AEC: Have Your Cake and Eat It Too.
Superior Pool Moisture Control at Lower First Costs

Rebound Technologies
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SUMMARY: NEW TECHNOLOGY UNLOCKS PERFORMANCE AND SAVINGS

AEC™ is a new breakthrough ice banking product set to disrupt cooling across the industrial and commercial sectors. AEC uses a self-healing active surface chemistry to achieve a 5X improvement in cost, a 10X improvement in productivity, and a 2X improvement in efficiency. **This step-change improvement in cost and performance unlocks thermal energy storage systems that will change pool moisture control forever.**

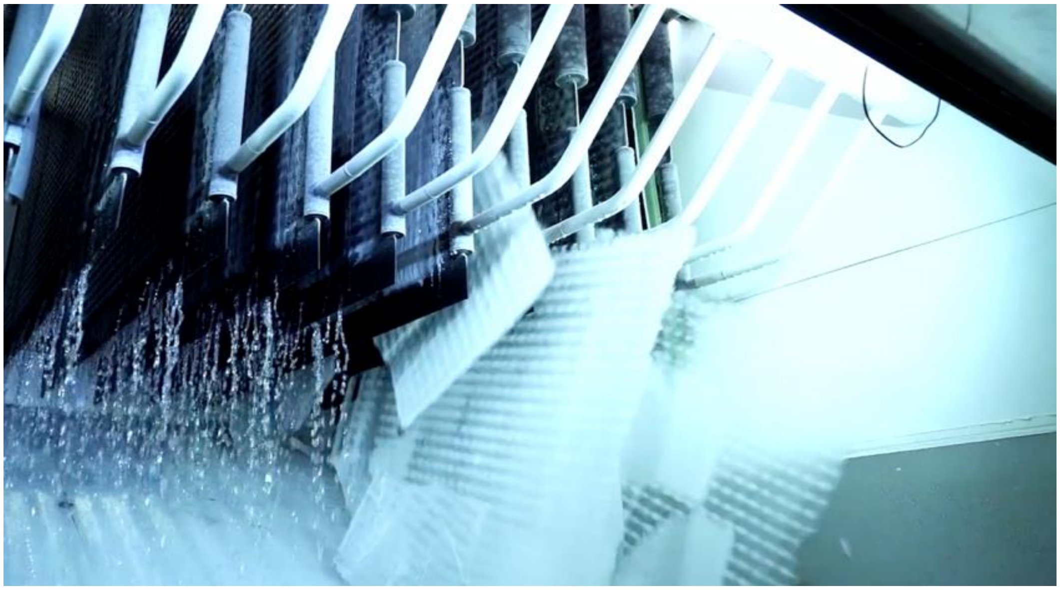

Figure 1: AEC during its harvest phase. The ice maker is significantly more productive than the current state of the art.

Pools, on the other hand, present an age-old cooling conundrum that has yet to be solved in a robust and cost-effective way. Take the constraints of the environment:

1. Poorly managed chloramines, corrosive chemicals produced during the use of pools, and humidity cause dangerous structural damage to pool facilities.[1]
2. High ventilation loads lead to large energy bills and expensive heat reclaim equipment.
3. Corrosive air streams lead to short-lived equipment and reliability problems.
4. Moisture removal produces a cooling year-round load, even though the pool requires space heating most of the year.
5. Peak cooling and moisture removal loads are significant but short-lived and set by intermittent activities such as swim meets and swim practice.
6. Higher cost Fresh-air-first approaches offer a path to better performance at improved efficiencies, but require significant mechanical cooling for short periods when ambient temperatures rise.

The cost constraints set by high peak loads, extreme moisture levels, and tight safety-related setpoints make the aquatics market especially hard for conventional refrigeration systems, whose inflexible architecture leads to expensive, oversized, and poorly utilized installations.

[1] Pool corrosion accidents

Rebound's AEC product, on the other hand, addresses these constraints with a new approach. Its internal thermal energy storage and low chilled water temperatures allow for higher efficiency, moisture control, superior Thermal Agility[2] in the face of peak load events, and lower project costs.

AEC represents a clean sheet approach to the challenges of pool cooling with its Agile approach to managing peak loads and peak moisture. It aims to deliver the highest performance on the market at the lowest cost.

