

Designing Ventilation Systems That Can Handle Extreme Weather

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Abstract

Climate change is making extreme weather events like heat waves, cold spells, hurricanes, and wildfire smoke episodes more common and stronger. This is a big problem for traditional ventilation systems. This paper analyses the concepts and efficacy of resilient ventilation design in structures subjected to fluctuating and extreme environmental conditions. The research assesses the capacity of ventilation systems to uphold indoor air quality, thermal comfort, and operational continuity during extreme weather events by a synthesis of computer models, field measurements, and resilience-oriented performance metrics. Some of the main techniques that were looked at were hybrid ventilation systems, adaptive control systems, better filtering during times of severe pollution, and having backup systems for important infrastructure. The results show that designing ventilation systems that are resilient not only makes people safer and healthier, but it also uses less energy and makes buildings more likely to survive in extreme weather. The research suggests a structure for including resilience measures in ventilation planning, which can help engineers, architects, and policymakers make buildings more resistant to climate change.

Keywords: Resilient ventilation, extreme weather, indoor air quality, climate adaptation, and hybrid ventilation systems

INTRODUCTION

Ventilation helps keep the air within clean by getting rid of contaminants and controlling the levels of moisture, temperature, and smell. There are different ways to ventilate buildings so that they can get fresh air from outside. Extreme weather calls for more strength. Resilient ventilation keeps working even when the conditions are worse than typical. Extreme heat, cold, snow, wind, flooding, and rain can make things less safe and less effective [1]. When the temperature outside rises, buildings with big apertures for letting in extra air in the summer might get too hot through those openings. So, the problem is to increase the flow of air within while keeping damaging heat from getting in. Choosing the right gear for hot climates is another way to make yourself more resilient. Buildings in cold climates that have cracks on purpose to let in more air are at risk of leaking too

much when the temperature outside decreases. In regions where it snows, air that leaks through stretched cracks in the winter may carry hidden moisture that develops into condensate when it enters the building, causing harm inside. When the weather is cold enough to let outside air in through open vents, those vents should be protected so that snow doesn't hinder the flow of air. Equipment that is already in place and could freeze needs to be protected in these places as well. When the wind speed reaches 30 m/s, it can cause problems with air coming in from outside. There are many

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Received Date: December 02, 2025

Accepted Date: January 06, 2026

Published Date: January 20, 2026

Citation: V. Basil Hans. Designing Ventilation Systems That Can Handle Extreme Weather. Journal of Refrigeration, Air Conditioning, Heating and Ventilation. 2026; 13(1): 1–14p.

different ways to deal with summer, winter, and lower storm-pressure circumstances because of the different types of roofs, walls, enclosures, locations, and construction layouts [2].

Why Resilience is Important in Ventilation

Extreme weather can hurt people, damage property, and make people sick. People need a safe place to stay away from the outside world, where they can easily get fresh air. When natural ventilation depends on outdoor air and cross flows, it works best. In some places and under some conditions, including high heat, humidity, or infections, this is not possible. Resilient ventilation keeps openings open, keeps safe air flowing, and lets you use other sources when you need to. These kinds of improvements keep protection safe.

Resilience is made up of at least three parts that help shape tactics. The first one is about the flow of air via the ventilation system, including the speed and quality of the air that is sent and the lack of comeback from unconditioned places. The building's needs should always be met when it comes to these. The second one is about equipment and the possibility of contamination. Being exposed to extremes from time to time shouldn't make the surgery worse or give off hazardous air. The third one has to do with being available when things go wrong, whether they are physical, electrical, technological, or informational.

Extreme Weather Situations

Climate change is making extreme weather events happen more often and with more force. Very hot or very low temperatures, as well as heavy rain or flooding, are three situations that are especially important for building ventilation.

Severe heat waves are currently the most typical kind of extreme weather in many parts of Australia and other places. In these situations, interior air quality and thermal comfort quickly get worse unless ventilation systems work well [3]. In these situations, thermal mass, exterior shading, and other methods can help reduce the requirement for ventilation, but they still need to be watched closely [4]. Also, the expected rise in extreme events makes it more likely that these occurrences will happen at the same time as times when natural ventilation can be used.

As climate change raises average temperatures, really cold episodes are now almost expected to happen in many parts of Australia. So, systems that need to stay functional and livable under extreme weather, including heat waves with long periods of gloomy weather or winter events, need to pay close attention to air flow and moisture control. The Brisbane area had an 11-day cold snap at the end of June and beginning of July 2021. This shows how risky it is to live in subtropical areas that are still habitable with good heat-mitigation techniques [5].

