Identifying Disruption in Advanced HVAC Technologies for Commercial Buildings

AUTHORS

Alex Herceg, P. Eng., Analyst (Lux Research)

Yara Bot, Intern (Lux Research)

ABSTRACT

Buildings represent the largest energy end use in the world, consuming one third of all final energy, and half of global electricity. In commercial buildings, almost 40% of this energy is consumed by equipment that conditions indoor environments – heating, cooling, and ventilating them. To improve the efficiency and quality of space conditioning, a number of new entrants have developed advanced HVAC technologies. In this report, we examine the current landscape of advanced HVAC offerings, and evaluate new entrants using the Lux Innovation Grid, a methodology which evaluates the technical merit and business execution using weighted criteria. Lux has conducted comprehensive primary research of emerging startup companies in this space globally (this research is ongoing, and this report draws on data as far back as 2012). While we uncovered promising innovations in heat and enthalpy recovery, there is more activity by nimble sensors and controls companies poised to uproot the large incumbents. As we see HVAC-related technology "servitized," good opportunites for building equipment companies, utilities, and investors will present themselves.

Landscape

We define conventional HVAC as *systems that are tasked with providing a stable, comfortable temperature and humidity while maintaining healthy airflow and air quality.* Building upon this well-established terminology, we describe advanced HVAC as *HVAC systems that make marked improvements to occupant comfort, controllability, and energy consumption when compared with conventional technologies*.

A mix of conventional and advanced HVAC technologies exist in the commercial building stock, and the delineation between the two is becoming blurred. For example, variable-speed drives (VSDs) are now considered standard equipment (and thus "conventional") in new construction. VSDs allow real-time modulation for fans and pumps, and enable advanced control strategies such as system-level optimization and machine learning; Optimum Energy is one company that leverages VSDs to provide advanced cloud-based control.

We have used Lux Research's extensive coverage of emerging and established companies in the Intelligent Buildings space to identify novel advanced HVAC developers. To understand their capabilities, we have classified them using the following technology categories (as shown in Table 1), based on their function defined by the American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE):

Heating: The process of adding heat energy to the space, causing a rise in temperature

Ventilation: The process of supplying air to or removing air from a space for the purpose of controlling air contaminant levels, humidity, or temperature within the space

Air Conditioning: The process of treating air to meet the requirements of a conditioned space by controlling its temperature, humidity, cleanliness, and distribution

Sensors and Controls: Devices for communication to, and feedback from, the equipment, enabling operation

Table 1. Advanced HVAC technologies introduced by startups cover a very wide spectrum

Function	**Technology**	Companies
Heating	Heat recovery air to air	Airmaster
	Heat recovery air to fluid	7AC Technologies
	Heat pump	WaterFurnace, ClimateWell, boostHEAT
	Waste heat recovery	Electratherm, RenewABILITY Energy, Invensor
Ventilation	Enthalpy recovery	UltimateAir, dPoint technologies, Architectural Applications
Air-Conditioning	Evaporative cooling	Coolerado, Thermal Flow
	Thermal energy storage	Ice Energy, Calmac
	Alternative cooling	Astronautics, Camfridge, Xergy
Sensors and controls	Boiler efficiency	Fuelstretcher, Lumec
	Thermostatic control	Save energy systems, Cypress Envirosystems, PowerWise Systems, Telkonet, Vigilent
	Demand control ventilation	Aircuity, Airtest, Apix, Gas Sensing Solutions, Bes-Tech
	Integrated BCS	Cylon Controls, Powerhouse Dynamics, Entic, WEMS International Ltd, Truveon

Technology developers have focused on heat recovery and cooling technologies

Startups are offering heating technologies aiming to recover heat from outgoing air, but also other sources. Heat and enthalpy (heat and moisture) recovery are two promising technologies – though the payback of the latter may stretch beyond the tolerance limit of three to five years (depending on climate). They are best suited to heating-dominated climates, but their penetration to date has been relatively low; the U.S. Department of Energy estimates that 1% of the potential application has been deployed by commercial buildings. An important distinction must be made between heat exchange and enthalpy exchange (the latter also exchanges moisture between air streams). Interestingly, startups have focused their attention mostly on heat recovery from air, such as Airmaster, and 7AC Technologies. There are only a handful of companies that have pursued waste heat recovery from other sources, such as RenewABILITY Energy (drain water capture), and Invensor (adsorption cooling), for example. While the waste heat produced

from industrial processes is quite large and has implications for district heating (as identified as one of the biggest "fuel sources" of district heating systems in Europe (Lux Research, 2014), in-building applications are limited.