HOW THERMAL AGILITY UNLOCKS LOWER COSTS

Pools require very different cooling loads at different times of the day. Figure 2 shows a typical cooling load for a small rec center pool. Since the cooling load is predominantly a latent load[3], it is driven by the amount of water moisture escaping from the pool. If the pool has a nighttime pool cover or cooler nighttime air ventilates the space, the mechanical moisture load from the pool is essentially zero. Likewise, if many children are taking a swimming lesson at the same time and splashing a lot, the moisture load will increase dramatically.

Figure 2 shows two high-activity periods: one in the morning when the pool is opening and the setpoints are changing at the same time as morning swimmers are doing lap swimming, and one in the afternoon and evening as swim lessons and after-work lap swimmers are in the pool.

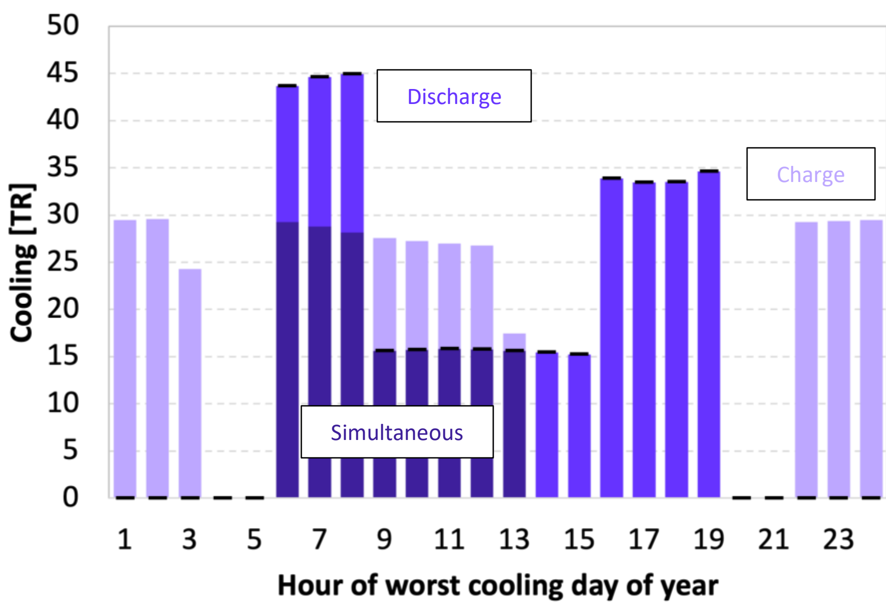

Figure 2: Typical cooling load for a small rec-center pool area over a 24-hour period during summer. This volatile load is met by AEC through charge: the banking of potential cooling for the future, discharge: the draining of stored potential cooling, and simultaneous: the creation and immediate melting of ice.

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[2] Thermal agility white paper

[3] Latent means the removal of water moisture from the air in the form of condensed water.

This creates a challenge for traditional equipment, which must provide cooling instantaneously to meet the entire load. In the above example, the peak cooling required to meet the demand of the pool area is 45TR, but the average demand is only 15TR. This means that in order to serve the load, a traditional system would need to be 3X bigger than the average load for the facility and then would run at 30% of its capacity, on average, over the course of the day.

Thermally Agile systems like AEC address this issue using energy storage. In the above example, the AEC unit is a 25TR system, not a 45TR system, and runs at a 75% capacity on average, over the course of the day[4]. This means that AEC's compressor, condenser, connected load, fans, and other high-cost equipment are nearly 50% smaller than the incumbent system. This directly leads to a lower cost unit, even though the AEC is able to deliver higher overall performance.

Agile cooling reduces the required refrigerant circuit size from 45TR to 25TR, leading to significant cost savings.

ADDRESSING SENSIBLE HEAT RATIO AND WASTED COOLING

In environments like pools with a high latent load and much of the year under heating conditions, one cooling metric stands above all others: the sensible heat ratio[5] (SHR). The SHR, which tells you how much of your cooling is going toward removing moisture and how much is being used to just reduce the air temperature, should be minimized in pools. This is because a low SHR shows that more of the cooling being performed by a system is being used to remove moisture from the air.