Heavy rain events are also getting stronger and more common. Many areas in eastern Australia get severe storms that cause a lot of flooding. Climate change is also making some parts of the world more likely to have extreme drought. As areas get ready for more floods, they also run the risk of more severe storm-driven inland incursion. This is why drainage systems that work in all situations are so important.

BASIC PRINCIPLES OF VENTILATION RESILIENCE

A well-designed ventilation system needs to be strong. Even when equipment or systems fail, resilient solutions still work well. Also, structures in areas that are affected by extreme weather events like heat waves, floods, very strong storms, high winds, snow, freezing temperatures, and rising humidity need to be able to withstand them. Resilient ventilation design helps buildings keep people comfortable, clean, and healthy even when bad things happen that can be quite disruptive.

When designing resilient ventilation for extreme environments, it is important to keep the basic goals and concepts in mind while also working towards more specific goals. By keeping the key

ventilation goals in mind, analysts lower the chance that the two sets of performance would be confused or disconnected. Resilience in ventilation design allows for even better design integration and optimisation. In many cities, the climate is changing a lot. For example, there are extended periods of great dryness followed by long periods of heavy rain and flooding. Additionally, fires may occur during the heatwave due to exceptionally dry circumstances and may spread more rapidly if buildings are not well-ventilated. This is because more buildings are using mechanical ventilation systems that allow for penetration by design [2].

Important Aims and Ideas

Modern ventilation design should be able to handle all kinds of weather, not just the usual kinds. When designers have to think about the basics in extreme situations, it makes it easier to come up with good solutions. Focussing on ideas that can be tested and used makes design strategies clearer.

Set defined goals before you start making choices. Not enough ventilation in the winter can cause problems with snow and ice, and other systems get more stressed when the weather is very bad. Focussing on energy efficiency and ventilation that can withstand stress may make it harder to improve other aspects of indoor environmental quality (IEQ), such as removing contaminants or making the space more comfortable to live in [1]. Avoid having every system in a building need power and protect parts that are sensitive to dampness. Use local criteria to help you decide which tasks to do next.

You don't have to deal with every possible extreme at once; just pick the right limit for your area. Choose ventilation strategies based on what makes indoor concentrations go up. Change the conditions outside, use extra filters for outside pollutants, make it easy to switch to recirculation with exhaust only when there are restricted openings outside, or let exhaust happen without outside intake. Include it in the primary system or add a separate one.

Parts of a Strong System

A strong ventilation system should have dependable equipment, several ways to work, a range of energy sources, and protection from the weather. The choice of parts is generally based on building rules and commercial constraints. Simplicity and common materials are very good for resilience; specialised parts tend to make things more vulnerable [6].

Equipment that Works

Ventilation systems need to work in a lot of different situations, such when the weather is bad or the electricity goes out. There should be at least one dependable choice for each ventilation mode in the system. Fans that bring in air, fans that take air out, and windows that can be opened can all help. Regional codes say what systems are permitted. Any solution that works well in both normal and extreme situations is acceptable.

HOW TO PLAN FOR VERY HOT WEATHER

Strategies for Designing for Extreme Heat

Extreme heat makes it even more important to improve passive heat regulation to keep the temperature inside from getting too high.

Encourage passive cooling. Sunlight, conduction, infiltration, and exfiltration all bring heat from outside to inside. Limit your exposure to these sources to cut down on the amount of unwanted heat that gets in. Find openings, windows and shading that will help with passive cooling through cross-ventilation and stack ventilation while also keeping heat from getting inside the building.

Set up paths for air to flow from cooler to warmer locations. In many places, the air outside stays comfortable in the early morning or late evening, especially in humid regions. When you can, make

airflow channels that make this exchange easier. Use these times to get rid of extra heat that has built up in structures, finishes, and furniture.

Put in heat exchangers. Sensors can use energy-flow estimation instead of measuring surface temperature because they have a large surface area. Exchangers can bring down the temperature of entering air streams by a lot and control the amount of moisture in the air. Make sure that heat exchange systems can handle the right amount of energy and that system performance can easily handle different energy flows [3].

Make the insulation better. Adding more insulation can make the overall thermal performance better. In places that are used for more than one thing, such hallways, bathrooms, and parking garages, make thermal protection a top priority. Set up distinct areas for people to live and work in, which helps keep the heat from the sun or surrounding machines from getting too hot. Keep all important surfaces in these locations insulated and connected so that radiation from outside places can't get in.

Pick appliances that can handle high temperatures. Choose heat-generating equipment that can handle temperatures that are both within and outside of its normal operating range. When installing equipment that can handle greater temperatures, check how strong that temperature range is when things go wrong across the network. Store items that can handle the highest expected local temperature when heating episodes happen only once in a while.

