet residential area                              |
| 30                         | North rim of Grand Canyon                                    |
| 20                         | Ticking watch; whisper (5 feet away)                         |
| 10                         | Normal breathing   |
| 3                          | Smallest perceptible change in sound to an average listener  |

Table 1 - Typical sound levels. From Center for Hearing and Communication, Centers for Disease Control, Environmental Protection Agency, Hearing Health Foundation, NIDCD, NIOSH, and OSHA.

Once the vibrations cause the fluid inside the cochlea to ripple, a traveling wave forms along the basilar membrane. Hair cells – sensory cells sitting on top of the basilar membrane – ride the wave. ... The stereocilia that perch on top of the hair cells bump against an overlying structure and bend. Bending causes pore-like channels, which are at the tips of the stereocilia, to open up. When that happens, chemicals rush into the cell, creating an electrical signal. The auditory nerve carries this electrical signal to the brain, which translates it into a sound that we recognize and understand.<sup>7</sup>

“The louder the sound, the shorter the amount of time it takes for NIHL to happen,” concludes NIDCD.

The Hearing Health Foundation estimates nearly 50 million Americans, including one in five teenagers, suffer from NIHL. It adds that “regular exposure of more than 60 seconds at or above 110 dB risks permanent hearing loss. Prolonged exposure to any noise at or above 85 dB can cause gradual hearing loss. No more than 15 minutes of unprotected exposure at or above 100 dB is recommended.”<sup>8</sup>

#### ACOUSTICAL STUDY OF WIND-DRIVEN FAÇADE SYSTEMS

As of January 2020, no available research could be located that effectively recorded the sound levels generated by wind-driven kinetic façade systems.

ic façade systems.

EXTECH/Exterior Technologies, Inc. commissioned an acoustical study to model and predict the sound that would be emitted by a pin-mounted, wind-driven façade system installation in the areas surrounding the building structure. The study would assess the sound relative to objective levels and limits as compared to applicable noise ordinance and regulations, and to subjective human perception of what a nearby listener would hear.

A physical test unit was constructed to evaluate a kinetic façade system’s structural dynamic behavior, and to measure the sound generated by wind-induced motion of its flappers and its support structures (Figure 5). This test unit consisted of:

*Figure 5 – A physical test unit was constructed with 32 flapper panels and a 2-point pin-mount suspension system to evaluate a wind-driven kinetic façade system’s structural dynamic behavior, and to measure the sound generated by wind-induced motion.*





*Figure 6 – A pin-mount suspension on a wind-driven kinetic façade system allows the flapper elements to seemingly float in front of the support rungs and side rails as a veil.*

- 22.2-sq.-ft. overall area
- 32 8-sq.-in. flapper panels manufactured with 0.040-in.-thick 3003 alloy aluminum with mounting holes, and finished in a polyvinylidene fluoride (PVDF, Kynar®) architectural coating on the fronts and a wash coat on the backs
- 2-in. spacing on all sides
- 2-point, pin-mount suspension system, including 300 stainless steel supports
- Sound-dampening bushing
- Extruded aluminum framing
- Flappers set for 80 degrees total movement

A pin-mount suspension on a wind-driven façade system allows the flapper elements

to seemingly float in front of the support rungs and side rails as a veil (Figure 6). This configuration minimizes the appearance of the supporting structure and makes it convenient to create innovative aesthetic designs by mixing flapper shapes to create geometric patterns.

This type of suspension also makes installation possible at various mounting points, facilitating changes in kinetic activ-



*Figure 7 – Pin-mount suspension systems allow the flappers to be removed and replaced without any specialized tools if repair or maintenance is needed on wind-driven kinetic façade systems.*

ity. Pin-mount suspension systems allow the flappers to be removed and replaced without any specialized tools if repair or maintenance is needed (Figure 7).



Figure 8 – Installed in a large open field in a high-wind area of rural western Pennsylvania, the wind-driven kinetic façade test unit was exposed to varying wind conditions, and the wind-induced sound was measured and correlated with the wind parameters.

The test unit was installed in a large open field in a high-wind area of rural western Pennsylvania (Figure 8). This location was selected due to its minimal extraneous ambient noise sources, reducing the poten-

tial for background noise to contaminate the study. The test unit was exposed to varying wind conditions, and the wind-induced sound was measured and correlated with the wind parameters.