Startups introduce new materials to improve the already existing enthalpy wheel. A highly untapped area is enthalpy recovery in the air streams of ventilation. Improvements are made with the help of the enthalpy wheel, which not only recovers sensible heat, but also latent heat, resulting in a transfer of condense and increasing the efficiency, resulting in savings of 25% and a payback time of a little over three years. There are many types of materials that can be used to transfer heat between two air flows, like plastic or aluminum, each with its own properties. We have looked into the startup landscape and found multiple applications when it comes to enthalpy recovery. One of the leaders in the enthalpy recovery area is dPoint Technologies, developer and manufacturer of a polymer-based membrane for energy recovery ventilators. UltimateAir has developed a material called "random fiber matrix," a washable membrane capturing the high amount of 94% of thermal heat and 70% of latent heat out of the passing air stream, depending on weather conditions. Architectural Applications combines their membrane capturing heat and moisture from one air flow, with a dynamic system that is able to adapt to hot and cold seasons.

Cooling technology trends are shifting towards more efficient evaporative coolers and the incorporation of energy storage. Companies have largely concentrated their efforts on the incorporation of thermal energy storage (TES), but there has been some innovation related to evaporative cooling. For example, Coolerado (which was recently acquired by competitor Seeley International), a company specialized in novel indirect evaporative cooling systems, claims to achieve an energy efficiency rating (EER) of 40, while a typical chiller achieves an EER of 12. In the case of alternative cooling (such as magnetocalorics and electrochemical), the technologies in this area are still in the development stage, and we cannot reasonably assess their cost for application in a building. TES developers have been active for quite some time, though focused not on improving performance of cooling systems, but on shifting peak cooling loads (during the day) to times when electricity tariffs are lower (during the night). They achieve this using ice storage, which has almost negligible thermal losses. One startup, Ice Energy, has also proved there are marginal gains to be had from operating condensing equipment at lower ambient temperatures (i.e. night time).

Methodology

The Lux Innovation Grid provides a framework to assess HVAC players' capabilities. To determine the projected performance of HVAC in a building, would-be partners, customers, and investors in this space also need concrete data and logic to measure the performance of start-ups. By conducting primary research interviews with companies developing novel HVAC products, we have compiled information on technical and business performance to assess companies developing technologies that touch an array of applications and markets and operate a wide range of business models. Through this primary research, we assess companies in ten different areas, and assign a score of 1(low) to 5 (high) for each area. In Table 1 below, we have presented an explanation of the scoring rubric we use.

Table 1. Innovation scoring rubric (individual company)

Scorecard metric	Details of scoring rubric
Technology solution	Strength of the company's technical solution (cost and performance)
Addressable market size	Scale of the total addressable market (annual, USD)
Competitive landscape	Extent and threat of competition to company
Barriers to growth	Severity of barriers to overcome to grow
IP position	Assessment of the value of patent portfolio
Regulatory factors	Are regulations supporting or hindering the business
Management team	Strength of the management team
Partnerships	Strength and extent of the partnerships
Momentum	Measure of the progress over time

Working with the scoring data shown in Table 1, we aggregated this into three attributes – technical value, business execution, and maturity. For the "The strength and value of a company's technology determines its Technical Value score. We weighted the scores for technologies or solutions, the addressable market size, the competitive landscape, and IP position to score companies in this area (see Table 2). A company's ability to perform and achieve success determines its Business Execution score. We calculated the score for each company by weighting management strength, profitability, partnership value, overall momentum (see Table 3). The completeness of a company's development reflects its Maturity. To calculate a Maturity score, we weighted company size, stage of development, and annual revenues (see Table 4). On the figure, dot size indicates the company's Maturity on a scale from 1 (immature) to 5 (developed). A company's success is measured holistically by the Lux Take.

Table 2. Technical value criteria

Criterion	Description	Weight
Technology/solution value	Qualitative measure of the value of a company's offering, in terms of performance and price	40%
Addressable market size	Quantitative measure of total addressable market for the company's products	20%
Competitive landscape	Qualitative rating of the strength and amount of competition a company faces	15%
IP position	Qualitative measure of the value of the company's patents or trade secrets and considers defensibility	25%

Table 3. Business execution criteria

Criterion	Description	Weight
Barriers to growth	Qualitative measure of a company's obstacles to commercial growth	25%
Management team	Qualitative measure of the strength of the company's executive team, including ability to lead a small company, connect with industry, commercialize technology, and technical ability	20%
Partnerships	Qualitative measure of the strength and number of a company's partnerships	30%
Momentum	Qualitative measure of the rate of a company's progress	10%
Regulatory factors	Qualitative measure of the influence of regulations on the company's growth	15%

