A Foundation for Sustainable Design

Crystalline-Waterproofed Concrete Tunnels Deliver Low-energy Space Cooling

By Les Faure and Steven H. Miller, CDT

Mountain Equipment Cooperative (MEC) is a company that has thought a great deal about sustainability, and their commitment to greening all their operations and buildings has been made concrete in each new store they build or acquire. Their Marche Central store in Montreal, Quebec was built as a model of sustainable design and construction from the ground up, literally: it incorporates a natural ventilation system based on huge underground concrete ducts.

Image courtesy of Consortium MTF

The MEC store in Montreal is a model of sustainable design, the first retail space in Quebec to be built under the C2000 program for Advanced Commercial Buildings.

To keep air quality in the ducts safe from microbial contamination, it was necessary to waterproof the concrete, and they chose an equally green strategy: crystalline waterproofing technology. This integral waterproofing method works without the application of a membrane or other external barrier. Instead, it prevents liquid penetration by improving the structure of the concrete to make it less porous. It is an especially green waterproofing method because it has no VOCs or other negative impact in air quality in the ventilation system, it eliminates consumption of additional materials (the membrane system), and it has no impact on the quality of groundwater in the adjacent area. Moreover,

unlike membrane systems, it does not deteriorate over time; it improves, eliminating the need for replacement for the life of the concrete.

The Great Indoors

MEC is the leading supplier of outdoors sports and adventure equipment in Canada. It is a cooperative, and its members are, almost by definition, people who value the natural environment. MEC has made sustainability a goal in virtually every aspect of its operations.

Image courtesy of Consortium MTF

The MEC store in Montreal is a long, narrow building with a high central vault. The space is ventilated in hot weather by air drawn up from underground concrete tunnels. Waterproofing the tunnels was mandatory to maintain healthy air quality.

The Montreal store, which opened in 2003, was the first retail building in Quebec built under the C2000 Program for Advanced Commercial Buildings, a demonstration program for high-performance office buildings developed and sponsored by the CANMET Energy Technology Centre (CETC), Natural Resources Canada. The emphases of this program are on energy and environmental performance.

The MEC store achieves major energy efficiencies in the area of temperature control with an innovative natural ventilation, cooling and heating system. The building won numerous awards including, significantly, the ASHRAE (American Society of Heating, Refrigerating and Air-Conditioning Engineers) Technology Award for Commercial Building Engineering Excellence. The building's architectural team was Consortium MTF (Studio MMA, Lyse M. Tremblay, architecte, and Duschenes & Fish/DFS architects). The structural engineer was the firm of Saia, Deslauriers, Kadanoff, Leconte, Brisebois, Blais. Mechanical engineer was the firm of Pageau Morel et Assoc. Inc., which also performed energy analysis of the design.

The HVAC system is based on two major elements: a series of below-grade concrete tunnels that run around the perimeter of the building, and a system of geothermal wells linked by heat pumps to a radiant concrete floor. Heat is pumped out of the ground and into the radiant floor in winter. In summer, the floor is used to pump heat out of the store and into the earth.

The tunnels are the heart of the ventilation function, circulating air (both heated and cooled) using a combination of mechanical and natural ventilation methods. In the hotter months, hot air collects in the high central vault of the store's main space. When louvers in the tower section of the vault are opened, hot air naturally rises up out of the building. The shape and orientation of the roof are designed to take advantage of the local prevailing winds and enhance the effect. Displacement draws air up from the tunnels.