The data collected from the test unit were then applied to a larger, wind-driven façade model on a full-scale building elevation (Figure 9). The building elevation dimensions were:

- North facing
- 55-ft. high, four floors tall
- 560.5-ft. long
- 21,632 sq. ft. of moving flapper panels installed 8 ft. above grade

The model was used to predict the aggregate sound that would be emitted at increasing distances from the building's wind-driven kinetic façade systems. Sound levels were calculated at ground level from the building's center (280.5 ft.) (Table 2) and at approximately 140 ft. from the building's corner (Table 3).

For the quietest predicted sound level of 35 dBA, a person would need to stand 100 feet from the building with a 5-mph wind blowing. This would be the equivalent of hearing a soft voice at a distance of 5 feet.

For the loudest predicted sound level of 62 dBA, a person would need to stand immediately in front of the building (0.0 ft.) with a 25-mph wind blowing the kinetic façade system. This "noise" would be the equivalent of hearing a conversation at a distance of 3 ft. (Figure 10).<sup>9</sup>

Research shows that installed in an

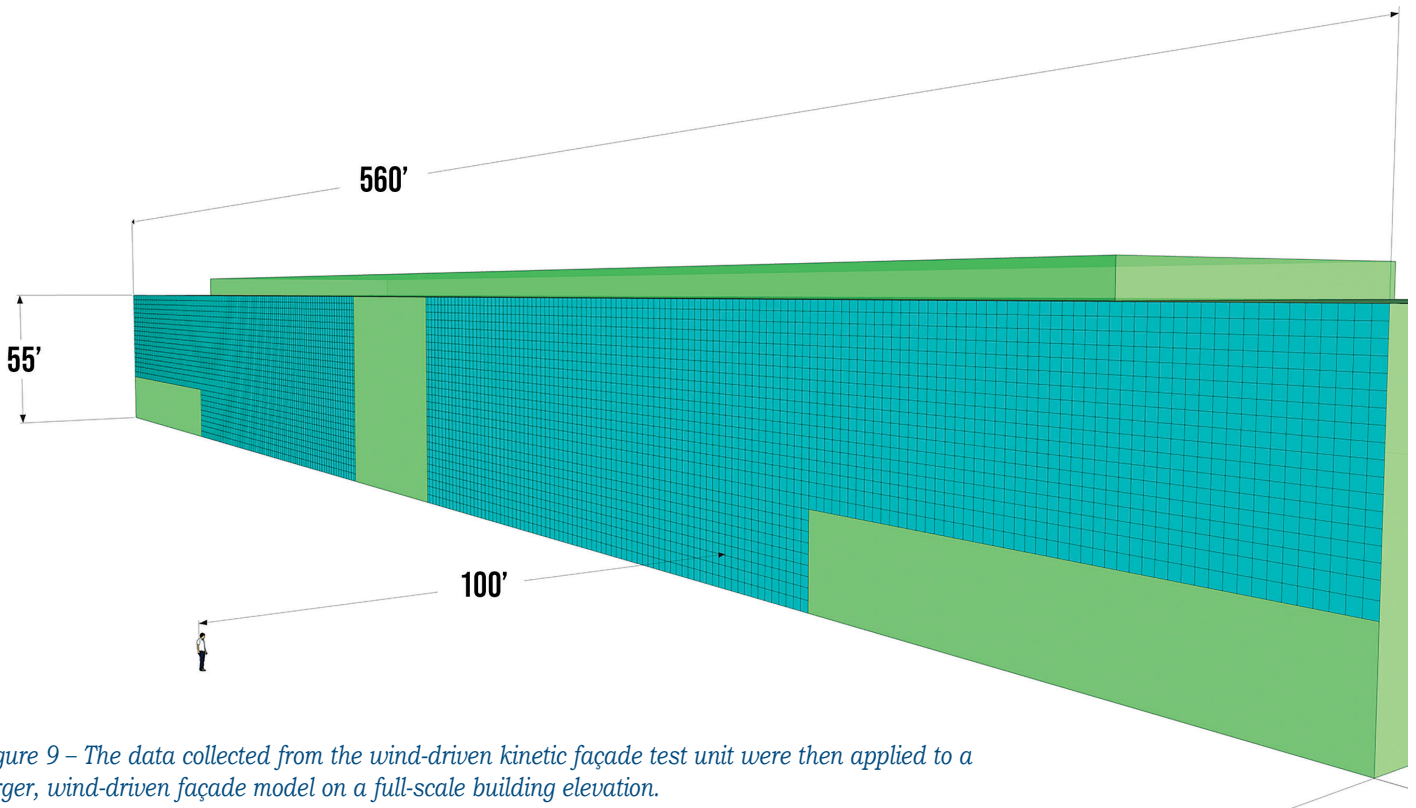


Figure 9 – The data collected from the wind-driven kinetic façade test unit were then applied to a larger, wind-driven façade model on a full-scale building elevation.

urban setting, a city's ambient noise further masks the sounds produced by a building façade. Current examples of wind-driven façade installations can be seen on airports, downtown offices, sports stadiums and event centers, high-end retail stores, museums, and parking garages. In these applications, noise from vehicle traffic, aircraft, performances, and energetic visitors help negate the sound produced from the kinetic system itself.

In addition to the location-specific noises of a kinetic wall installation, the wind inducing the flapper panels to create the system's dynamic visual effect also will generate ambient sound. In many cases, the wind itself will be loud enough to mask the sound level of the façade system.