Table 4. Maturity criteria

Criterion	Description	Weight
Employee count	Number of employees	30%
Stage of development	Qualitative score based on stage of development of the company's primary product	30%
Revenue	Company's total revenue in the previous fiscal year	40%

The “Lux Take” is an overall ranking mechanism based on the considerations taken in the above areas, placing companies into five categories: Strong Caution, Caution Wait and See, Positive, and Strong Positive. Colors ranging from red (Strong Caution) to blue (Strong Positive) indicate the Lux Take. It’s important to note that Wait and See is not a neutral judgment; instead, companies with this assessment face significant unknowns regarding their technologies or markets that can’t be meaningfully judged today. After evaluating each company by the above four factors, we mapped them across four quadrants.

“Dominant” companies are HVAC top performers. With both strong business execution and technical value, these companies make strong partners and good investment targets. Companies in this group are often first to the market with disruptive technologies, and should be poised for solid growth.

“High potential” companies have attractive technologies, but little to show for them. This group contains both young companies struggling to gain market share and older companies unable to capitalize on their technologies or solutions.

“Undistinguished” companies perform well in the market despite lacking high technical value. These companies overcome competition not with best-in-class technologies or solutions, but with good strategy and efficient execution.

“Long-shot” companies lag behind in execution and lack valuable technologies. Companies in this quadrant may not be risky forever, however; they can escape through technological advancements leading to more attractive products or better-conceived strategies, speeding up market adoption.

Results

We have separated our analysis into two separate sets of companies. The first set are those advanced HVAC developers that focus on “core HVAC” technology, such as novel chillers, heat and enthalpy hardware, etc., as presented in Figure 1. The second set of companies are those that produce sensors and controls that enhance the performance of existing “core HVAC” hardware. Examples of these technologies include connected thermostats, indoor air quality sensors, and so on; the landscape of these companies is shown in Figure 2.

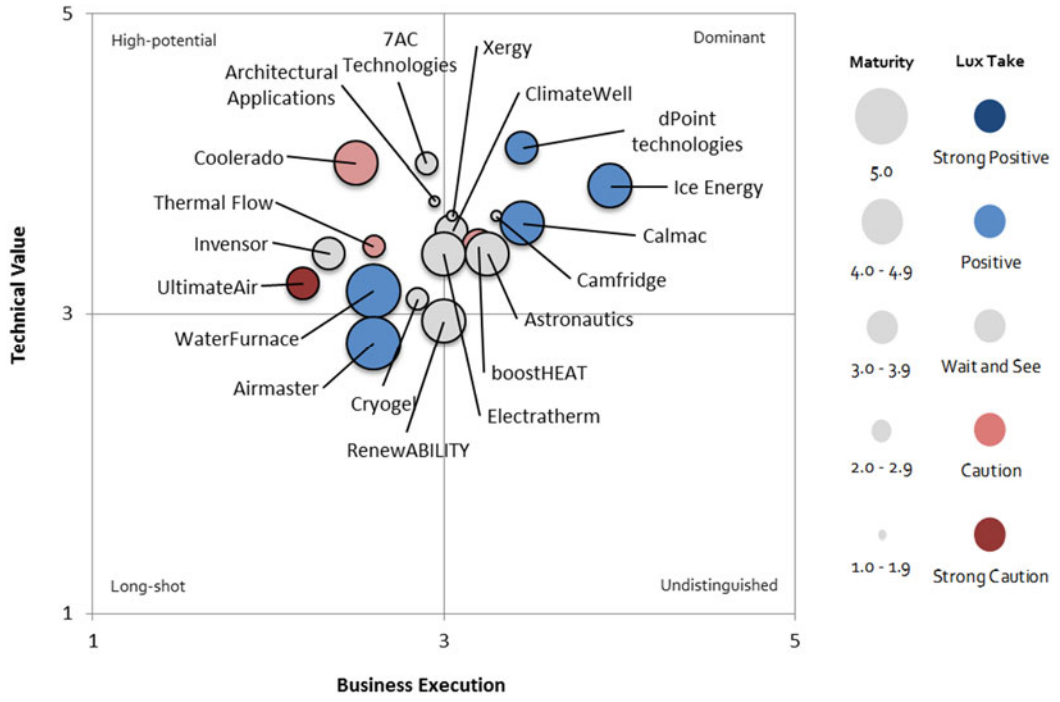

Figure 1. Business execution is the key differentiator in a crowded field of heating-dominated technologies. *Source*: Lux Research

Core HVAC technology development has a long path to scale

We see that the landscape of core HVAC technologies is relatively crowded, with companies mostly focusing on heating-related technologies. Overall, the technical value scores range between a moderate to a good score; the key differentiator is in the business execution score amongst these companies. Based on the relative positioning of the various players on the Lux Innovation Grid, we find the following conclusions.