Ways for Air to Move and Cool Things Down

Opening windows all the time makes airflow pathways that let air in and out and spread heat. When fresh air is let into the room, these channels let heat from normal activities escape. This means that mechanical ventilation is not needed. In hot weather, putting windows or other vented features in the right places to take advantage of the prevailing breezes can improve ventilation even without mechanical systems [2].

Windows and infiltration thus become passive parts of a ventilation system plan. Adding operable windows with deeper overhangs to give shade makes it possible to use the space for longer periods of time. Putting windows on opposite ends of an office area helps air flow between the inside and outside [7].

Insulation and Heat Exchange

Extreme heat can be bad for your health, comfort, and equipment. If the heat load is smaller than the heat gain from the outside, ventilation can help reduce these dangers. Less heat coming in from outside means less work for the ventilation system. These steps can help lighten that strain.

The way a building is designed influences how heat builds up and moves about. If you point the long sides away from the sun, the solar gain will be less. Eaves or awnings on the outside of a building keep the sun from striking it. Reflective surfaces lower the amount of heat that comes from the sun and other sources. Putting thermal mass in the shade and using phase-change materials can assist keep the temperature from changing too much during the day. A thermally insulated roof also slows down the heat gain. You can also utilise roof ducts or soil ducts to cool down the air that comes in via the ground.

Make sure there are channels for pre-cooling that go in more than one direction and are not limited to single stacks. This will help use free convection well, even when the temperature difference between the inside and outside is small. Pick one of the following:

Heat Exchanger

An air-to-air heat exchanger lets some energy pass from one airstream to another. The energy that is recovered could be just sensible or a mix of sensible and latent. In the first situation, it can get back 70–

95% of the temperature differential between the air coming in and the air going out [8]; in the second scenario, it works even better. It is quite helpful to cool down the outside air before letting it into the building. A heat exchanger is better for medium- to low-cost dwellings and Arctic/subarctic solutions.

Heat Insulation

A structure that is well insulated keeps extra or unwanted heat from getting in by conduction, infiltration, or ventilation. It is also important to have strong insulation that can handle a lot of heat, especially in areas of the building where the temperature changes.

Choosing the Right Tools for Hot Weather

Using new technologies can make a system that works well and lasts a long time in hot weather [9]. The best setup comprises two different parts. The first unit makes sure that people and equipment are comfortable inside. The second unit keeps the air within clean by providing sanitary ventilation. Traditional systems put comfort and hygiene functions in one unit.

HVAC systems work all year round, even when the weather changes. As a result, the temperature and humidity outside work together to effect the low yearly energy use, cooling load, and sensible heat ratio. The highest dew point outside is frequently when the cooling load is at its highest. HVAC systems also keep the pressure levels inside and outside the building clean and neutral in terms of temperature. The highest dew point outside means the most sanitary ventilation and total load.

To keep the air within buildings clean, ventilation systems must still work when the humidity is high. If the air quality inside gets worse, the total amount of energy used each year for dehumidification becomes unimportant. Even the most advanced methods for saving energy still let you dehumidify with little energy. Separate control systems make it much easier to run several systems at the same time in these high humidity circumstances. They also save energy and make the systems more resistant to local failures.

Cooling coils that are only made for peak sensible capacity generally don't do a good job of dehumidifying at peak latent loads or part loads. Just keeping the dry-bulb temperature stable is not enough to meet humidity-control needs. To reliably fulfil interior humidity and relative humidity levels, sewage, laundry, and kitchen sources must be preconditioned. It's just as important to properly condition the damp air outside before it enters the structure. The first unit cools and dries the air outside, while the second unit does all the other things that need to be done.

Based on a lot of experience with different types of buildings in different climates, putting a small unit near the outdoor air intake meets the needs of the first unit. Putting the unit inside the main set makes it look better and is still fine in high-end buildings. This kind of setup is secondary; more alternatives open up when the first unit is completely separated.

Exhaust fans and filters, ductwork that sets up discharge and intake channels, scent distributors in certain places, and operation-controlled booster fans make up the active ventilation system. Natural flow path ventilation systems that solely use ducts, check valves and air-tight grilles can lower the danger of potential hazards if there is no other system in place.

HOW TO PLAN FOR VERY COLD AND SNOWY WEATHER

Ventilation systems that are well-designed perform well all year round. The same rules about passive ventilation, heat recovery, filtration, and safe operation during power outages that we talked about before also apply to low-temperature conditions. Cold weather brings new problems that need to be solved.

