Novel Air Treatment Technology for Reducing HVAC Energy Use

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Overview

Modern buildings rely upon central heating, ventilating and air conditioning (HVAC) systems for maintaining the comfort, wellbeing and productivity of their occupants and it’s not just in the developed world. HVAC increasingly is being embraced by most emerging economies for the attendant productivity and lifestyle benefits.

The consequence of this convenience is that in much of the world, cooling systems are the largest single contributor to the energy budget of buildings and one of the largest loads on the entire electrical grid, especially during times of peak heat and humidity. Heating buildings in cold weather demands very large amounts of energy as well. Reducing the power consumption of HVAC is therefore an important goal in the overall energy efficiency strategy of any economy.

A new, commercially available technology can significantly reduce the energy consumption of HVAC in commercial and public buildings by diminishing the volume of outside air that needs to be brought in, and then heated or cooled. The technology is implemented via a device called an HLR™ Module, explained below, which brings together chemical engineering, mechanical innovation and software technology. The development of the HLR module was spearheaded and orchestrated by our company, enVerid Systems, working together with some very well-known players in the HVAC, chemical and air quality industries, as well as the U.S. Department of Energy and a number of universities.

The central concept is that selective removal of gas contaminants from indoor air is a practical and cost-effective substitute for air replacement. The key lies in novel sorbents, originally invented by U.S. government research scientists to address greenhouse gas emissions. These adsorbent materials can perform low-energy cyclical capture and release of indoor contaminants. The technology can be integrated – as a simple add-on retrofit – into most existing central HVAC systems to provide immediate reduction in cooling power consumption, lowering it by more than 40% during peak hours. The technology also can be incorporated at the design stage for new installations and reduce the overall cooling capacity required.

Motivation

The key to understanding HVAC load reduction (HLR) technology and its benefits begins with understanding the way ordinary central HVAC systems address indoor air quality (Figure 1).

In most central systems today, air circulates throughout a building by means of ducts and fans. Air collected by manifolds or plenums returns though the central air-handling unit where it is cooled or heated as necessary. The air handler typically also filters the air for dust and other particles. As air is recirculated, its molecular composition changes -- predominantly due to human respiration and the evaporation of organic
molecules in the building. That means carbon dioxide (CO₂) concentrations increase, and a host of other contaminants, mostly volatile organic compounds (VOCs), also accumulate, albeit the latter at much lower levels than CO₂. The relative importance of these contaminants in commercial buildings has been a subject of debate and changing viewpoints over the years, but their collective role in indoor air quality is universally recognized.

The most prevalent and least understood contaminant is CO₂, a naturally occurring gas in the atmosphere that is exhaled by all living creatures as a natural byproduct of metabolism. CO₂ builds up indoors typically 1000 times faster than all other indoor contaminants combined. Because CO₂ is colorless and odorless, it is easy to ignore until it becomes toxic to humans at concentrations of about 0.5% to 1%. However, recent studies indicate that CO₂ is detrimental to human brain function at much lower concentrations — as low as 0.1% — a concentration level found in many buildings and considered normal.

VOCs span a wide gamut (hexane, limonene, ethanol, formaldehyde and many others) and occur at much lower levels in buildings, typically in the few parts per billion. Some have odors, and some, including formaldehyde, can be toxic or carcinogenic over extended exposure. Inorganic contaminant gases are rarely generated inside a building, but radon can enter from the ground, and outdoor pollutants such as ozone, NOx and SOx can be a concern in some urban environments.

Interestingly, oxygen depletion is seldom an issue, given the natural abundance of oxygen and the negligible depletion that can be induced by normal human activity. The banning of indoor cigarette smoking has led to improved air quality in buildings, but the need to remove contaminants and offset the buildup of CO₂ and VOCs is still imperative for indoor air management.

To maintain wholesome air quality, current HVAC systems are designed to gradually replace the indoor air with outside air. Typically, the entire volume of air in a building is replaced 10 or more times per day by drawing outside air into the building after passing it through an air handler for conditioning and pretreatment. The conditioning of the outside air results in a significant incremental thermal load on the HVAC system; in fact, in warm and humid climates, air replacement is the single largest contribution to cooling load and can account for 40% to 50% of the cooling power consumption.