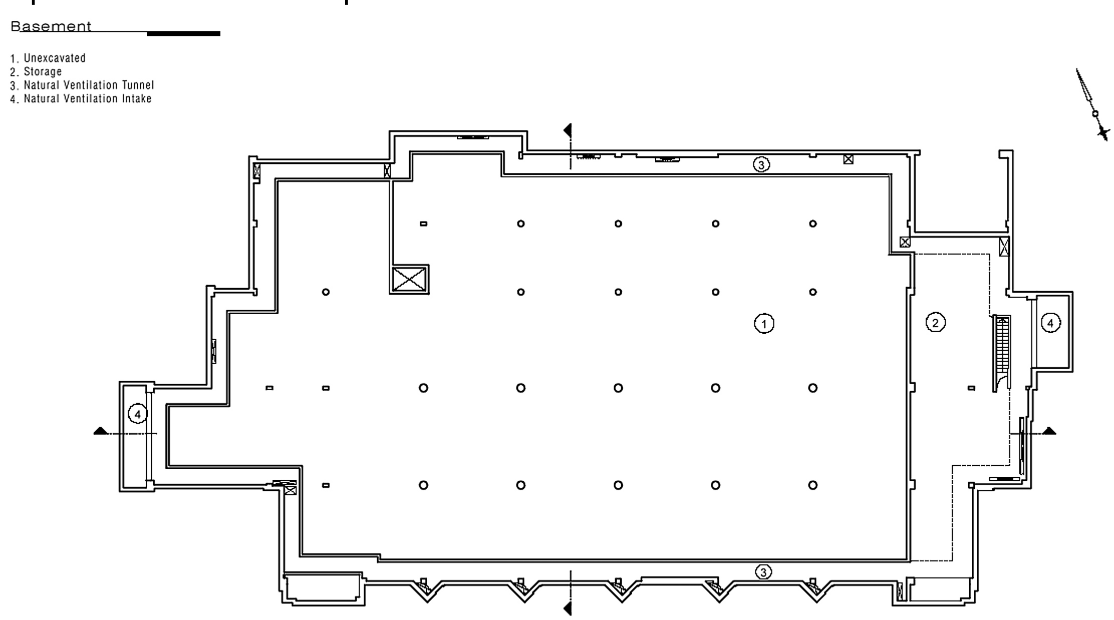

Image courtesy of Consortium MTF

Plan view of the basement level of MEC Montreal. Tunnels encircled the building below grade, using the building foundation as the exterior tunnel wall. Air intakes, labeled 4 in the drawing, are located at either end of the building.

The system's air intakes are on the narrow ends of the building, and feed into the tunnels. Radiant coils located at the intakes are connected to the heat pump system. In summer, the coils cool incoming air, and dehumidify it to prevent condensation in the system. This cooled air is drawn up by displacement through vertical shafts built into the masonry of the structure, and distributed throughout the interior of the space.

In winter, fresh air intake is reduced to a minimum acceptable level, to minimize heat loss. Air from the store space is returned to the tunnels, where it is mixed with fresh air and mechanically re-circulated to the store.

The exterior side of the tunnels is the building foundation-wall. The tunnels are approximately 1.3m x 1.3m (4 ft x 4 ft) in cross-section (inside dimension). The interior section of the basement level is largely unexcavated, so the tunnels are surrounded by earth on three surfaces.

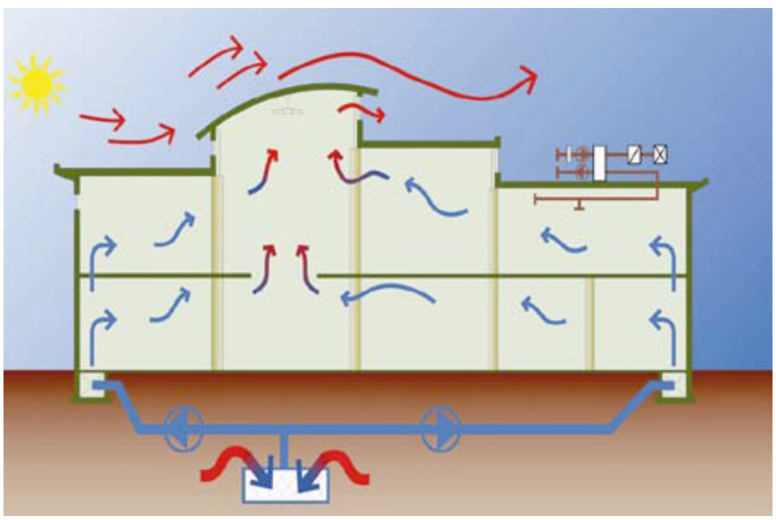

Illustration courtesy of Consortium MTF

Hot air collects in the upper area of the vault. When allowed to rise out of the upper louvers, displacement draws cooled air up from the underground tunnels, and distributes it through ventilation shafts built into the masonry of the upper structure.

Why Waterproof?

The designers wanted to be extremely careful about maintaining air quality in this system. Waterproofing of the underground tunnels was considered a must, both to keep them accessible for maintenance, and to avoid the growth of bacteria and fungi that almost inevitably blossom in dampness or standing water. Moreover, waterproofing a foundation has its own value, since it protects reinforcing steel from the corrosive effects of ground water and aggressive chemicals from the soils or surface (*e.g.* chlorides) that may be dissolved in it.

Keeping water out of habitable spaces has been a consistent human endeavor since we first moved into caves. It is one of the most basic functions of a building. Waterproofing the portions of a building that are above grade can be accomplished by a number of means, since the exterior of the envelope is readily accessible and a wide variety of waterproof barriers or architectural finish materials are available.