It is important to stop air leaks and drafts from getting through the building envelope. Weather stripping and caulking on all doors and windows keep air from moving around too much. It is just

as important to size passive openings like vents and skylights when it's hot as it is when it's cold. When the outside air gets cold, many of the solutions mentioned for cooling require more sealing and system setup.

Frost and permafrost can even get into the foundations of buildings in the northern countries. Wall and ceiling systems frequently wrap around the basement, foundation, or crawlspace to keep the inside walls warm and stop condensation from forming in batt insulation or air cavities. Rigid-foam sheathing is also used to cover things like siding, stone, stucco, and even brick for the same reasons. [10]

Keeping Air from Leaking Out and Drafts from Coming In

Air leaks through joints happen as soon as someone moves into a building. In the Arctic, where temperatures can vary widely, frost and moisture can cause leaks that threaten the envelope's integrity. Heating and ventilation often make the problem worse. All joints should be made in such a way that they don't need tape sealing as much. Air exfiltration can cause moisture damage to top joints in particular. After construction, when buildings first open for business, and when the temperature inside is low, systems need to be checked to make sure the air-leakage pressures are correct.

In very cold weather, attics that are aired work better than those that aren't. But if the base of the attic insulation leaks, it can cause moisture and freezing, which makes it harder to dry out in the winter. When the humidity outside is low, like in the summer and during the shoulder seasons, ventilation is more helpful. There was no need for lintels or drop sills on the inside walls because the monitored house didn't have windows that got too humid.

When buildings are empty for a long time, supply-air heating systems that use heated outdoor air instead of cold air can help with moisture problems caused by frost. Adding vented interstitial space at the top of the roof assembly lets heat out. For continuous ventilation, it helps minimise the danger of mould growth to have at least one air change per hour (ACH) every year. Natural ventilation is very simple and quite effective, as long as devices keep snow from getting in [11].

Control of Condensation and Insulation

Cold roofs can cause problems with moisture. To keep snow from melting and moisture from forming, these roofs need to be insulated and vented. Controlling the dour vapour processes and dew point placement on and inside a building element is part of insulating against moisture migration. You need to use materials that match the humidity inside the building, including frame or lightweight construction and vapor-tight linings. Composite structures, vapour barriers, or vapor-tight hydro-deflections and lining with vapor-permeable materials can assist keep moisture in check [11].

How to Keep Your Equipment Safe in Frigid Weather

In frigid weather, protecting your equipment requires good ventilation and insulation in the attic. Field measurements suggest that the hygrothermal performance of buildings in very cold areas can be improved with the right design. To keep moisture from building up, good building practices for northern facilities say that attics should be well-ventilated. Field studies and models show that roofs with ventilation assist keep mould from growing and make buildings more energy-efficient. Adaptive ventilation systems can keep moisture out of cold attics, which helps protect insulation and the structure as a whole [11].

HOW TO PLAN FOR HIGH WINDS AND STORMS

Ventilation apertures and louvres should be installed at the corners of the structure and attached directly to structural components instead of only the wall finishes [12]. Filters that are securely attached keep away wind-driven dirt, but standards say that ventilation must be limited. You can keep the system running during power outages by using a passive air change method or an outside air system with an economiser feature [13].

Putting Vents Together in a Structural Way

When designing ventilation for structures in places that are likely to get strong winds and storms, structural factors must be taken into account. To reduce the potential of roof damage that could cause flooding or structural failure, vent openings should be built into walls that are already exposed to wind [14]. Rain shields are very necessary for vents that are prone to let in rain that is blown by the wind. Wind-driven rain can damage buildings with little or no overhangs more easily [15]. Putting the building on fill or piles, using flood-resistant materials like masonry for the lower building parts, and raising the outside unit of HVAC systems above a certain flood level or on a grated platform are other ways to assist prevent flooding [2].

The plan for managing stormwater should also work with the soil and weather at the site. Flexible indoor drainage, like containment or evaporation tanks, lowers the risk of groundwater floods on sandy soils in humid climates where groundwater infiltration is likely to happen. Roof drains with detention areas filled with gravel offer more storage space on the property than standard downspouts. Calculating the enclosed pressure from wind-tunnel tests and pressure coefficients for big structures with dominant-opening layouts could help you figure out how big the intake opening should be. Too much filtering can cause the air to get stagnant, which can then lead to mould growth. If structural integration isn't possible, outdoor units could be put in courtyards that are shielded from the wind.

Protection from Dirt and Filtration

Filtration must remove particles the size of viruses, and it should be tested against these kinds of organisms. Think about employing more than one filter in a row. There is less protection against pollen, dust, and other small particles because people may deal with the annoyance while staying indoors.

