Next Gen New Construction Programs

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Executive Summary

Accelerated roll outs of energy codes and standards are putting the squeeze on commercial new construction programs throughout the country. Equipment standards, control requirements, and envelope performance are pushing physical, economic, and in some cases absolute limits. Little can be accomplished by way of energy impacts with incremental improvements over energy codes used as baselines for determining savings for these programs.

However, substantial, real savings can be accomplished with next generation system design and control that precisely matches system capabilities with the needs of the facility.

Energy codes do not specify the types of equipment or systems, or what types of fuels the systems will use. A simple example includes a 0.65 kW per ton chiller that does not meet code while a packaged rooftop unit requiring twice the power per ton meets the code. There is no restriction on using expensive, valuable electric resistance heating versus more efficient water source heat pumps or natural gas-fired heating of any type. This allows for flexibility amongst design and construction communities, but does not well serve the energy efficiency industry.

Still more code-compliant designs are poorly understood from energy usage and efficiency perspectives, difficult to design and still more difficult to control efficiently. Central air handling systems have evolved over a century starting when energy was very inexpensive. As energy costs have risen, the central system has been modified into an overly complex variable air volume system that almost always permits excessive simultaneous heating and cooling, and fan and pumping energy. In fact, in some applications "excessive" simultaneous heating and cooling cannot be avoided.

Wasted energy from simultaneous heating and cooling, pumping, and fan energy have been witnessed at many facilities investigated by Michaels Energy. These include facilities that were built through the process of new construction programs and LEED®; facilities that use substantially more than median energy consumption reported by Building Energy Consumption Survey 2003. Why? Not because their energy models and design intents aren't good necessarily, but because the systems are overly complex, poorly understood by key stakeholders, and rarely commissioned with functional testing of systems to ensure design intent integrity.

One way to avoid this inherent propensity for waste is to use dedicated outdoor air systems that decouple ventilation heating and cooling from zone heating and cooling needs. This avoids the vast majority of potential simultaneous heating and cooling. Compared to conventional HVAC (variable air volume) systems, these systems:

- Are no more complicated to design.
- Can be cost competitive with less ductwork, no variable air volume boxes, smaller fans, and less complex controls.

- Provide better comfort for occupants.
- Save energy and have a lower life cycle cost for owners[1] presenting a competitive edge for contractors.

There are many options designers can use with dedicated outdoor air systems: boilers, chillers, heat pumps (water-to-air, water-to-water, air source, water source, ground source, and ground-water source), fan coil units, radiant heating and chilled beam cooling. Applications include nearly all types of commercial facilities.

Further incremental savings are simple to control. These include demand controlled ventilation with carbon dioxide sensors and occupancy sensors. Systems can use cooler heating temperatures and warmer cooling temperatures, allowing heating and cooling equipment to operate at maximum efficiency.

Fan energy is greatly reduced as friction losses from high volumes of air flow and static pressure can be nearly eliminated. Much of the delivery of cooling and heating to the occupied zone can be carried out with no driving fan energy using natural convection and buoyancy effects.

Note there are other next-generation systems that have many similar advantages. This includes displacement ventilation systems, which can be designed with other inherent energy-saving characteristics.

Energy efficiency programs ought to start promoting and requiring systems that make wasting energy as difficult as making the majority of conventional new systems save energy. Simply providing a laundry list of better-than-required equipment, envelope features, and even control strategies can easily be overcome by inherent risk and realization of waste due to complex, inefficiently operated systems.

[1] Further study is required.

Commercial New Construction Energy Efficiency

You may recall a scene from one of the Star Wars movies where the heroes, heroines, and the wookie are trapped in a huge trash compactor with high walls closing in on them. They were getting squeezed with little room to breathe just before they magically escape.

Commercial new construction (CNC) efficiency programs are in a similar plight. The American Society of Heating, Refrigeration, and Air Conditioning Engineers (ASHRAE) 90.1 and International Energy Conservation Code (IECC), which has virtually the same content, are rapidly tightening the requirements for energy efficiency toward ultimate physical and scientific limits. These documents are adopted as energy codes directly or, in some cases, states use them as a starting point for their energy codes. A few examples illustrate this issue.

Lighting power densities have reached a plateau near 1.0 Watt per square foot for typical spaces like offices and classrooms. This is perhaps half what it was twenty years ago, but the next half, which will eventually come via light emitting diodes, will not have as much impact due to diminishing returns on lower and lower baselines.

Insulation values for massive (masonry) commercial buildings have reached a cost effectiveness plateau near R-20 for roof insulation and R-13 for wall insulation. Specified insulation levels are already at or beyond levels that are cost effective given today's electric, fossil, and renewable energy costs.

Large chillers have reached a plateau near a coefficient of performance of 6.0. Direct digital controls have been the standard for nearly 20 years. Thus "advanced" control strategies, which are more easily implemented with digital control systems, have been incorporated into ASHRAE 90.1 and IECC. The most efficient heating equipment operates with roughly 95% efficiency, leaving negligible room for improvement.

The result is one can no longer cost-effectively buy his/her way to substantial energy efficiency by purchasing incrementally more efficient, more expensive equipment. The big impacts are in system design and control.

Small Commercial Market

The impetus for this paper was to address the small commercial new construction market. However, the design concepts in this paper apply to most any commercial facility.

The small commercial market is especially challenged for numerous reasons.

First, the facilities are small and therefore, the market is perennially difficult to cost-effectively approach from an energy efficiency perspective. Typical program measures are limited to things like lighting, programmable thermostats, and low-flow aerators to save hot water.