Waterproofing below grade is a thornier problem. If the ground is wet, it applies constant water-pressure. The material used for virtually all foundations in modern construction – concrete – is porous and permeable to water. This porosity is created when the concrete first sets: excess water in the concrete mix occupies space in the matrix of cement-paste. As it evaporates out of the concrete, it leaves behind a contiguous network of pores, perfect channels for water to find its way back into the concrete.

When liquid water under constant pressure is applied to the surface of concrete – such as a foundation wall – water can get through the concrete in a matter of a few days, sometimes even a few hours.

Moreover, real-world concrete is rarely an ideal monolith. It is subject to drying shrinkage cracking, some of which is only of micro-crack magnitude, but invisibly narrow cracks do allow water to leak through. Earth or building movement can also cause cracking at any time.

One of the most common methods of waterproofing below grade is an applied membrane system. However, membrane systems are vulnerable to failure. If applied to the interior surface of a building foundation wall (the "dry side"), it is prone to delaminating as water permeates the thickness of the concrete to encounter the barrier. A membrane applied to the foundation surface in direct contact with the source of water (the "wet side") is preferable, but can still be vulnerable. The quality of the membrane, and therefore its performance, is dependent on field conditions and the skill of the applicator. Unless applied perfectly, the membrane will have defects that can allow water to penetrate and spread into the concrete immediately surrounding the defect, where it will begin to undermine adhesion of membrane to concrete. This is the beginning of membrane failure.

An alternative to membrane systems is integral waterproofing of the concrete. Crystalline technology is so-named because it is a chemical system for growing non-soluble mineral crystals in the pore network of the concrete matrix, which plug the pores and prevent liquid water from passing through them. (See sidebar, Crystalline Waterproofing Explained)

The designers of the MEC project rejected a bituminous membrane waterproofing system on sustainability grounds, because of VOC emissions. Crystalline waterproofing, which contains no VOCs, was selected instead. The designers also noted that crystalline waterproofing is used in water reservoirs,

demonstrating that it would be free of any other emissions that might cause contamination. In addition, the long-term durability of the crystalline system was important in their selection.

Crystalline Waterproofing Methods

There are several ways to apply crystalline waterproofing. The MEC store actually used most of them.

For New Concrete

Admixture in new concrete batching is a very clean and efficient way to introduce crystalline waterproofing to concrete. The process ensures thorough dispersal of the chemistry throughout the concrete without altering the material's appearance. Crystalline admixtures require no effort, expertise, or labor on the part of the contractor. Waterproofing and concrete cure simultaneously, and there is no coating or residue to remove afterward.

Dosage for the admixture is generally in the range of one-to-three percent of cement content by weight. Aside from adding the admixture, all other operations are the same as with normal concrete. Normal best practices for proper curing must be observed.

Concrete dosed with crystalline waterproofing admixture may achieve higher compressive strength than similar 'standard' mixes. One documented product test showed increases in excess of five percent at 28 days, varying with the dosage of waterproofing.

Dry-shake crystalline waterproofing products are used on freshly-placed horizontal concrete surfaces during finishing. The product can include a floor hardener in addition to waterproofing, making it a good choice for surfaces that require improved resistance to impact and abrasion. It should not be confused with other dry-shake hardeners – not designed for waterproofing – that often are used to apply color in addition to surface hardening. Dry-Shake, Crystalline waterproofing does not change the appearance of the slab.

After the concrete reaches initial set, waterproofing powder is broadcast onto the wet surface, then troweled in. Care must be taken to evenly spread and work the powder for proper distribution. This method may reduce material costs for waterproofing as compared to admixture, but it adds some labor to shake on the waterproofing.

The MEC store used dry-shake waterproofing on the horizontal surfaces of the tunnels. The admixture product was not used on the MEC store.

Image courtesy of Consortium MTF

The tunnels were constructed on the inside of the foundation-wall. Waterproofing not only protects air quality in the building, but also protects the foundation concrete and its steel reinforcement from damage by water or aggressive chemicals.

For Existing Concrete

Surface-applied crystalline waterproofing coatings are the only choice for existing (*i.e.* cured) concrete. The waterproofing's 'active ingredients' come premixed with portland cement and fine sand. The applicator mixes in water to make a cementitious slurry that is either brushed or sprayed onto the concrete. It forms a thin 1.5-mm (1/16-in.) coating that adheres to both vertical and horizontal concrete, keeping the chemicals in contact with the surface. The slurry coating acts as a concentrated source of waterproofing chemicals that penetrate the pore network by diffusing through water.