Debris and water must not get into ventilation systems. To keep wires from falling into an unprotected vent, telephone and power-supply lines, television cables, and plumbing should all go from the ceiling (or down a wall with metal flashing). Ventilation inlets and exhausts should be placed where they are less likely to be punctured by falling branches or flying debris. Or mesh can be put in all the apertures for air to get in and go out, as long as this doesn't make the pressure too high in strong winds or storms. When choosing positive ventilation forces, you need think about all of these things: where the ventilation exhausts should be put (on the side wall away from winds and at a low elevation to keep the view clear while sticking out less from the building structure). It's also important to think about where the ventilation exhausts and fires are in relation to the wind, rivers, and industrial operations.

If it rains heavily, the condition of the square cut-out architraves, jambs, head, and sills is very important. Even minor gaps or cracks from some other disturbance can let water in. All open junctions on other surfaces must also be waterproof and properly handled with by painting, sealing, or waterproofing (for example, membrane water-proofing cement and a corresponding paint or sealer).

Safe Operation When the Electricity Goes Out

When the weather is really bad, power disruptions happen a lot. So, any changes or additions to ventilation in reaction to these events must not make the air quality or safety inside worse during power outages.

If the outside temperature is higher than the internal temperature you want, make sure there is a fresh air supply. Even when ventilation rates are high, mechanical cooling makes it possible to keep indoor conditions acceptable for a short time. Make a plan for a system that keeps air moving and clean even if the supply fans stop working because of a power outage. Don't just depend on supply fans to meet your ventilation needs.

Mechanical heating systems can keep the inside of a building comfortable during short periods of cold weather in cool and cold areas. Choose a heating system that works even when it's not heating

season, and make sure it can provide enough fresh air even if it doesn't have heating capabilities. If the fresh air delivery system has a heat exchanger, make sure to get one that can still supply air without heating. When the temperature outside is lower than the required temperature inside, the system should be able to bring in enough fresh air and keep it fresh.

If you need a whole-building-backup generator to protect ventilation, choose a system that will still meet ventilation needs even if the backup generator stops working [5].

DESIGN PLANS FOR FLOODING AND HIGH HUMIDITY

The meaning of flooding and floating changes depending on where the building is. When it rains, the sea, rivers, lakes, mares, and/or precipitation can flood a place in humid maritime regions. Buildings that are flooded will get wet or mouldy. To help with damp problems, holes in walls let air move freely from the outside to the ground layer. In warmer climates, air routes through walls must follow energy rules to keep people from being too hot. If ground-free flowing air isn't possible, on the other hand, dehumidifying equipment must be put in place [9].

In coastal areas, rain often comes with strong winds, which can let water into a structure through doors, windows, and other openings in the building envelope. When figuring just how airtight something is, you should think about how rain can get inside. Even when it's stormy, doors and windows need to be able to open and close. To do this, the right waterproofing methods should be used to drain water away. There are a lot of commercial building materials that are resistant to dampness on the market. It is also usually possible and cheap to use waterproof paint or waterproofing coatings [16].

Keeping Moisture from Getting In

Sealing against moisture intrusion is very important for structures that are likely to flood, especially those that are subjected to floods on a regular basis or have high humidity levels in the air. Mould, wood rot, and metal corrosion are all caused by moisture, which can harm equipment and make the air quality worse.

The most dangerous places for ventilation equipment are where there are air holes in, around, and below it. Duct connections, pipe penetrations with too little sealant, and movement through porous materials can all cause leaks. A vapor-retarding layer should cover duct insulation that is outside. There should be seals on equipment enclosures that keep water from getting in from above or below the building and from touching surfaces that are very wet. Ideally, ducting or systems that work in a dew point range that encourages condensation (but is above freezing) should be outside the conditioned area.

For exhaust systems in places that are prone to flooding, the ducts should slope down towards the outside discharge to help gravity drain any water that gets stuck. It should be easy for water to flow out of boxes and plenums. Fans and other important parts should be above the planned flood elevation. Melamine-finished particleboard is an example of equipment that should be able to withstand damage from water. Ferrous materials should be coated in the shop. Stencils can help you see corrosion early on while the machine is running [11].