This acoustic study also verifies that the perceived sound levels of this type of wind-driven kinetic façade are highly unlikely to be of concern to applicable noise ordinances and regulations.

In conclusion, remember to consider the volume and quality of sound generated by a kinetic façade installation as early as possible in the project's design and material

| Overall sound level (dBA)<br>measured from the center (280.5 ft) of the building elevation |                                    |    |    |    |     |
|--|------------------------------------|----|----|----|-----|
|  | Distance from façade system (feet) |    |    |    |     |
| Wind speed (mph)   | 0                                  | 25 | 50 | 75 | 100 |
| 5  | 40                                 | 39 | 38 | 36 | 35  |
| 10   | 43                                 | 42 | 41 | 39 | 38  |
| 15   | 46                                 | 45 | 44 | 43 | 41  |
| 20   | 50                                 | 48 | 47 | 46 | 44  |
| 25   | 57                                 | 56 | 54 | 53 | 52  |

Table 2 – Sound levels calculated from 280.5 ft.

| Overall sound level (dBA)<br>measured from 140 feet from the building's corner |                                    |    |    |    |     |
|--|------------------------------------|----|----|----|-----|
|  | Distance from façade system (feet) |    |    |    |     |
| Wind speed (mph)   | 0                                  | 25 | 50 | 75 | 100 |
| 5  | 46                                 | 42 | 40 | 38 | 36  |
| 10   | 49                                 | 45 | 43 | 41 | 39  |
| 15   | 52                                 | 48 | 46 | 44 | 42  |
| 20   | 55                                 | 51 | 49 | 47 | 45  |
| 25   | 62                                 | 59 | 56 | 54 | 53  |

Table 3 – Sound levels calculated from 140 ft.

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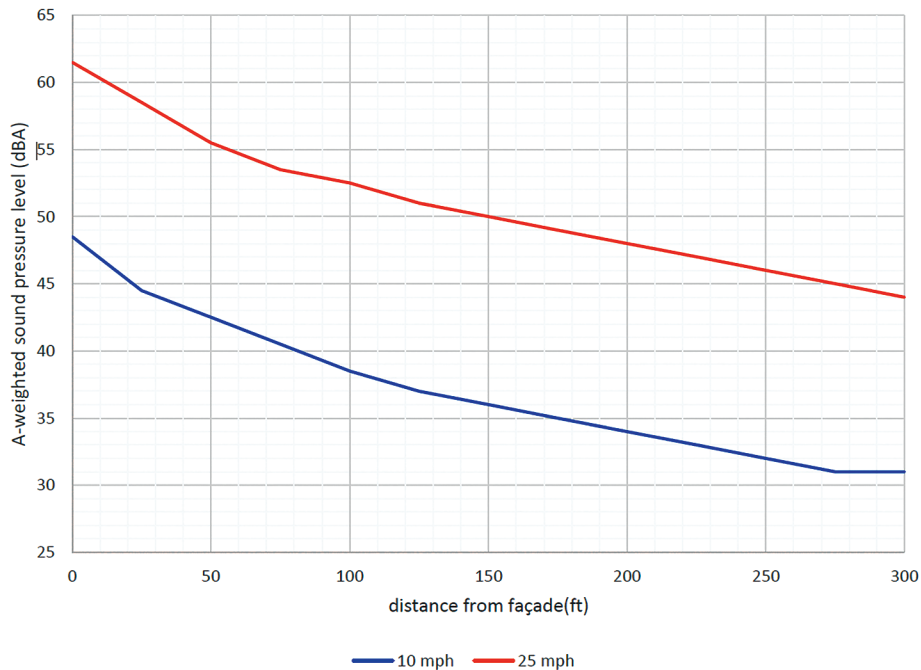