A number of companies, led by enVerid Systems, have been collaborating on solutions that reduce the rate of air replacement and the energy waste associated with it, while maintaining optimal indoor air quality (IAQ). The novel approach diverts part of the return airflow through a unique air treatment module designed to remove CO₂ and VOCs, and send the treated indoor air back into circulation. With this method, the intake of outside air is substantially reduced, by as much as 80% to 90%, depending on the original outside air intake rate and the minimum exhaust requirements. The residual amount of outside air intake, required for
maintaining building pressure, still enables the building air to be replaced, but at a much lower rate, typically just 1 or 2 times per day instead of 10 or more times. This reduction brings about a commensurate 80% to 90% reduction in the thermal load associated with air replacement. The air treatment module is referred to as an HVAC Load Reduction, or HLR™, module (Figure 2).

Figure 2: A schematic representation of the HLR (HVAC Load Reduction) module for removal of CO₂ and VOCs from indoor air.

Technology
The HLR module approach to indoor air quality management is based on a combination of unique sorbent materials that are (a) highly targeted at the unwanted contaminants prevalent in indoor air, and (b) easily regenerated for repeated cyclical use in what is essentially a hybrid temperature/concentration swing adsorption (TCSA) cycle. The cycle is comprised of two phases: adsorption and regeneration. In adsorption mode, indoor air flows through the sorbents which capture and hold the contaminants, while clean air flows back into the building; this can continue for several hours until one or more of the sorbents is saturated. In regeneration mode, the module is sealed off from the building by means of automated dampers, and the adsorbents are flushed with heated outside air, purging the contaminants and returning the sorbents to their “clean” state, so they can be put back to work. The TCSA technology enables the treatment of indoor air using small units that can be easily installed and connected alongside the existing HVAC system.

The feasibility of the HLR module solution is based in part on a new generation of CO₂-sorbent materials created through government and university research on carbon capture and sequestration (motivated by concerns about atmospheric greenhouse gases and global climate change). These solid sorbents are chemically designed for highly targeted CO₂ capture at rapid flow rates and at ambient temperatures. No less importantly, captured CO₂ is readily desorbed, or released, from the sorbent material at moderately elevated temperatures, as low as 45 – 50°C (113 – 122°F), thus allowing low energy reconditioning of the CO₂ sorbent materials that can be achieved with inexpensive or even free heat sources.

But CO₂ management is only one part of the picture.

Most VOC removal is achieved by a different sorbent material, formed in a mesh of high-surface-area carbon fibers which are exceptionally efficient at capturing a wide range of organic and inorganic gas molecules. This technology has seen industrial and military use for years, and can work extremely well for
many indoor air contaminants. Some VOCs are inadequately captured by this mesh – notably and very importantly, formaldehyde. For these VOCs, proprietary adsorbents and catalysts are incorporated into the system to complete the job.

The combination of sorbents used in HLR modules are deployed in multiple replaceable cartridges in a compact, modular mechanical layout that easily lends itself to scalability for different airflow rates and building air volumes. The cartridges are held in a sealed chassis with motorized dampers that manage the TCSA cycle. This forms the entire HLR module, which is positioned in the vicinity of the return air flow path, with ducted connections to the return air as well as an inlet and exhaust for outside air used during the reconditioning phase of each cycle.

While material science and chemical engineering are the foundation of this technology, operational algorithms and control software that manage the timing of reconditioning cycles and air flow rates make the technology practical and cost effective. Sensors for CO₂ and VOCs are positioned at the inlets and outlets, and their readings are used by a central processor to monitor sorbent performance and determine when regeneration is needed. The sophistication of the software is key in enabling a relatively modest amount of sorbent to maintain desirable air quality in a larger building, without excessive regeneration downtime and energy costs. The combination of unique sorbents, compact mechanical elements and smart algorithms presents a complete and economically viable solution to managing all indoor air gas contaminants.

Figure 3. **Left**: Rooftop installation of two HLR-1000B units. **Middle**: Mechanical room installation of the HLR-500B in a mechanical room of a high-rise office tower. **Right**: Mechanical room installation of the ultra-compact HLR-500C in a Houston mid-rise office building – in this particular case positioned on top of the existing air handler.