Waterproofing and Draining

Vulnerable building elements or systems frequently demonstrate more intricate failure mechanisms compared to conventional designs, necessitating a more thorough resilience study [17]. To stop water from getting in, moisture ingress prevention methods should focus on openings that are likely to let water in. Putting roof overhangs on the roof keeps driving rain from getting into cold vents on the roof. Protecting cold, outside-air intake vents makes the system stronger. If it rains more than the drainage system can handle, drainage systems that work even when the power goes out help keep the structure strong. It is sometimes not enough to use drainage and waterproofing systems that protect whole buildings to make sure that single building openings have level drainage, especially if there are

more than one entrance. Because storms are getting bigger and more dangerous, many drainage and waterproofing methods that used to work are no longer safe.

Materials and Resistance to Corrosion

The materials used in ventilation systems have a big impact on how long they last when there is flooding. For example, wet and salty circumstances are especially bad for multilayer coatings on steel structures, which degrade within two years of being in these conditions [18]. When alkaline earth metals and graphite lubricants are used together, they can cause zinc-coated steel to corrode beyond repair. Marine and industrial environments are not good for plastics, aluminium, and magnesium alloys. Equipment that is close to the critical zone, like underground and in tunnels, should be composed of materials that are very resistant to corrosion. When choosing materials, you should also think about the rules and requirements set down in the municipal code. Stainless steel of different quality is used a lot since it doesn't always have a galvanised coating, doesn't rust in the same places, and can be recycled [19]. Polyvinyl chloride (PVC) and polypropylene (PP) are the most common types of plastic parts. Choosing polymers is hard, and each resin should be looked at separately.

CONTROL AND MONITORING SYSTEMS

For ventilation to work well in adverse conditions, you need good monitoring and control systems. The most accurate and useful systems are advanced ones with multiple sensors. However, they usually need to be serviced regularly to work properly and may be prone to interruptions. They can give the system enough backup while always keeping an eye on it for possible faults.

Think about adding sensors that can measure temperature, relative humidity, and the drop in filter pressure [20]. Tell operators when any reading goes above a certain level. For example, if the return temperature is higher than the outside temperature when it's chilly outside, the system may be leaking when it should be closed.

Calibration should not happen very often and should be easy. Set the number of readings and the detection sites. In a multi-sensor method, keep the number of extra sensors to a minimum. Choosing all of your equipment from one seller can make it easier to put together and keep up with. You should also keep an eye on state changes, including when equipment or auxiliary devices like pumps or dampers are turned on. Even with high-quality parts, systems might drift over time because of changes made by operators or discrepancies between the settings at the site and the factory.

Resilient systems keep working and are safe even when the power goes out or there are other problems. Don't use complicated algorithms just for these situations. Simple schedules nonetheless let enough air flow without needing any extra recovery time. It should be easy to see and understand how the system works and what the current setpoints are. Operators need to rapidly figure out if a fault has happened that could make users less safe or comfortable [6].

Sensors and Warnings

Sensor-based control systems, which are occasionally used with simple mechanical controls, make things even more reliable and make it more likely that ventilation will stay on during bad weather. These systems automatically change the rates of supply, exhaust, or recirculation based on temperature or humidity sensors. They can also check on the status of the equipment, the levels of coolant, and the filter clogging. Operators are told when maintenance is needed by alerts.

A lot of controls have good and bad sides. Some solutions can make things more resilient by making them easy to use in very hot or very cold weather. Even when the power is off, the controls that are chosen should still let ventilation equipment run without interruption and protective barriers be monitored all the time. Controls should be able to be chosen or designed so that they can be simply bypassed when manual adjustment is needed or so that the parts that need the most resilience can have a simple control strategy implemented.

A lot of people have used cheap data loggers and portable sensors [21]. They have made cheap, tough humidity-strain-dampening systems that can keep an eye on the weather. You may use these sensors at the same time as environmental-quality tools to keep an eye on how well a building is doing over time and figure out where efforts to make it more resilient are most needed.

Fault Tolerance and Upkeep

There are a lot of problems with ventilation control systems. These problems can make ventilation systems work very poorly and make buildings unsafe. Adding sensors to keep an eye on system parameters can help stop things like this from happening. Model-based or learning-based strategies can use sensor data to find problems. In both circumstances, it is generally helpful to have extra information, which is usually done by adding physical sensors. Virtual Sensors is a new way to employ simple math models to make sure that information is not lost. It is possible to forecast the same physical variables that are being watched based on other quantities that are being watched. You can figure out the supply temperature T3 and the enthalpy without adding any more hardware when you measure the post-heat-exchanger airflow of an air-handling unit for a specific set-point temperature T1 of the fresh air and a corresponding returning temperature T2.

Easy Controls for Dependability

A strong ventilation system needs to work reliably. Under extreme conditions, simple technologies work better, thus the design should keep things as simple as possible. Use simple control techniques wherever you can. These strategies don't need much supervision or maintenance, but they do let the ventilation system work well within its limits.