Several TES storage companies appear promising, but scalability is a challenge. Developers of TES storage (using ice) dominate the high-potential category; however, it is important to note that there are two divergent strategies that these startups use. The first is to pursue utilities, using TES as a demand side management (DSM) tool, such as Ice Energy. The second is to market the hardware directly to commercial customers with the aim of lowering their demand charges; Calmac uses this strategy. Ice Energy has succeeded in the utility market, having grown to 15MW of capacity across 1,000 sites; however, its geographies depend on local offers for storage from utilities, which limits its geographic expansion. Calmac has installed storage capable of shifting more than 1GW of cooling capacity globally; however, its growth in recent years has been modest (less than 10%), as it struggles with a payback that may stretch up to five years. We believe TES could be an interesting technology as distributed generation continues to rise, particularly in cooling dominated climates. Cyrogel lags behind its competitors largely because it is in the introduction stage, as opposed to the others who are scaling. The company was established in the late 1980s; however, it has struggled to increase revenues over $1 million. The company could potentially be an acquisition target given it has limited debt, is cash flow positive, and has limited IP around the design of its ice storage balls.

Ventilation related technology leaders differentiate on fundamental material innovations. There are several companies in Figure 1 that focus on innovating around ventilation air delivery. However, the successful ones are those that have leveraged a key technical differentiator, such as dPoint Technologies. This Canadian startup has devised a new approach to enthalpy recovery of exhaust air, using a stacked polyethylene membrane. This membrane means it has no air leakage between incoming air and exhaust air, allowing it to be used in sensitive applications, such as health care buildings. This stands in stark contrast to competitor UltimateAir, which relies on conventional enthalpy wheels to facilitate heat and moisture transfer. Its performance on sensible heat recovery. The two have comparable performance for latent heat transfer (up to 70%), and while UltimateAir edges ahead on sensible heat transfer (94% vs. 70% for dPoint), its equipment capex is more than 10 times that of dPoint, at $9.50 to $11.50/cfm. Architectural Applications (A2) is another interesting company targeting ventilation innovation. The company is attempting to shake up the building envelope market by incorporating enthalpy exchange membranes into the building façade itself. The company recently secured its first revenue-generating projects, and is seeking ASTM certification for its product. While the company has filed nine patents, it is worth mentioning that A2 relies on dPoint's membrane, albeit manufactured using a very specific geometry. Companies that only focus on heat recovery (and neglect moisture transfer) are not as versatile as the aforementioned players, and thus must prove more competitive on cost. However, as the unfavorable positioning of AirMaster shows, this approach is difficult.

Limited prospects exist in novel cooling equipment, outside of niche applications like data centers. While there are promising technologies related to addressing cooling energy efficiency through ventilation, we cannot say the same for core cooling technology. Coolerado, which has developed a completely different approach to chilling air (using a working air stream to dehumidify incoming air), is the one standout in the space. It has pursued several patents around this cooling technology, but lacked the distribution partnerships to scale up. From 2010 to 2012, the company actually sustained negative revenue growth; however, it recovered in 2014, and in mid-2015 it was acquired by competitor Seeley International. Apart from this bright spot, novel developers like 7AC Technologies and Thermal Flow are aiming to replace conventional compressors in refrigeration equipment, which is proving a tough argument in a risk-averse industry. Another compressor replacement option is magnetocaloric chillers, which to date have been limited to prototypes for appliances by leaders Astronautics and Camfridge. Their quiet operation may eventually make them suitable for appliances and certain building segments (e.g. hotels); however, the cost of permanent magnets is still an inhibitor. Similarly, electrochemical refrigeration is still some time away from mass market adoption. Xergy, however, will be manufacturing sub-components, such as membranes and membrane and electrode assemblies, for applications like fuel cells, sensors, batteries, and de-humidification systems this year; it will aim to produce electrochemical compressors in volume in a few years. Conversely, many startups, such as Iceotope, have been active in the data center cooling market, particularly focused on cooling servers. Due to the high process cooling demands, several companies have devised unique liquid and immersive cooling solutions; these are not generally suitable for building applications.