**Load Reduction and Energy Savings**

Energy savings can be modeled for any given set of conditions accounting for outdoor temperature and humidity and comparing the amount of outside air intake in conventional ventilation rates corresponding to ASHRAE Guideline 62.1 versus the reduction in outside air intake enabled with the HLR module. enVerid has calculated these savings, and in a wide range of summer climates we’ve determined that cooling loads can be reduced by 20% to 50%. The reduction is most impressive when humidity levels are high and latent heat is the dominant driver of the cooling load. Savings are lower in temperate and dry climates, and the
solution is not applicable when no cooling is required or when the HVAC is operated in economizer mode (maximizing outside air). The HLR’s operation does require some energy, which is subtracted from the gross savings to yield the net energy savings. Much of the annual HVAC costs accrue when cooling loads are highest and the relative potential savings are correspondingly high. Accordingly, the annualized savings can come in at 20% or more in many large cities around the world.

In one carefully monitored installation of the HLR, a very precise week-to-week comparison of heat load was performed on a single rooftop air handling unit (AHU) rated at about 10,000 cubic feet per minute (CFM) that was supplied chilled water from a central chiller plant. Heat load was determined by constantly measuring the flow rate and temperature of the incoming and outgoing chilled water.

On alternating weeks, the AHU was operated (a) with normal intake of outside air and (b) with minimal intake (enough to maintain building pressure), while treating contaminants with a prototype HLR module. The total chilled water energy consumption was summed for each week. The experiment was conducted over a seven-week period in the summer of 2012, and the results show approximately 50% reduction in heat load during the weeks where the outside air intake was minimized (Figure 4).

![Figure 4: Results from the first HLR prototype test, comparing weekly cooling power under conventional operation (shown in gray) with reduced outside air intake enabled by the HLR module (shown in green). Load is reduced by as much as 50%.](image)

In another installation – this one in an office building in central Texas in late summer 2013 – a more granular comparison of energy consumption was performed, day by day, over the course of a six-week period from mid-August to late-September. The climate was moderately dry, with peak daytime temperatures between 90°F and 100°F or 32°C to 38°C, and with coinciding relative humidity in the range of 25% to 40%. What made this test particularly interesting is that, unlike the first installation, it was a 24×7 facility that ran its air conditioning around the clock, so energy impact was relative to a full 24-hour cycle. Night temperatures dropped significantly and the air often would reach dew point by dawn. Here too, chilled water was metered...
to measure the cooling power load. Over the course of the six-week period, a 39% reduction in cooling power per day was realized when operating in HLR mode.

While the aggregate energy savings throughout the year translates into the annual financial savings associated with the electricity bill, the reduction in peak load is a very important consideration for a number of reasons. First, peak demand drives grid overload and the economic cost of peak power is extremely high – whether or not it is passed on to the end user in the form of demand charges or variable rates. Second, peak load is the driver of design specifications for all HVAC systems. A substantial reduction in peak load cascades into reduced and less expensive design requirements for the entire cooling infrastructure. As a result, it also allows the HVAC to operate for longer durations at optimal, full loading conditions, which generally yields higher efficiency.

In the Texas installation, air quality remained very good with the HLR module. CO₂ levels were continuously monitored in several locations and were successfully maintained near or below 800 ppm at all times, which was a very good result given the high occupant density. VOC levels were monitored continuously with a VOC sensor, and air samples were taken at multiple times and dates, and sent to analytical labs for comprehensive, highly granular analysis and comparison. Total VOC levels, as well as specific levels for the most salient VOCs, were similar to the levels seen under conventional ventilation. Formaldehyde levels were actually lower under HLR treatment than under ventilation. Importantly, the HLR system has built-in feedback mechanisms that can keep up with changing levels of contaminants inside the building, so contaminant levels are always controlled for satisfactory air quality.

It is interesting to note that the substantial reduction of outside air intake actually has the potential to deliver some important indoor air quality improvements, particularly in heavily polluted urban environments. It also reduces the particle contamination load on the HVAC filtration systems, which can be quite pronounced due to natural outdoor dust and/or man-made smoke and fumes. A further benefit is less water condensation on the main coils.