Unlike large facilities, the savings potential by nature is relatively minor for a given facility. However, the percent savings can be just as high and collectively small buildings make up a large percentage of new and existing building stock.

Second, this is an extremely cost competitive construction market. Typically, projects are bid to the design-build community and the competition is brutal. Schedules are aggressive. The contractor typically does not want to study options for energy efficiency and the owner does not want to pay for the study. There is typically little interest or return on investment for more efficient equipment or systems.

Third, many if not most times building spaces are leased for relatively short periods of time. Tenants are typically far more concerned about signing this sort of "long-term" lease (in the lessee's mind) compared to the energy cost they will be absorbing with the lease. Building owners pass the energy costs on to the tenants or in many cases tenants take "ownership" of the utility meters. Therefore, it is tough to sell building owners in this market on energy efficiency.

Fourth, the equipment available for these facilities is minimally efficient and generally of poor quality. Heating efficiencies are typically the minimum 80% and cooling efficiencies are stuck in the 10-12 SEER range. Studies have shown that economizer cycles that provide free cooling with outdoor air when weather permits are dysfunctional more often than not.

Fifth, equipment is sized to kill an ant with a sledgehammer. Heating and cooling equipment is often oversized. Lighting systems may provide almost twice the light level needed for the task. While it is obvious how excessive lighting wastes energy, oversized equipment wastes energy by excessive cycling. Cycling can waste energy for cooling by reintroducing moisture into the air when the compressor cycles off. Heating cycling requires excessive purge cycles that cool heat exchanger surfaces or boiler heat exchangers. Over-sizing occurs because (1) "designers" skip true load calculations to keep costs down – the incremental cost of larger equipment is less than the cost of the analysis, (2) oversized equipment is presumed to not result in temperature control problems, and (3) owners want to be ready for a potential chain of diverse tenants moving in and out over future years.

Sixth, tenants often take poor temperature control into their own hands by bringing in expensive-to-operate space heaters. These 1,500-Watt space heaters are establishing a small plume of warm air around the occupant, but meanwhile the larger air handling system is simply offsetting these heat gains with more cooling – either free cooling with economizer or not free with mechanical cooling.

Although these issues are more prevalent in small commercial new construction, they can also apply to some larger facilities. The content of the rest of this paper covers most sizes and types of facilities.

Out with the Old

Central air handling systems serving multiple control zones, defined as any space served by one control point or thermostat, have been used since at least the early 1900s. Buildings from the early 1900s had air handlers in the basement that drew in fresh air from the roof and exhausted air through the roof by gravity or by forced air flow with a fan. Zone temperature control was provided by cast iron radiators with hand valves, typically heated with steam. Cheap thermostats or even pneumatic thermostats may have been added to these radiators over the years.

Post WWII systems included sheet-metal ductwork for air distribution. Unlike their early 1900s cousins, many of these systems included cooling via the air handling system, rather than operable windows. Cooling may be from the economizer only using cool outdoor air when available, or it may also include mechanical cooling.

Any number of wasteful types of temperature control were used. These included constant (air flow) volume reheat systems where air is supplied from the air handler at a given temperature, typically 55F to 60F for all zones and where necessary, and the air was heated back up to meet zone temperature requirements. This wastes energy by providing more cooling than necessary for most zones and then "reheating" as required.

Two other similar types of systems include multi-zone and dual duct systems. These work in similar fashion and are slightly less wasteful than constant volume reheat. In these systems, cool and warm air streams are mixed as necessary to meet zone temperature control requirements. Waste is reduced somewhat because at least the flow of cool air can be throttled back rather than having to reheat the entire volume. Nevertheless, heating energy is wasted because temperature is controlled by mixing cool air with hot air.

Reheating air or mixing warm air with cool air to control temperature is called simultaneous heating and cooling. Cooling is provided by outdoor air or mechanical cooling (chilled water or direct expansion), while heating is typically provided by a boiler.

Out with the Current

The next generation of central air handling systems included variable air volume, which has been around for roughly 40 years. Variable air volume systems greatly reduce simultaneous heating and cooling by throttling air flow and thus varying the volume of air delivered to the space. A zone that needs partial cooling is throttled back to reduce flow, and therefore reduces cooling, without adding heat to the zone – at least to some extent. With modern digital controls, substantially greater energy savings can be achieved by adjusting the air temperature delivered by the central air handler. Increasing the air temperature further reduces cooling available to the space and further reduces reheat energy required.

Variable air volume systems meet today's current ASHRAE 90.1 and IECC standards, but at a price: they are complex and generally poorly understood from an energy-use perspective at all levels: design community, contractors, and facility managers. Sequencing supply air temperature, control dampers, reheat valves, and fresh air supply for optimal energy performance is extremely complex. There is almost always excessive simultaneous heating and cooling with these systems, especially for facilities that have stringent air conditioning requirements, such as hospitals and certain types of manufacturing.

Furthermore, using "advanced" control strategies such as demand controlled ventilation with carbon dioxide sensors is virtually impossible and very expensive to do it right. There is percent flow to the zone, and there is percent fresh air supplied at the unit. Moreover, most of the flow delivered by the air handler is return air from other zones. The system must be controlled by a mind-boggling strategy developed by ASHRAE. With all due respect, the chances of even the very best engineers and controls contractors getting this right makes pulling a camel through the eye of a needle sound pretty easy.

Air handling systems that were common in WWII era have been complexified by orders of magnitude in order to save energy. It is time for the building industry to step back and observe this Rube Goldberg of air handling systems and say "there's got to be a better way," and there is.