Many new entrants are enabling advanced HVAC control strategies

Moving on from core HVAC equipment to companies developing sensors and controls to enable better operation of HVAC, we find a crowded landscape. There is a wide distribution between players in terms of their technical and business execution scores, and a strong correlation between "Lux Take" and the position on the grid – with only Strong Positive and Positive companies emerging as "Dominant."

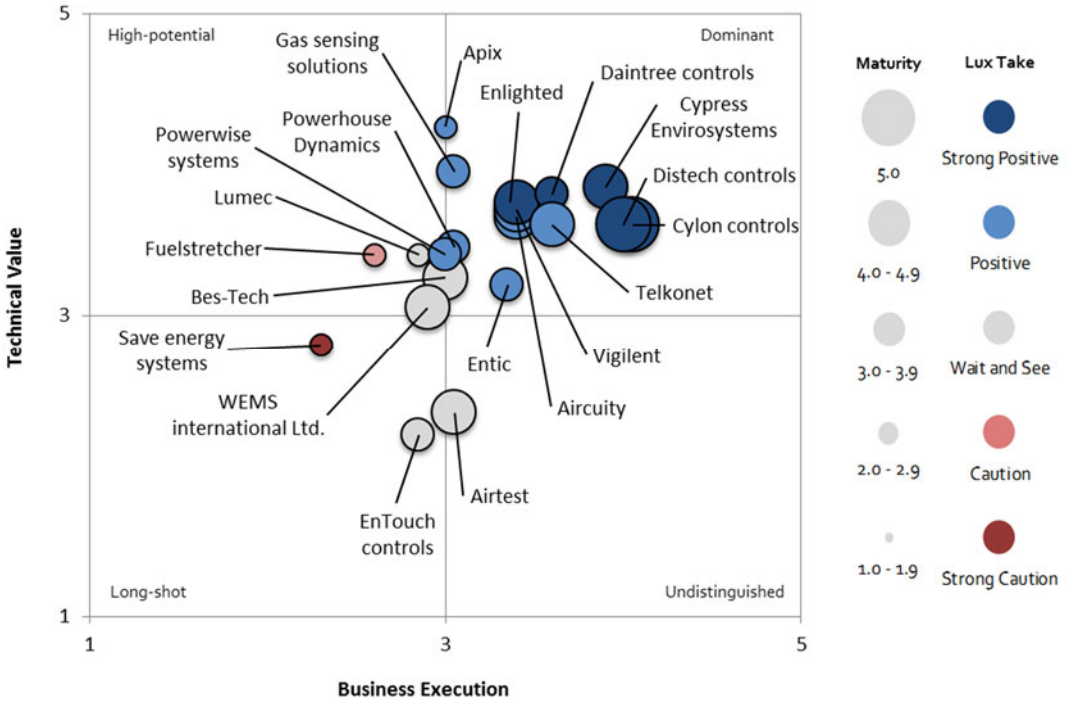

Figure 2. A wide distribution of technical values and business executions exists in the HVAC sensors and controls landscape. *Source*: Lux Research

There is high value in targeting specific building types, such as hotels and data centers. While the "Dominant" quadrant is crowded, several of the companies have one trait in common – they are all focused squarely on a narrow vertical. Telkonet, for example, is focused on the hotel and hospitality segment. Its thermostats, while similar in capabilities to many of the competitors, are programmed to properly manage temperature drift (from a pre-defined set point); this is how it minimizes cooling unoccupied guest rooms, despite constantly-fluctuating occupancy. Similarly Vigilent is exclusively focused on the data center segment. The company uses a network of temperature sensors, coupled with HVAC controllers, to minimize hot spots among data center server racks. The goal is not only energy savings, but also minimizing equipment failures in mission-critical applications due to inadequate cooling.

Having a full suite of sensing and controls products is resonating with customers. The most pervasive type of companies across the "Dominant" quadrant are those with comprehensive building sensing and control product suites. Specifically, Daintree Networks, Cylon Controls, Enlighted, Distech Controls, and Entic all touch multiple building systems, with the core primary systems being HVAC, lighting, and security. Building owners are showing insatiable interest in these platforms, and both Daintree and Enlighted have noted growth of over 300% over the past

12 months. The companies that can supply a comprehensive solution mean owners can centrally manage major functions, such as lighting and temperature control – a strong benefit. A company like Distech Controls moves a step deeper, as it not only has basic thermostatic and lighting control, but it also makes a full suite of building automation sensors (such as flow, pressure, etc.) and controllers. This allows it to target building owners for new construction and retrofit opportunities, but also large HVAC OEMs, such as Johnson Controls, who purchase its white-labeled components.