Surface-applied coatings can also be used on new concrete. It is preferable to apply it as soon as the forms are stripped. If the surface is dry, it must be re-wet before application.

Crystalline waterproofing coating can be applied to either the wet or dry side (positive or negative) of concrete. When applied on the wet side, chemicals will immediately begin diffusion, since the concrete is already saturated for the application. As the concrete dries, diffusion will slow and eventually stop. When applied to the dry side, the same initial diffusion takes place. However, as water from the wet side works its way through the concrete, it will re-start diffusion, extending the protection through more and more concrete thickness wherever there is water present.

When applying crystalline waterproofing coating, concrete surfaces must be clean and free of laitance, dirt, film, paint, coating, or other foreign matter before treatment. Surfaces must also have an open capillary system to provide 'tooth

and suction' for the coating to adhere and gain access to the pore network. If the surface is too smooth (*e.g.* where steel forms are used, or it is hard-troweled during finishing) or covered with excess form oil or other foreign matter, the concrete should be lightly sandblasted, waterblasted, or etched with muriatic acid before application – a concrete surface profile (CSP) of 3 is recommended. As well, the concrete surface should be saturated with water (or as close as practical), with the excess removed.

For diffusion to take place, the concrete must be kept moist for two days after application. Manufacturers offer specific instructions on curing time and methods for their products. Care must be taken not to over-wet the coating and cause leaching of chemicals away from the concrete in runoff.

A Crystalline Waterproofing coating can be left in place permanently within certain practical and aesthetic limits. On floors, it will usually handle normal foot traffic and even light vehicles, although it will wear away over time, causing light dusting. For heavy traffic conditions, the coating should be removed after sufficient time for diffusion has elapsed (21 days). Likewise, in any location where a cement-gray appearance is undesirable, it should be removed. High-pressure wash, light sandblasting, shotblasting, or diamond-grinding are all removal options.

If a cementitious system (*e.g.* topping, finish coat, mortar for tiling, grout, or cement parge coat) is to be applied over the waterproofing coating, it is important to do it before the crystals completely plug the pores—this is usually within 8-48 hrs. A bonding agent is also recommended.

When paint or epoxy will be applied over the waterproofing coating, the coating should be allowed to cure for 21 days. Then it should be washed with a three-to-five percent solution of muriatic acid, flushed of all acid, and allowed to dry before applying paint or other finish.

Crystalline waterproofing coating can sometimes be effective with very porous concrete materials such as concrete masonry units (CMUs). As these blocks' porosities widely vary, tests should be conducted before committing to this method.

Image courtesy of Xypex Corp.

This standard CMU was coated with crystalline waterproofing surface coating slurry. Untreated CMU's are totally porous, but this block holds water perfectly.

In the MEC store, surface coating was applied on the exterior of the ventilation tunnel walls (wet side).

Dry-pack application is used for sealing construction joints and repairing defects or damage. As noted above, concrete structures are rarely perfect and monolithic. There are usually construction joints and control joints as well as unplanned cracks. Waterproofing systems must take into account the joints, tie holes, cracks and other defects.

For faulty construction joints and visible cracks, experts recommend a combination of the coating slurry and a stiffer patching mixture—a 'dry-pack'—made using the same material, but mixed with a much smaller percentage of water.

The crack or joint is routed out to make a U-shaped slot. The concrete is thoroughly wetted, and the areas inside and surrounding the routed crack are then coated with waterproofing slurry to achieve maximum chemical diffusion around the repair. The crack is filled with dry-pack, which bonds to both sides and supplies more waterproofing chemicals to diffuse in all directions.

Large repairs of faulty concrete, exposed rock, or 'honeycombs' can be waterproofed during repair. Repair mortars which include crystalline waterproofing are suitable for these repairs. Control joints must be left open and allowed to move, making crystalline technology inapplicable. Flexible sealants are made specifically for control joints.

Dry pack/slurry coat combination was used to seal construction joints and defects on the MEC store tunnels. Dry pack was applied as detailed above, then compacted using mechanical pressure (pneumatic packer or hammer and block).

Naturally Cool

MEC's efforts to achieve energy efficiency were well-rewarded. Theoretical energy savings were calculated using several different evaluation tools including C2000, GBTool, and LEED. The building was designed to use 69.2% less energy than a typical large-scale retail outlet. The modeling is able to break out savings from each different system in the building. It predicted an 80% energy reduction for space cooling, and an 83% reduction for space heating as compared to the Model National Energy Code reference building, the national standard for sustainability certification.