Variable air volume proponents will say that there is nothing wrong with these systems. They can work great and use minimal energy. Steam can also work great and doesn't need to waste energy either. But for maintenance and simplicity, most designers have converted to hot water both on a retrofit basis and for new construction. This is because facility managers and owners simply do not have the manpower, time, or expertise to maintain steam systems. A strong case can be made that variable air volume systems are much more complicated than steam systems, and therefore one has to ask themselves, why continue with this?

Many small commercial facilities have packaged single zone systems. As discussed later in this paper, all else equal, single zone systems are difficult to compete with from an energy consumption standpoint, even if the units have poor heating and cooling efficiency. Why? Because there is less risk of excessive simultaneous heating and cooling. If the zone they serve needs cooling, the unit is in cooling and vice versa. It is not serving one zone that needs cooling and one that needs heating at the same time.

However, cheap single zone systems have drawbacks. First, all else equal, they are cheap and less reliable. Studies have shown that more often than not, in the range of 70% of the time, the economizer control for free cooling with outdoor air does not function properly.

Second, temperature control may be poor because the single zone units serve multiple spaces that should really be split up into separate zones for acceptable temperature control. One room served may have west facing glass and another may be internal. In the winter, the room with the glass is too cold and the opposite occurs during summer, or even spring/fall/winter afternoons when solar gain is high. Systems serving small commercial facilities are notoriously poor in this regard.

Third, humidity control is poor. Packaged systems are typically oversized and therefore, the cooling cycles on and off, excessively. When cycled on, the cooling coil becomes saturated with moisture from the air, but before significant moisture has a chance to drain away, the space temperature setpoint is reached and the cooling shuts off. The moisture on the wet coil is then reintroduced to the space as it dries. For good humidity control, cooling coils should be slightly undersized to avoid this.

Lastly, many small commercial facilities use very cheap "variable air volume" systems. These range from the not-so-bad system with canned controls and direct expansion cooling, to the poor performing on/off zone control with no modulation for temperature control or consistent flow of fresh air to occupants. These are, in many ways, worse than cheap packaged single zone systems. They come with most of the same baggage of packaged single zone systems but they use more energy, and in may cases provide no better space conditioning control.

Newer, Simpler, and Efficient

Varying the volume of air flow to a zone to control temperature, and in some cases to precisely control ventilation, in sequence with an air handler serving many other zones is very complicated. Varying the flow to a zone only to provide adequate ventilation with 100% outdoor air, while heating and cooling loads are met independently is far simpler, possibly less expensive to build and certainly less expensive to maintain and operate. Providing conditioned outdoor air independent of heating and cooling systems that maintain desired zone temperature setpoints is generally known as a dedicated outdoor air system.

Dedicated outdoor air systems have been around for decades as well. Did you know that most ground source heat pump systems actually use dedicated outdoor air systems? A primary reason that ground source heat pump systems are inexpensive to operate and energy efficient is they don't come with the complexity and waste of central air handling systems. What is the significance of this? As you probably know, a significant barrier to ground source heat pumps is first cost. This is a major barrier for small commercial facilities, again because energy consumption and cost is of minor concern to key stakeholders. However, there is no reason dedicated outdoor air systems must be confined to ground source heat pump systems. Significant savings can be achieved using many variations of heating and cooling sources.

The Energy Code

ASHRAE 90.1 and IECC merely require characteristics (prescriptive) or theoretical performance to be met when designing and building a given type of heating and cooling system. With few exceptions, such as constant volume reheat, they do NOT prohibit the use of systems that use a lot of energy or a lot of expensive energy, such as electric resistance heating.

Furthermore, energy codes do not discount the poor performance, which is very real per our experience in retrocommissioning fairly new buildings, associated with complex variable air volume systems. Certainly, any type of system can be controlled to waste energy, but variable air volume systems are inherently difficult to control in an efficient manner.

Therefore, to establish real space between a code-compliant building and an efficient building, designers need to implement next-generation design concepts. Surprisingly, many next-gen systems are simpler to build, control, and maintain than the nearly ubiquitous variable air volume system.

Commercial New Construction Program Savings

Commercial new construction (CNC) programs take savings as the difference in the energy consumption of a proposed and theoretically operated building and a baseline design prescribed by ASHRAE 90.1 and operated in the same way. This is also how LEED scores its energy credits for registered facilities. Therefore, it seems reasonable to examine LEED facilities and project trends and outcomes on CNC programs.

Several articles have been published in recent years regarding the energy impacts of LEED certified buildings and whether these facilities are really any better than the garden variety new building with regard to energy consumption. While actual performance data for certified buildings is sparse and may not provide a statistically valid representation of the entire population of LEED certified facilities, there do appear to be potential problems with predicted versus actual building energy use and savings. The Chicago chapter of the US Green Buildings Council led a study of 25 certified buildings, completed in the fall of 2009[2]. Notable data from that report include building-simulation-predicted performance versus actual, post-construction performance.