Economic Analysis

For the purpose of this analysis we focus only on direct cost savings and net annual energy savings, without factoring in secondary benefits or utility incentives like differential rates, rebates or penalties. Here it is important to distinguish two different use cases for the HLR module:

- As an integrated feature included in a new installation
- As a retrofit to an existing HVAC system

The economics in the first case – new installations – are helped by two factors: minimal incremental costs associated with the installation, and reduced cooling capacity requirements due to peak load reduction. The latter offsets the entire incremental cost of the HLR module(s), making for a very compelling economic value proposition.

In retrofit situations, we examine the most common case of a retrofit by focusing on the segment of mid-size to large commercial buildings, including office buildings, hotels, malls, and other public venues. The following case analysis applies to a 100,000 sq ft commercial building which would typically be served by 5 to 10 air handlers and a corresponding number of HLR modules. In this example, typical airflow could be 100,000 CFM and maximum design occupancy might be approximately
500 persons. We compare three sub-cases in terms of energy cost per sq ft, but assume 20% savings in all three cases.

As demonstrated below (Table 1), the total annual savings are significant. A complete economic analysis would have to take into consideration the cost of the HLR unit as well as the installation expenses and the annual maintenance costs, which are outside the scope of this paper. However, based on these anticipated savings and with a relatively compact and simple mechanical design of an HLR module, the economic case for an after-market retrofit looks very advantageous, especially in regions where there are long cooling seasons or where electricity rates are high. The authors estimate the return on investment (ROI) period will typically fall within a two- to three-year timeline in most warm and/or humid climate zones.

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*Table 1: Economics of the HLR system for a 100,000 sqft zone, comparing three representative climate scenarios.*

The case for new installation is even more compelling. Consider a 100,000 CFM installation requiring 250 tons of peak cooling power. Because peak load reduction is so significant, even a conservative estimate would allow a design with 20% less cooling power, namely only 200 tons. This results in smaller chillers, water lines, transformers, lesser weight, and more. These savings alone would cover the incremental cost of installing the HLRs, and would create a positive economic case for virtually any climate and utility rate.

Comparison to Current Technologies

The energy cost of air replacement has been a challenge for many decades, but two existing approaches provide partial relief to this challenge. The first is energy recovery ventilation (ERV) and the second is demand-controlled ventilation (DCV).

ERV maintains the conventional amount of ventilation, but uses various types of heat exchange elements to transfer energy between the exhaust air leaving the building and the incoming fresh air. The more sophisticated of these systems use enthalpy wheels that transfer heat and humidity between the two air streams. However, even in the most advanced of these systems, only a fraction of the heat is successfully transferred. Additionally, the amount of energy that can be recovered is limited by the amount of exhaust air available in the vicinity of the fresh air inlet. Adding together the cost and the maintenance required for these systems, they have demonstrated fairly poor ROI. Many decades after their introduction, the adoption rate of ERVs remains very low. HLR promises to offer substantially higher energy savings and a simpler and more reliable mechanical solution.

DCV is a method of reducing ventilation without treating the air, simply by monitoring CO₂ levels in the building and adjusting ventilation rates accordingly. Energy savings are achieved when occupancy is
substantially lower than that for which the building was designed. While easier to retrofit than ERV, this approach does not have the ability to reduce peak load or peak design requirements, and perhaps more troubling, it generally ignores VOCs. Since the source of many VOCs is not the human occupants but rather inanimate objects and materials in the building, these are not correlated with CO₂ and therefore in most settings a passive DCV system does not really have the ability to guarantee acceptable IAQ. Indeed, some practitioners view HLR as an advanced form of DCV, not only for actively mitigating CO₂ accumulation but also for monitoring and actively managing VOCs.

Summary

A new technology is now commercially available for HVAC load reduction and energy savings, by means of selective removal of CO₂ and VOCs from indoor air. Eliminating these indoor contaminants enables high indoor air quality with less outside air ventilation, thereby saving 20% or more of the energy consumed. The HLR module can be retrofitted onto a wide variety of existing HVAC systems and promises a very attractive ROI, especially in warmer and humid climates where cooling costs are high. The excellent economics and a number of secondary benefits position this new technology as a superior solution to energy recovery systems, setting a new standard for green buildings.