In the case of AEC, a SHR below 0.2 is possible because of the unit's cold working temperature of 32°F. At this lower temperature, the thermodynamics of moist air and the cost scaling of agile systems discussed above allow for air handling units with better (lower) SHR to be installed at a lower cost. Incumbent systems operate at a much higher instantaneous working temperature of 50°F and are not able to take advantage of these superior thermodynamics. As such, incumbents operate at a SHR of 0.6, and while incumbent systems with lower SHRs do exist on the market, they are rarely, if ever, installed due to their high CAPEX and long payback.

[4] Including a 6hr demand response period at the end of the day which reduces the customer's energy bill by more than 40%.

[5] Sensible heat ratio is the amount of cooling, as a percentage, that goes to reducing temperature. Learn more here: https://www.hvacrschool.com/sensible-heat-ratio-shr/

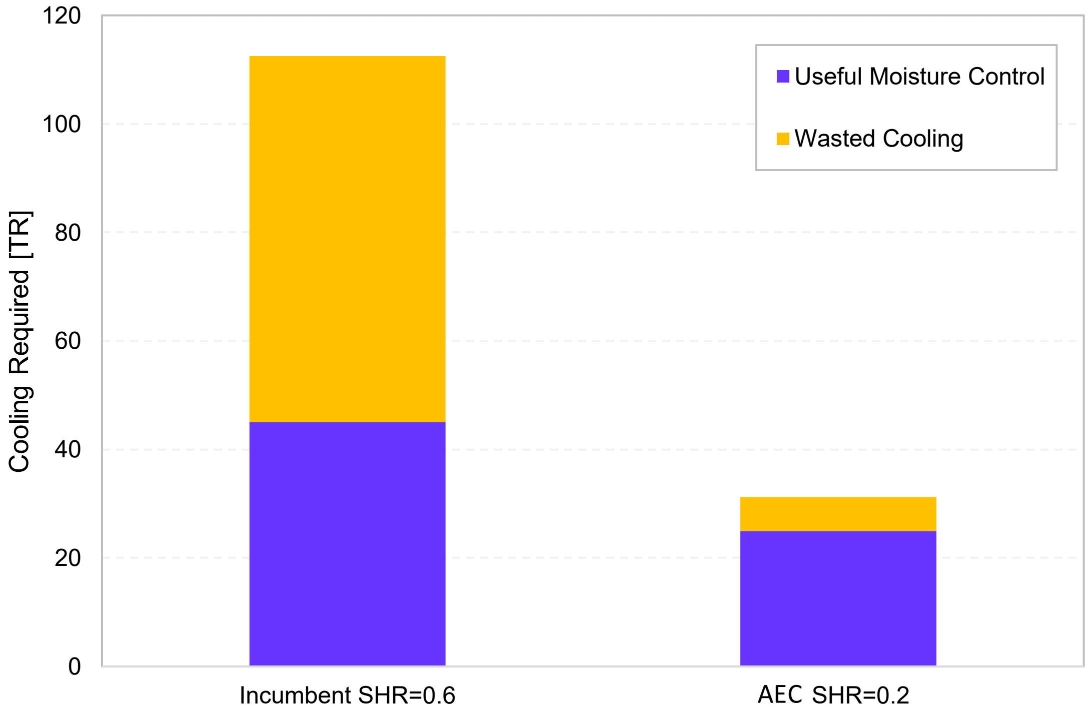


Figure 3: The effect of SHR on the example from the above small rec-center pool case. The required system sizes are carried forward, including the impact of agile cooling. The system sizes are then expanded based on the system's sensible heat ratio.

Figure 3 shows the striking impact of this superior cost scaling and thermodynamic operation. To fulfill the same duty, the incumbent, with a SHR of 0.6, must provide 110TR of refrigeration at 50°F where the AEC unit only needs to supply 30TR at 32°F. Reaching this lower working fluid temperature requires a higher lift and a 1.6x larger compressor, but all other aspects of the system are reduced. Overall, even with compressor size taken into account, a low SHR Agile system like AEC can offer a significant reduction in equipment scale and cost.

MOST EFFICIENT, MOST SUSTAINABLE, MOST AFFORDABLE.

Thermal Agility and SHR both have a significant impact on equipment cost, but not at the expense of efficiency. Quite the opposite, both increase energy savings and sustainability.