[2] Widener, D., Folk, S., (2009) *Regional Green Building Case Study Project: A Post-Occupancy Study of LEED Projects in Illinois.* Chicago, IL: US Green Buildings Council, Chicago Chapter

FIGURE 1: DESIGN (PREDICTED) BUILDING ENERGY CONSUMPTION COMPARED TO ACTUAL POST-IMPLEMENTATION CONSUMPTION

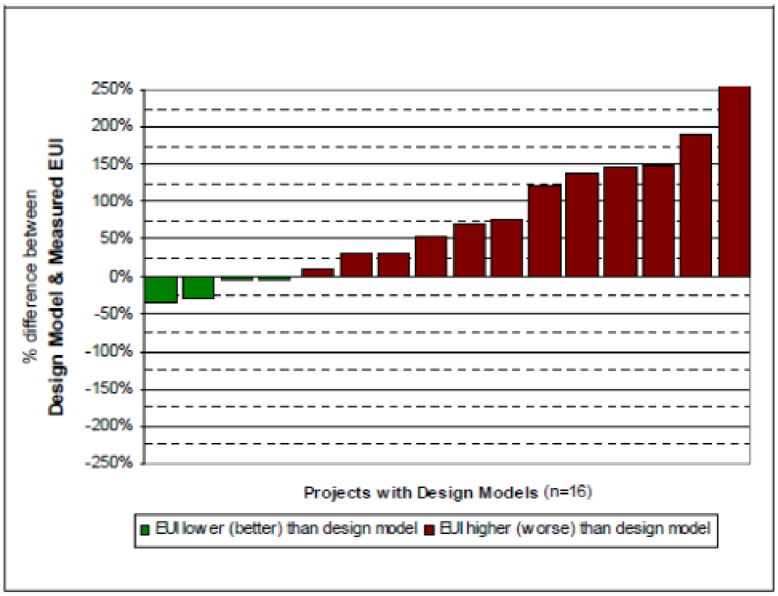


Figure 1 shows that most certified buildings in the study are consuming substantially more energy than their predicted **design** model performance. Furthermore, the magnitude at which the poor performers are underperforming is very large in most cases. Roughly a third of them more than 100% high and nearly half are more than 50% high. Simulations are not meant to predict energy consumption but rather savings. However, consumption and savings are clearly related and therefore, when consumption estimates are largely in error, savings estimates will tend to have significant error as well.

FIGURE 2: ACTUAL POST IMPLEMENTATION CONSUMPTION COMPARED TO BASELINE MODELED CONSUMPTION

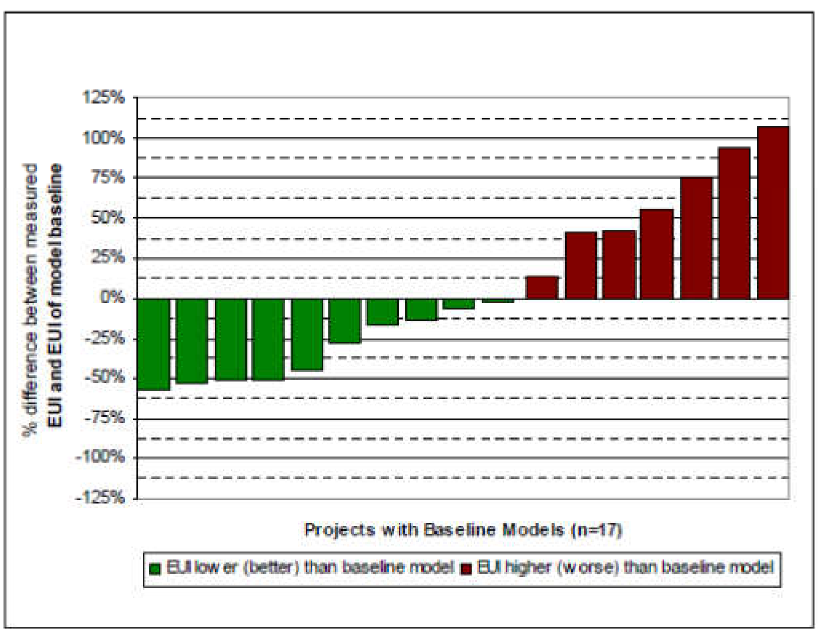
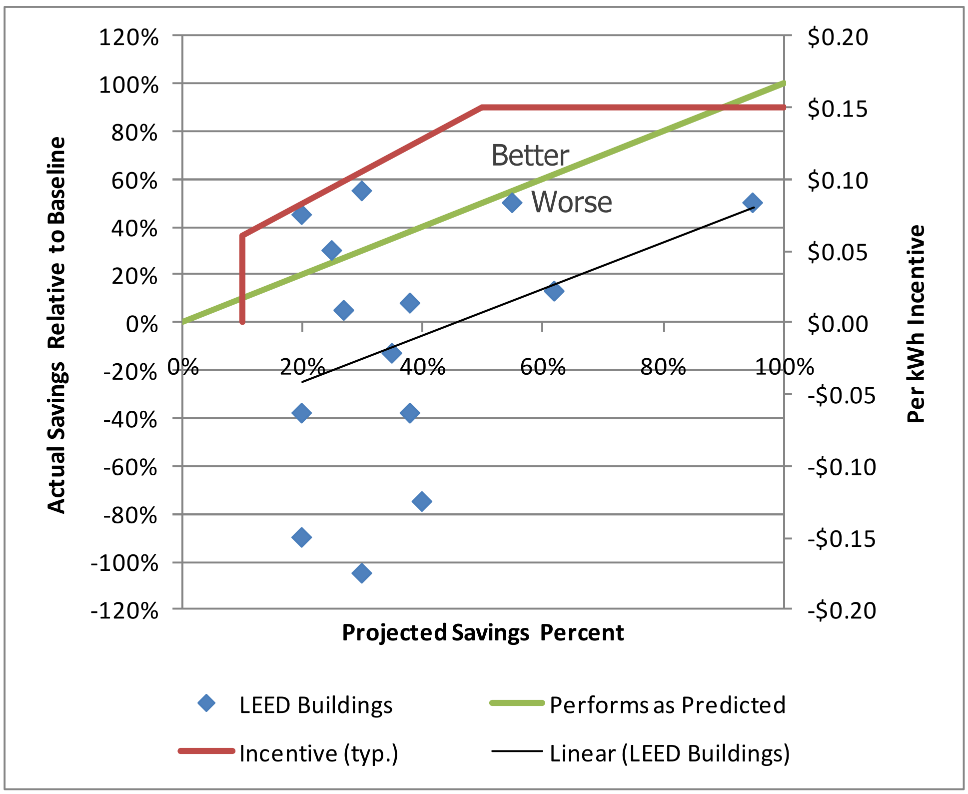