Figure 10 – The overall sound pressure level produced by the wind-driven kinetic façade test unit is plotted as a function of distance for 10- and 25-mph wind speeds. Chart by EXTECH.

selection process. If necessary, verify sound levels and tonal quality on an individual project with a full-scale mock-up.

Given the complexity of kinetic façade systems, seek an experienced designer and manufacturer to participate early in the project’s design. Look for one offering preliminary cost estimating, mock-ups, and a variety of fabrication and installation options to meet each project’s functional and aesthetic requirements. 

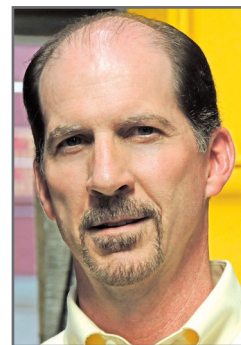
## REFERENCES

1. The Los Angeles ordinance states: “Sound Level Meter” is an instrument including a microphone, an amplifier, an output meter, and “A” frequency weighting network for the measurement of sound levels which satisfies the pertinent requirements for Type S2A meters in American Standard Specifications for sound level meters in S1.4-1971 or the most recent revision thereof. (Amended by Ord. No. 156,363, Eff. 3/29/82.)
2. Environmental Protection Agency Office of Noise Abatement and Control. *Information on Levels of Environmental Noise Requisite to Protect Public Health and Welfare With an Adequate Margin of Safety*. 550/9-74-004. March 1974. <https://nepis.epa.gov/Exe/ZyPDF.cgi/2000L3LN.PDF?Dockey=2000L3LN.PDF>



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Jim Leslie is the general manager of EXTECH/Exterior Technologies, Inc., in Pittsburgh, PA. He and his team redefine the intersection between the natural and built environments with wall, window, skylight, canopy, and custom systems, such as dynamic façade designs. Leslie has a bachelor of science in mathematics from Penn State University and is a member of the American Production and Inventory Control Society (APICS). He may be reached at [jleslie@extechinc.com](mailto:jleslie@extechinc.com).



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3. National Institute for Occupational Safety and Health. “Noise and Hearing Loss Prevention Guidance and Regulations” “Occupational Noise Exposure.” 1998. <https://www.cdc.gov/niosh/topics/noise/reducenoiseexposure/regsguidance.html> and <https://www.cdc.gov/niosh/docs/98-126/pdfs/98-126.pdf?id=10.26616/NIOSH PUB98126>
4. National Institute on Deafness and Other Communication Disorders. “Noise-Induced Hearing Loss.” Updated March 2014. <https://www.nidcd.nih.gov/health/noise-induced-hearing-loss>
5. *Ibid.*
6. Hearing Health Foundation. “Hearing Loss & Tinnitus Statistics.” Accessed June 30, 2020. <https://hearinghealthfoundation.org/hearing-loss-tinnitus-statistics>. See also: World Health Organization. “Deafness and Hearing Loss.” March 1, 2020. <https://www.who.int/news-room/fact-sheets/detail/deafness-and-hearing-loss>
7. The study did not evaluate noise at higher wind speeds. Higher sound levels may be expected, dependent on material selection and detailing; however, as wind speed increases, so does the surrounding ambient noise, which can mask that produced by the kinetic façade.