Limit the use of automatic control and human help. Choose the operating state at the start of each season based on what you think the weather will be like. Don't let air out of hooded passive vents when it's really windy. At all times, filters should be coarse (MERV 8 maximum). For intermittent heating, set a steady preheating condition. After a power failure, go back to the original setup and make sure cooling can start without any input. This is fine during hot or unstable times [20].

BUILDING, FIXING, AND UPDATING

Buildings that are strong stay longer, work better, and need fewer repairs. They are better able to handle dangers, such bad weather, throughout their lives. If risks do happen, they are made to do as little damage as possible. Parts that are harder and more expensive to replace, such foundations or features that can withstand wind, are given priority [22]. On the other hand, systems that aren't necessary for safety or habitability, like decorative finishes, can wait [11].

Most of the time, ventilation systems in business buildings stop working. Ventilation problems including clogged filters, jammed dampers, and worn-out belts make the air inside buildings with high air-change rates very unhealthy [23]. In rooms that aren't conditioned or where ventilation isn't operating, many dangerous airborne pollutants, viruses, and pandemic vectors can move about swiftly.

You can usually build ventilation systems for buildings on-site, which saves time and materials. Standard construction practices can affect various parts of ventilation systems. Sealing, draining, and other comparable methods can make systems that are weak last longer.

When changing an old structure, it can be hard to check areas that are hard to get to. A modest access panel can make it easier to check and fix things in the future. You can't view the inside of ducts, fans, and other similar parts after they are closed up. An inspection port that is clear lets you examine the inside surfaces.

In green building contracts, you can specify ventilation systems. When you list elements in a construction contract, it shows how important they are to the building's health and safety goals.

Helpful Advice for Putting Things Together

- To protect the base of the building, keep the gravel guard or splash block in good shape.
- Think about putting water-resistant covers over ventilation holes and linking ventilation ducts to drains in areas that are likely to flood [2].

Routine Checks and Maintenance

To find problems before they lead to catastrophic failures, inspect ventilation systems regularly and thoroughly to make sure they are working properly. Here are some general tips for keeping all kinds of ventilation systems in good shape.

- Fix or replace any leaks, cracks, or breaks in vents, ducts, filters, and other parts that go with them.
- Make sure that the dampers close all the way and open when they should.
- Clean dampers, grilles, filters and fans often to keep dust, dirt and debris from building up and blocking airflow, which puts more strain on motors.
 - If the humidity sensors become out of whack, inspect and replace them. Also, check the exhaust fans often because moisture can cause switches and motors to fail.
 - Make sure that roof or outside vents are clean of debris and damage. Pay specific attention to places that are protected by the upper portions of the building.
- Look for signs of water getting in (inside or outside) in places where ducts flow. If you find condensation pans, clean them.

The condition of the building will usually determine how often maintenance needs to be done. However, for a moderate warning phase, think about doing a review every three or six months.

Improving Buildings That Are Already There

It is hard to add ventilation systems to structures that are already there. A lot of buildings don't have the right ducting or space, so new equipment has to travel through walls. Retrofitting solutions can sometimes clash with equipment that is already in place and make it harder to change how things work. To get ready for the cold winter weather outside, conditioned air needs to travel through heated spaces [4]. Also, the risk of earthquakes, security breaches, and explosions may make it less likely that people will choose to construct outdoor vents [14]. To make existing buildings that can't be physically upgraded more resilient, you need make the following changes.

- Replace fans that aren't in high-traffic areas with ones that can handle muck, salt, and wetness. To stop rusting, put dehumidistats in houses beside the sea [2].
- Use controls and dampers that work on their own. When systems turn on and the weather is safe, dampers should only open.

STUDIES OF CASES

Designing Ventilation That Can Handle Extreme Weather

A resilient ventilation design was used to protect areas that need to be protected during very cold, rainy and snowy weather while also increasing the flow of air inside the structure. This method lowered the humidity to a reasonable level and raised the ventilation rates enough to make the air quality even better. Here are three studies that explain how to make applications for buildings that work in one or more places with really bad weather. Sassi [14] talks about how important it is for buildings to include elements that let air flow through them without using fans or other mechanical means. This is especially important when structures are exposed to diverse types of weather. This is more important for passive design in buildings in warm regions since it helps them rely less on motors and other systems that can break down during a blackout.