Figure 2 shows that actual building performance is centered about the predicted **baseline** model performance, as opposed to predicted **design** performance shown in Figure 1. In other words, about as much energy is being wasted by half the buildings compared to the simulated baseline as is saved relative to the baseline by the other half. The result is only three buildings exceeded savings projections.

Figure 3 shows the performance of LEED certified buildings from the Chicago USGBC study as the blue data points. The green line represents buildings that perform exactly as predicted. Using a linear fit of actual performance data, a typical project would require roughly 45% projected savings just to meet the projected baseline performance (zero savings). Indeed, the linear fit of actual performance is roughly 45% below the expected savings line over the entire performance range.

As noted above, only three buildings outperformed projections. These three points are shown on Figure 3, above the green line, which would represent buildings that achieve savings exactly as predicted.

FIGURE 3: ACTUAL SAVINGS AND TYPICAL PROGRAM INCENTIVE VERSUS PROJECTED PERFORMANCE



Five buildings underachieved but saved some energy while nearly half used more energy than the predicted baseline. Please refer to the five points between the green line (predicted savings) and 0%, the x-axis in Figure 3. Perhaps most telling is that while 10 of these certified buildings have lower energy intensities than the average of all Midwest buildings in the CBECS[3] database, seven of them actually use more than the average Midwest commercial facility. In total, the report points out that the sampled projects are "performing slightly better (5%) than the regional Midwest average" for all Midwest buildings in the CBECS 2003 database. This is consistent with Figure 2, which shows performance is centered about the baseline.

Also consider that LEED certified facilities require commissioning, presumably to make them perform well. Commissioning is provided for a tiny percentage of "non-LEED" buildings. Removing the commissioning, which is not part of most new construction programs, would likely further move new building performance into the average category. One cannot draw quantitative conclusions from this study but it would be fair to state that simulation results are heavily biased toward efficiency. Reported reasons noted for divergence between simulation and actual results typically include a strong dose of building use that is different than anticipated use. However, it is reasonable to conclude that differences between anticipated and actual use are not causing 100% overuse of energy as indicated in Figure 1.

Some wasteful control strategies can be simulated but others cannot, and either way, it would be completely arbitrary to introduce poor control into a building simulation. Complicated systems like variable air volume systems are always going to use as much or substantially more than a simulation indicates because of inherent difficulty in controlling the system efficiently while providing comfort conditions.

Perhaps more troubling is that many new construction programs use progressive incentive levels, shown as the red line (right scale) in Figure 3. That is, the higher percent "savings" the greater the per-unit incentive on energy "saved".

What is the solution?

Answer: Systems that are inherently easier to understand and control – systems that tend to operate efficiently rather than tend to waste energy as the norm.

Next Gen

Although it may sound oxymoronic, like most high-impact energy efficiency measures there is nothing new or revolutionary about next-generation HVAC systems. However, the concept is like that of the daylighting "revolution" ten to twenty years ago. Designers and the energy efficiency community realized that old buildings built for copious daylight might be a good reversion. People like to see and have connection with the outdoors. They like the full spectrum of natural daylight. And if done right, we can even save energy while providing it.

Reverting back to something like early 1900s style of heating, ventilating (and cooling) also makes sense. These old systems use a central air handling system for ventilation and space

[3] Commercial Building Energy Consumption Survey conducted by the US DOE, all Midwest buildings in this case.

temperature is controlled in individual zones independently with radiators and operable windows. Note, this is not how they were all designed, but they were closer to this than the modern variable air volume system.

Using a central makeup air system for ventilation and other decoupled means of meeting space temperature requirements can save enormous amounts of energy.

The list of advantages for dedicated outdoor air systems is long and significant.

- **Minimal simultaneous heating and cooling:** Only fresh air is supplied via central air handling systems. It is typically supplied in a relatively neutral state, providing minimal zone heating or cooling. Control strategies are discussed in a later section.
- **Lower fan power:** Since the volume of air delivered to zones by the central air handling unit is relatively tiny compared to a conventional system, air flow friction losses and offsetting fan power is greatly reduced. Depending on the design, some forced air flow at the zone level may be required, but this fan energy is minimized since there is little if any ductwork through which to push air. These systems also do not normally require a minimum static pressure control setpoint like variable air volume systems. There is always some wasted energy with static pressure control.
- **Efficient humidity control:** In most small commercial applications, the primary source of moisture in the space is outdoor air. If humidity is being controlled, many times it is accomplished by cooling air to 55F or some other desired dew point, and then reheated at least to some extent. It must be reheated because the zone(s) do not require even minimum flow of 55F air to maintain temperature set point. As discussed in the first bullet, with a dedicated outdoor air system, the fresh air supply provides minimal cooling even when delivered at 55F because the flow rate is so low. Almost assuredly, when dehumidification of fresh air is needed, the cooling supplied to the zone will not be excessive such that heating is also needed. If reheat is necessary, it can be provided for free from the unit providing the cooling/dehumidification – i.e., warmer air of same moisture content can be delivered.
- **Easy ventilation control:** All air supplied by the central dedicated outdoor air system is 100% fresh outdoor air. What is happening in other zones is of no consequence from a ventilation perspective. Carbon dioxide level and air quality in zones can be precisely and simply controlled with a dedicated outdoor air system. Fresh air can be easily reduced to zero if the space is unoccupied. The minimum fresh air flow for the building as a whole will be maintained to make up for exhaust requirements for restrooms and other spaces that require exhaust.
- **Better temperature control:** Although one can have lousy temperature control with just about any type of system for any number of factors, one phenomenon presents a huge barrier to comfort in northern climates: warm air does not sink. All-air systems, and in particular variable air volume systems that deliver all of a zone's heat through a ceiling diffuser, are notoriously problematic and energy intensive. To get