The sustainability impacts of AEC are multifaceted and cover a wide range of benefits. Facilities can stack these benefits based on their location, utility structure, and operations. They are:

- A superior SHR means more useful cooling, and compressor power is not wasted cooling then reheating air.
- Built-in hot water reclaim from compressor heat means pools are heated by waste heat, reducing natural gas consumption.

- Energy storage means ice can be made when energy is cheapest at night or during high solar panel output hours.
- Agile cooling reduces connected load, decreasing grid strain and allowing AEC to qualify for more utility incentives.
- The ability to shut off ice making without sacrificing performance means facilities can participate in local demand response programs and generate additional revenue.

Table 1 gives a summary of the anticipated results for Rebound's AEC installation.

Table 1: Summary of model-based results of AEC's first YMCA installation in Colorado Springs.

Briargate YMCA	
Electricity cost reduction	35%
Gas cost savings	>$2000
Demand response asset size	30kW
Connected load reduction	20%
Payback	0yr (lowest cost)

SUMMARY

AEC is poised to disrupt the aquatics market with a lower first cost, higher performance, and more sustainable value proposition. AEC represents a fundamental shift in approach to tackling the challenging pool environment and does not suffer from the age-old issues that existing incumbent and derivative technologies face. With thermal agility, low sensible heat ratio, and higher sustainability impacts, AEC will usher in a new era of comfortable, affordable, and safe pool spaces for all.

APPENDIX

AEC PRODUCT BACKGROUND: ICE MAKER PHYSICS

All ice makers, regardless of design, function under a fundamental constraint: as ice grows on any surface it inherently inhibits heat transfer through that surface. This constraint drives the cost, efficiency, and reliability of all modern ice makers. Despite a great need for energy storage and the significant advantages ice storage enjoys, these tradeoffs have not yet been effectively optimized. This is evident in the universal failure or commercial stagnation in the market development of ice-based energy storage efforts[6,7,8,9.]

AEC PRODUCT BACKGROUND: REBOUND'S APPROACH

Rebound has developed a novel approach to ice making that charts a new course through these constraints to realize a machine capable of producing higher quality ice at 5X lower costs than traditional approaches. Importantly, this ice maker uses 100% off-the-shelf process equipment and can be produced at scale without massive investment in new product development or new manufacturing processes.

Fundamentally, AEC is a plate ice maker that goes through a typical growth harvest cycle: ice grows on the cold plate, then is harvested when it reaches a desired thickness. However, unlike a traditional plate ice maker, AEC harvests using subcooling instead of heating, which leads it to harvest significantly faster without any losses even when ice is grown in thin sheets. This is accomplished by pairing a chemically matched plate coating and an oil dopant in the water that creates an ideal surface chemistry for ice making. Figure 5 shows the basic process.

By controlling surface chemistry with a thin liquid film (1um thickness) over a solid coating, a robust self-healing layer is created that dramatically improves the overall ice maker performance. This configuration leads to several key benefits of AEC over the state of the art:

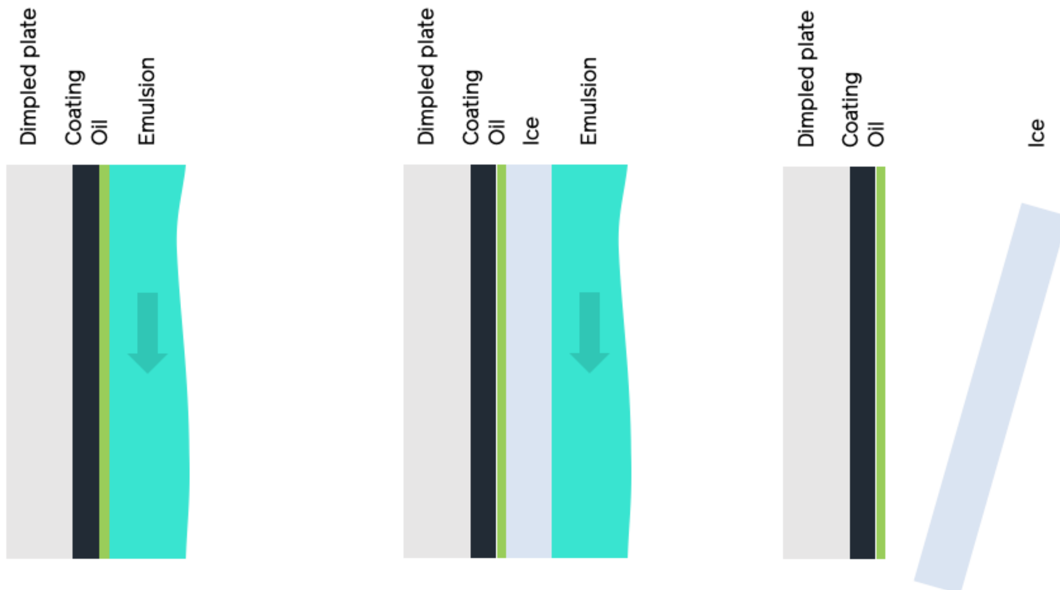
1. Thinner ice can be grown and harvested without loss.
2. Subcooled 100% solid ice is produced.
3. Harvest is rapid, leading to a 90% reduction in wasted time.
4. Plate temperatures are (relatively) high, leading to higher efficiency.
5. No mechanical harvesting techniques are required; the only moving part that is used is a mag-drive water pump.
6. Off-the-shelf dimpled plates mean the ice maker is infinitely scalable today.