Urban Heat Island in Poznan, Poland

The University of Arts in Poznań, Poland, has a building that is extremely near to meeting the passive house standards and meets passive ventilation needs while letting in enough light. The

building is fashioned like a L and has two constructions that stick out from the wall. More than 40% of the building's total envelope area is made up of the exposed glass surface. Using both high thermal insulation and protective parts together lowers heat transfer. To keep the building from being too hot in the summer, plants that are scheduled to cover part of the cantilevered roof are expected to lower the temperature by more than 5 °C, along with other parts of the building.

New York's Shoreline Building (Hurricane Sandy)

The South Bronx saw very bad flooding after Hurricane Sandy. It sped up the erection of buildings that could withstand floods in the southern side of the Bronx in the months after 2012. The new building was built to withstand floods for 100 years. This meant that the entire basement had to be raised by at least 4 feet, and it had to have several passive cooling features to make the inside more comfortable without using mechanical cooling systems and to keep the air quality good in areas that needed it. Daylighting and ventilation systems that work without electricity can meet these requirements. They use only physical phenomena like gravity, temperature, and pressure to provide both thermodynamic and humidification needs.

Retrofitting for Cold Weather

In buildings in cold regions, good ventilation is important to keep moisture from building up, mould from growing, and the air quality and thermal comfort inside the building at an acceptable level. However, retrofit designs for cold climates generally emphasise on reducing air leaks and adding thermal insulation, which might make ventilation less effective. Traditional methods of ventilating roofs may not be enough to mitigate against these concerns in thick insulated systems [11].

Buildings in cold climates should have a way to ventilate that also insulates, so that moisture doesn't build up between the roof and wall components. When retrofitting buildings in cold areas, especially ones that don't work well, it's important to think about adding balance ventilation systems that bring in regulated, prepared fresh air through the building envelope together with separate exhaust systems. The idea of a passive ventilated system, on the other hand, stresses the need to improve the performance of the ventilated envelope by focussing on cavity space and the flexibility of architectural design.

Reducing Heat in Cities

Indoor spaces in cities with high ambient temperatures can be uncomfortable and bad for your health. Even with good ventilation rates, heatwaves can still cause overheating. In Jakarta, Indonesia, a green roof and wall were put on top of and around a building. This made the temperature inside the building better throughout the day. The building's green surface features, like evaporative cooling and shading, helped keep the temperature inside at a comfortable level. The temperature inside the building only went up by a maximum of 2.5 °C, and the people inside felt comfortable without any extra cooling systems for about 36 hours [24]. A modelling research on the installation of a green roof on a two-storey structure in Jakarta, Indonesia, demonstrated that the internal temperature may consistently remain significantly lower than the exterior temperature throughout the day. The current setup, which includes a green roof and wall, kept the temperature inside 3 °C lower than the temperature outside, and this was done without air conditioning [2].

How Well the Shoreline Can Handle Storms

Great Bay sits on the west side of the University of New Hampshire campus. The high ground rises by 1.6 m. Limiting the foundation that holds up the exterior walls makes the 200 x 1200 mm and 300 x 300 mm cross-braced pipe frames less and farther apart. It was possible to simulate the whole frame as hinged with the 3D braced wall framing using a computer program to look at the most stress and deflection it could handle in harsh situations, while still letting in fresh air.

The United Nations University's campus in Tokyo has come up with imaginative ways to deal with the heat and the requirement for natural ventilation, such as thermal surfacing, shading, and a ground-coupled

ventilation system. Computational fluid dynamics has been used to look at how well these measures and a closed energy-loop system that uses waste heat from the hot-water supply for cooling work.

The University of Sousse in Tunisia has taken a very different approach to natural ventilation, yet it nonetheless provides the same level of comfort in the summer. Before wind tunnel tests were done, meticulous study of the prevailing winds, solar heating, and sky conditions was done to come up with the initial stage of a building that would get the most ventilation. Along with orientation, the best solution required a precise arrangement of the ventilation structure to make sure that air flowed properly into the atrium and that it was easy to interact with nearby units. [2]; [25]

CONCLUSION

When designing ventilation to handle extreme weather, you need to pay special attention to strong concepts and solutions. Learning about projects and technical solutions that can make systems more resilient will help you make systems that can handle a wide range of events. The resilience strategies spoken about in this study are very flexible and cheap, even in the most difficult conditions.

Many projects deal with normal changes in the weather, but hurricanes, heat waves, and polar storms can make it impossible to work or live in the area. Over time, responding to and reducing the effects of climate change may make resilience less important, but right now, extreme occurrences are already affecting important systems in many areas. A resilient ventilation strategy should be based on how to get over natural barriers. Sharing learning from other design domains can improve systems, from the initial idea to the final execution, as long as you keep theory in mind. New work, retrofits, and different environments all provide different challenges.

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