enough mixing, minimum air flows must be high and this costs fan energy and excessive simultaneous heating and cooling. It is easy to avoid this with a dedicated outdoor air system.

- **Lots of options:** Dedicated outdoor air systems can include water loop heat pumps, water-to-water heat pumps, water-to-air heat pumps, variable refrigerant volume systems, in-floor radiant heating and/or cooling, chilled beams, ceiling radiant heating/cooling, fan coil units with efficient boilers and chillers, among other options.

System Options

As indicated in the previous section there is a multitude of options for HVAC systems that can save as much as 50% over conventional variable air volume systems. Michaels designed two such systems for college laboratories, each of which earned LEED Gold. One of those buildings captured 10 of 10 energy efficiency credits from LEED version 2.2.

This section provides design considerations to achieve significant savings versus standard status quo systems that are energy code compliant.

Exhaust & Ventilation

It is absolutely critical to control exhaust and ventilation to allow dedicated outdoor air systems to function properly and not cause problems. In many ways it is more critical to manage these requirements than it is for conventional systems. Fortunately, simplicity is the name of the game for dedicated outdoor air systems, but they must function properly.

Standard Commercial Facilities

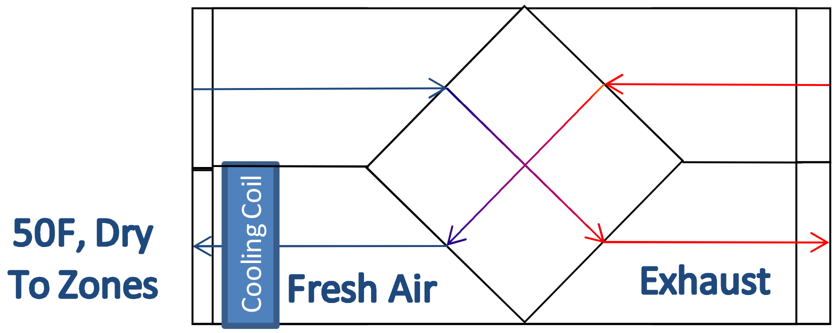
Standard commercial facilities include offices, government, K-12 and many college/university facilities.

All stand-alone facilities need at least some exhaust. At minimum, restrooms require approximately 75 cfm (cubic feet per minute) of exhaust per toilet and per urinal. Exhaust air must be made up by bringing fresh air into the building. Use an energy recovery unit to temper outdoor air used for makeup air. Distribute the fresh air to building zones as would be required with a conventional system. Since the makeup air is 100% outdoor air, the volume flow is much lower, thus requiring substantially smaller ductwork diffusers and delivery fans.

Providing adequate ventilation for occupants and drying this ventilation air to relatively dry dewpoints, such as 50F, is sufficient to control humidity in summer conditions in these typical commercial facilities. In most situations in warm humid climates, when dehumidification is needed, so is cooling. Therefore, in the typical commercial facility, reheat of ventilation air is not necessary and this also virtually eliminates the possibility of simultaneous heating and cooling. Other cases described below Figure 4 may be good candidates for free reheat.

A simple energy recovery unit as shown in Figure 4 works well for this application. This unit has a cross-flow heat exchanger. Other units may have energy recovery wheels, which accomplish the same thing. Warm, humid outdoor air is pre-cooled and dehumidified using relatively cool, dry exhaust air from restrooms and/or general exhaust. The pre-cooled air is then further dried and cooled using a cooling coil downstream of the heat exchanger.