[6] Ice energy files for bankruptcy: https://bit.ly/47XjfAV

[7] BAC has moved away from their ice storage product: https://bit.ly/3v1UxAY

[8] CALMAC sells to Trane after 70 years of tepid growth: https://bit.ly/3TtWDUm

[9] Axiom Exergy Fails to commercialize ice storage: https://bit.ly/3Ntkf7W



Step 1: Coating

An oil-water emulsion flows over a coated dimpled plate. The oleophilic coating draws oil out of the emulsion to form a self-healing submicron oil layer on the plate.

Step 2: Growth

Ice begins to grow on the plate trapping the oil between the ice and plate. Pure ice, free of oil, continues to form out of the emulsion.

Step 3: Harvest

The flow of emulsion is curtailed while refrigerant continues to cool the dimpled plate. The temperature drops, subcooling the ice and creating a thermal expansion driven strain between the ice and plate causing the ice to fall off.

Figure 4: the growth-harvest cycle of Rebound's ice maker

The system is ideal for large energy storage applications because it is highly scalable. Like traditional plate ice makers that sit over a large water/ice tank, the plates can be arranged above an emulsion tank where the movement of the water by a centrifugal pump creates the emulsion required for the plates. In this configuration, a single tank of water can be slowly converted to ice to store cooling for HVAC applications, turbine inlet cooling, or other industrial processes that require intermittent high levels of cooling. This system has one moving part, a mag-drive centrifugal water pump.

Rebound has built multiple full-scale units, generated millions of pounds of ice, and stored that ice for days at a time. This body of work has demonstrated several key performance and reliability features of this technology for use in thermal storage markets:

1. 100% dry subcooled ice production at -5°C and -10°C refrigerant temperature
2. Self-healing active coating with infinite life
3. Greater than 12 hours of continuous operation without defrost or plate heating of any kind
4. Rapid ice harvesting of <1min without ice loss
5. Ice storage in a simple fiberglass tank without re-solidification or "iceberging" for 1-5 days

6. Powder coating robustness through thermal cycles, incidental mechanical contact, and >10k ice harvests.

Table 1 shows the significant improvement AEC represents over the state of the art. Of note, all these systems use nearly identical off-the-shelf components and manufacturing techniques. The only additional step required to manufacture an AEC is the powder coating of the plates prior to the system assembly. This step is accomplished by a mature coating process performed by many coaters across North America and adds <5% to the cost of the ice maker.

Table 2: Comparison of Rebound's ice maker with a traditional thermally harvested plate and ice-on-coil ice maker

	Typical Ice-On-Coil System	Typical Plate Ice Maker	AEC
Harvest method	direct flow	hot gas	subcooling
Ice Lost in harvest	0%	10-20%	0%
Growth time [min]	multi-hour	>15	6
Harvest time [min]	multi-hour	5	1
Ice Thickness [in]	>6in	>1/2"	<1/4"
Suction temp [°C/°F]	-30°C (-22°F)	-18°C (0°F)	-7°C (20°F)
Overall heat transfer [kW/m^2-K]	0.04	0.2	0.5
Levelized Capex [$/(lb/day)]	$50	$20	$5