Energy usage was tracked and analyzed during the first year of operation. Energy consumption was slightly higher than projections due to longer-than-predicted store operating hours, but taking that into considration, actual usage

tracked well with the predictions. It indicates that the strategies overall were quite successful and the energy reduction analysis essentially correct.

The tunnels have performed well with no maintenance issues, dry and mold free.

Conclusion

The MEC store represents a confluence of environmental responsibility and good business sense. Green strategies were chosen that were also cost-effective. The use of crystalline waterproofing as a green alternative enabled them to install a permanent solution that has no negative impacts on surrounding air or water. The contribution of waterproofing in keeping the HVAC system clean points out the importance of eliminating water intrusion and dampness in basements, foundations, other interior environments. Crystalline waterproofing offers a simple, effective and durable way to avoid growth of mold and bacteria in these areas, and protect air quality and health.

Authors
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Sidebar: Crystalline waterproofing explained

Crystalline waterproofing technology is the process of delivering chemicals into the capillary tracts of the concrete and plugging the pores with a non-soluble crystalline formation. Different means exist to get the chemicals there (*i.e.* mixed into fresh concrete or diffused into cured concrete), but the way they achieve waterproofing is the same.

The concrete must be wet for the chemicals to move through cured concrete and for the chemical reaction to occur. In a surface application (*i.e.* dry shake or coating), the high concentration of chemicals at the surface naturally seeks to spread out or ‘diffuse’ into the saturated substrate. As long as the concrete remains wet, there is a conduit for the chemicals to travel. Under the proper conditions, a crystalline waterproofing application can spread up 305 mm (12 in.) into the slab or wall interior.

Image courtesy of Xypex Corp.

This Scanning Electron Microscope (SEM) photograph shows the mineral crystals plugging up the pores of concrete. By filling the pore cavity it prevents liquid water from entering. However, water vapor is still able to move through and evaporate out of the concrete.

The exact chemical formulations of crystalline waterproofing products are closely guarded trade secrets of the various manufacturers. However, in all cases, these materials must react with calcium hydroxide—a substance commonly called 'lime,' but more properly referred to as 'hydrated lime.'

Calcium hydroxide is a product of cement hydration; it resides in the concrete matrix but has no structural value. Its use is a common theme among many concrete additives and treatments including pozzolans and densifiers. Additives that utilize lime have an added benefit in that they reduce the potential for the efflorescence sometimes visible on the concrete surface.

Crystalline waterproofing chemistry reacts with lime to form small, needle-like mineral crystals that are insoluble in water. Crystal formation begins very soon after the chemicals come in contact with water and lime, but the crystals form gradually, much slower than the time it takes fresh concrete to set. It can be two to three weeks before the crystals to reach maturity.

The crystals grow across the diameter of the pore as 'stalactites,' forming a microscopic, mesh-like barrier. Clear passage through the pore is greatly reduced—liquid water cannot get through it because of properties such as surface tension. Even extreme hydrostatic pressure cannot force liquid water through the blocked pore network. Independent laboratory testing in accordance with U.S. Army Corps of Engineers (ACE) CRD C-48-92, *Permeability of Concrete*, showed crystalline-treated concrete withstood up to 123 m (405 ft) of head pressure—1.2 MPa (175 psi), which was the limit of the testing apparatus.

In the form of vapor, water molecules are small enough to pass through the crystal formation, so moisture can migrate out on the downstream side, allowing the concrete to dry. This means vapor transmission is also reduced and carbonation is slowed down.

While crystal formation largely matures in two to three weeks, the process can continue as long as there is water in the concrete. Cessation usually occurs as the crystalline formation fills the pore cavities and concrete dries up—the reaction effectively never runs out of lime. This means if water re-enters the slab years later, it reactivates the waterproofing chemicals and new crystallization will begin. In essence, it is an automatic waterproofing response.

Drying shrinkage cracking may be present in concrete, at least at the micro-level. These micro-cracks potentially create passageways for moisture infiltration. If cracking occurs while crystals are still forming, micro-cracks up to 0.4 mm (16 mil) can be bridged. If micro-cracks occur later and allow water infiltration, the water reactivates the waterproofing chemicals, making the concrete self-healing on the micro scale.

In the case of a surface application to the dry side an existing foundation that is continuously wet on the exterior side, the water could theoretically diffuse the chemicals all the way through the wall or floor.