FIGURE 4: ENERGY RECOVERY UNIT



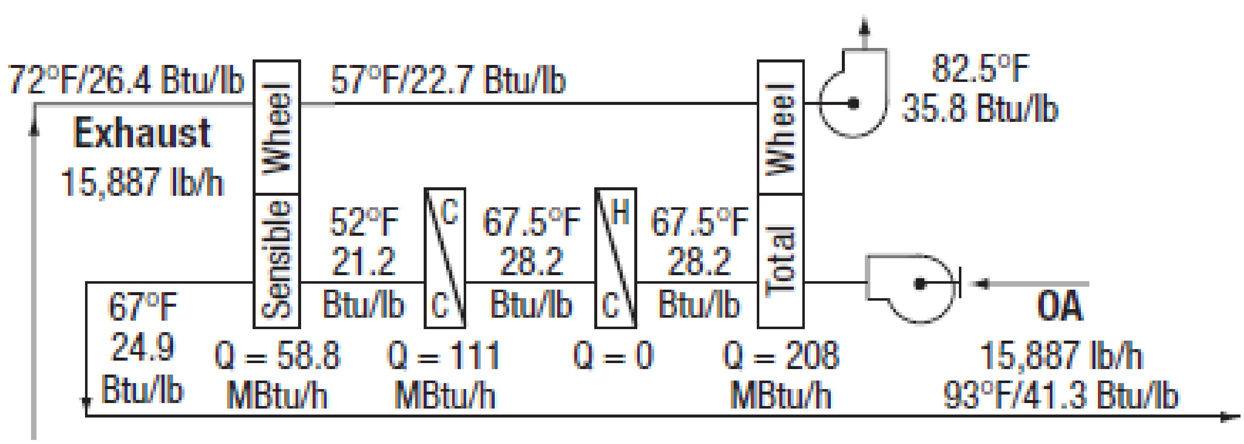
Exceptional Commercial Facilities

These "exceptional" facilities are those with substantial "process" loads and include laboratories and fitness centers. Other specific types of facilities, including natatoriums and commercial kitchens, are not covered in this paper.

Variable air volume systems serving laboratories are unavoidably very energy intensive. Recent energy codes only require variable air volume (fresh air and exhaust) OR energy recovery from the exhaust. Even when both variable volume exhaust/ventilation is coupled with energy recovery to achieve "savings", there is still extraordinary waste. Dedicated outdoor air systems avoid nearly all this waste.

Laboratories require far more fresh air for lab hood exhaust makeup than is required for occupant ventilation. In these cases, drying the air to the desired dew point and not reheating it would result in unacceptably cool/cold space conditions at all times. Therefore, a dual-wheel energy recovery and makeup air unit shown in Figure 5 is ideal.

FIGURE 5: DOAS WITH ENERGY RECOVERY. (FIGURE COURTESY OF LABORATORIES FOR THE 21ST CENTURY, U.S. EPA)



Fresh air is again pre-cooled and dehumidified using the exhaust stream, mechanically cooled to the desired dew point and then reheated by the exhaust stream with a second energy recovery wheel. The exhaust is cooled with the wheel that is reheating the fresh air and then it absorbs energy from the incoming warm humid air. This unit can provide large volumes of dry air with minimal energy input. 65% of the dehumidification is provided for "free" from the energy recovery process. The cool saturated air is then reheated for free to a nearly neutral temperature.

Zone temperatures are controlled with terminal equipment, entirely independent of the makeup air unit.

Zone Cooling and Heating

There are many combinations of zone heating and cooling that can be used with dedicated outdoor air systems. These can be classified as forced air systems or radiant systems.

Forced air systems include water loop heat pump systems with boilers and cooling towers, ground source heat pump systems, air source heat pump systems, variable refrigerant volume systems, and fan coil units. Radiant systems include in-floor radiant heating, radiant panels, and chilled beams. These options are shown in **Error! Reference source not found.** and Table 2.

TABLE 1: FORCED AIR SYSTEM OPTIONS

Forced Air Option	Advantages & Disadvantages	Comments & Considerations
Water loop heat pump	This type of system achieves zone temperature control at relatively low first cost and operating cost. A condensing boiler is used to keep the water loop temperature warm when the building is in block heating. Heat pumps deliver heat very efficiently using warm 70F loop water. Only one water loop is needed and piping does not require insulation due to mild water temperatures at or above room temperature.	This type of system has been around for decades and is therefore very reliable.

Forced Air Option	Advantages & Disadvantages	Comments & Considerations
Ground source and ground water source heat pump	This system achieves comparable electric-side (heat pump) performance but does not require natural gas for heating. All heat is supplied by and rejected to the earth. The addition of water side friction losses with much more piping due to the ground loop is offset by eliminating the need for a cooling tower (closed circuit fluid cooler). Only one water loop is needed (not primary/secondary loops), but pipe insulation is required in cold climates.	Capacity and cost of well field may be optimized by "boosting" loop temperatures with a boiler or tower, depending on whether or not the building is heating or cooling dominant. Controls must allow for the earth to provide maximum heating and cooling before booster equipment is used. Ground water source with an open well is less expensive, but also consumes large volumes of ground water.
Air source heat pump	This type of system is considerably less expensive to install than water source heat pumps noted above. Recent technology allows air-source heat pumps to effectively heat down to about -5F to -15F. Below this, more expensive electric resistance heating is needed. The evaporator coil outdoors will require defrosting as moisture from ambient air will freeze in some conditions.	This option is best suited for southern climate zones.
Variable refrigerant volume heat pump	This type of system in certain applications may use less energy than water loop heat pump systems (ground source, ground water, or conventional water loop). When some building zones need cooling while others need heating at the same time, this system provides both with one refrigeration cycle (compressor). Water loop systems would require one refrigeration cycle for a zone that needs heating and another for a zone that needs cooling while both extract heat from or reject heat to the water loop, respectively. This type of system costs more than a water loop heat pump system, but less than a ground source heat pump system.	Facilities that present the best applications for these systems are those that require many hours of heating in some zones while others need cooling, simultaneously. This would include larger "cube" type buildings with core zones that always need cooling and perimeter zones that need heating for at least six months per year. This type of system can also be supplemented by ground source heat exchangers, solar collectors, boilers and towers, similar to water loop systems. The same low temperature and defrost issues may apply, as with the air source heat pumps.

Forced Air Option	Advantages & Disadvantages	Comments & Considerations
Fan coil systems	These systems can provide heating or cooling as needed for space temperature control. These units are simple and relatively inexpensive. However, unlike the water-loop systems, fan coil systems almost always require two water-pipe loops, one for heating water and one for chilled water – also known as a four-pipe system. A two-pipe system may be used, but building zone loads must be nearly proportional with all zones needing heat or cooling at any one time.	Use larger coils than normal so cooler heating water and warmer chilled water may be used. Boilers and chillers always operate more efficiently in these conditions. Condensing boilers can only achieve their 90% efficiency and greater at relatively cool water temperatures below about 140F supply temperature. Use a separate cooling system for the ventilation so that it can be operated at colder temperatures to remove moisture from air, while using warmer chilled water for zones to maximize cooling efficiency.

TABLE 2: RADIANT SYSTEM OPTIONS

Radiant Option	Advantages & Disadvantages	Comments & Considerations
In-floor radiant heating with forced air cooling	In-floor radiant heat has two major benefits – comfort and efficiency. It has superior comfort because it is positioned along perimeters where the heating loads exist. Warm air rises naturally to the occupied zone and therefore, no fan energy is required and there is no associated fan noise for zone heat. In addition to no fan energy for this heat, heating water temperatures are low, in the 80F-90F range where condensing boilers operate near peak efficiency. A disadvantage may include rezoning constraints for remodeling and higher first cost compared to forced air (fan coil) units.	Zone cooling can be provided with fan coil units or water-to-air heat pumps. This system can accommodate water-to-water heat pumps for ground source and ground-water source options. This could help reduce cost as heat pumps can be used for both heating and cooling. Water-to-water heat pumps come in small enough sizes that one unit could be used for dehumidifying outdoor air while another unit is used for zone temperature control, operating at higher water temperatures where it is more efficient. Boilers and chillers/heat pumps should be operated at the lowest/highest temperatures possible for heating/cooling, respectively. Applications of in-floor radiant heat with massive (poured concrete) floors will have a slower response time and may not achieve typical savings for night setback, but this is a minor issue in the big picture.

Radiant Option	Advantages & Disadvantages	Comments & Considerations
In-floor radiant heating with chilled beams	This option has the same benefits as the previous option with radiant heating and cooling. The advantage for this option over radiant panels is that chilled beams with forced induction using the ventilation air can provide up to five times the cooling per square foot of ceiling used.[4]	Chilled beams are ceiling-mounted water-to-air heat exchangers that use natural and/or forced convection to provide cooling to zones. For free convection beams, air is cooled by the fin-tube cooling coil and the cool denser air falls out of the chilled beam, drawing in warm ambient air from near the ceiling. Essentially, this works like fin-tube perimeter heating, that everyone is familiar with, in reverse. The forced convection option uses a combination of buoyancy and the flow of fresh air to the space to induce air flow across the fin-tube cooling coil.

Recap

New construction programs claim savings relative to the energy code, but even if the energy code is enforced to a reasonable degree, such as reviewing plans and specifications, only equipment performance and certain factors like glazing performance and insulation levels can be verified. Moreover, the codes merely specify that if you build system X, thou shall comply with A, B, and C. The codes do not prohibit energy intensive systems or the use of systems that use excessive high quality energy (electricity) wastefully, such as in electric resistance heating.

Components, envelope, and even lighting and lighting controls are NOT where the waste is in today's new building stock. The major energy saving opportunities are in HVAC system design and control.

Building HVAC systems have evolved from central systems serving multiple zones to overly complex variable air volume systems that border on the impossible to minimize energy consumption, while providing acceptable temperature, relative humidity, and ventilation requirements. The alternative is to return to simple centralized ventilation-only systems with decoupled single zone temperature control. It is as difficult to make these next-gen systems waste energy as it is to minimize energy consumption in central variable air volume systems. In other words, next-gen systems are inherently efficient as a result of their difficult-to-screw-up design and control.

[4] Dieckmann, J., Roth,K., Brodrick, J., (2004) Radiant Ceiling Cooling. *ASHRAE Journal, June,* 42-43

The building design and construction communities need to evolve away from complicated, inherently wasteful, and difficult to control variable air volume systems. Once they understand the following virtues of dedicated outdoor air systems, they will be inclined to design and build these systems as a matter of course.

These systems:

- Are no more complicated to design.
- Can be cost competitive with less ductwork, no variable air volume boxes, smaller fans, and less complex controls.
- Provide better comfort for occupants.
- Save energy and have a lower life cycle cost for owners[5] presenting a competitive edge for contractors.

It should be noted that other promising next-gen design concepts exist, including displacement ventilation. Another option that can be used with some of the dedicated outdoor air systems above includes desiccant dehumidification, particularly where sensible cooling requirements are low relative to dehumidification needs, such as for supermarkets. When compared to conventional variable air volume systems, displacement ventilation systems use far less fan energy, can take advantage of substantially greater free cooling, mechanical cooling works more efficiently at higher temperatures, and less ventilation is required because of the "once through and out" type of air flow.

CNC Programs

Programs should consider requiring these types of systems that are much more likely to save energy for real, as predicted and as compared to typical facilities, rather than in theory and on paper only compared to a somewhat arbitrary energy-code baseline. Custom and prescriptive incentives are available for incremental improvements in component efficiency and envelope performance. Simply recommending a mélange of these sorts of measures for a project is an unfortunate lost opportunity. New construction programs should instead focus on systemic improvements that have real (compared to actual buildings) impacts of 20-50%.

At minimum, facilities that pass through CNC programs should be benchmarked against the Commercial Building Energy Consumption Survey. Variations are expected, but programs with a population of buildings that are substantially underperforming predictions coupled with anemic performance relative to CBECS data are indications that real savings are not being delivered to end users.

[5] Further study is required.