Hardware heavy offerings need to be "servitized." Several of the companies mentioned above, such as Entic, have begun to offer a packaged service model instead of selling hardware alone. This is subtly different from Enlighted, which offers turn-key, third-party-financed lighting retrofits. In the case of Entic, the company is amortizing the cost of its hardware and charging building owners a monthly fee – which includes installation. As we recently pointed out in a report benchmarking building energy management hardware and software, the costs of managing energy in a building are shrinking (Lux Research, 2015). Some startups are bucking this trend, and still offer hardware-heavy solutions with a relatively high capex compared to their peers, such as Powerhouse Dynamics and PowerWise. EnTouch Controls is another full-service controls company; however, its analytics are fairly basic, on top of mediocre execution.

Technologies that enable demand control ventilation are on the cusp of high potential. As we pointed out in the Landscape section, DCV is has the potential to drastically reduce HVAC energy, based on established methods of modulating ventilation rate based on CO_2 concentration. Aircuity enables DCV by sampling air from various building zones continuously to adjust exhaust and intake air accordingly. To date, Aircuity's cost of $3.50/ft2 to $7.00/ft2 offers a much more acceptable payback in critical environments, such as laboratory and health sciences buildings, with high outdoor air and exhaust rates. Widening the net to other building types is Gas Sensing Solutions, which manufactures a low-power wireless gas sensor module. The company generates 60% of its revenue from building applications (in addition to horticulture and mining), but expressed big aspirations to scale up production and bring in a strategic partner. Apix has developed a gas chromatography sensor for measuring indoor volatile organic compound (VOC) levels, which would be useful for indoor air quality sensing; however, its sensor costs are too high for the mass-market of commercial buildings presently.

Boiler efficiency startups have struggled to scale up despite novel products. Both Fuelstretcher and Lumec are interesting from a technical standpoint. However, due to exceptionally poor management scores, they slide into the "High Potential" quadrant. Specifically, both of these companies have struggled to generate partnership activity. Both of these companies could potentially represent an acquisition opportunity for a boiler manufacturer or building controls company with an interest in diversifying. In a similar vein, Bes-Tech has gained limited adoption, but has a large potential market given the high proportion of rooftop-mounted packaged equipment in North America.

Large companies interested in HVAC technologies need to be proactive

Utilities and telcos can leverage building sensing and controls companies to cross-sell services. The rise in building services, from various flavors of BEMS software, to turn-key hardware installations mean the business-to-business (B2B) and business-to-business-to-

consumer (BBC) markets have room to grow. Utilities and energy retailers can leverage many of the companies' services to offer differentiation and further engage with their customers. In fact, as credit markets continue to loosen, there is third-party capital available to finance projects – all that is needed is a channel. The startups mentioned above are different from energy services companies (ESCOs) in that these are targeted products, rather that invasive whole-building energy retrofits, and for this reason they should be actively explored, particularly in the area of indoor air quality.

Large building equipment controls companies must proactively partner with or acquire HVAC tech developers. Just as in the BEMS software space, startups are innovating faster with HVAC technologies than their larger incumbent peers. These companies should look to partner or acquire companies of interest in the near term. This has already begun, as the Zehnder Group established a strategic partnership (and then acquired) dPoint Technologies, and Seeley International acquired Coolerado in mid-2015. Similarly for sensing and controls startups, Acuity Brands acquired Distech Controls early in 2015, and Ingersoll Rand's building equipment company Trane has engaged several startups to supply software for its "comfort as a service" offering.

Investors in HVAC technologies will need to be patient, and bring in a party with expertise. As we pointed out in a venture capital funding survey in 2012, many startups in the building systems space raised an increasing number of rounds of financing in the late 2000s. While some of this increase is attributable to the increase in the cleantech (and building energy efficiency) space, it is also indicative of the long time horizon from inception to scale and profitability of many of these companies, particularly on the hardware side. Taking the recent exit of Coolerado as an example, the company was 11 years old at the time of acquisition. dPoint Technologies, while realizing strong revenue growth, has also been in existence more than a decade. Investors should be aware that hardware development is time and capital intensive, as is scaling sales. And, in many cases, startups in this space are not interested in dilutive investment from VCs, but would welcome strategic investors who will bring channels but also opportunities for synergies.

Conclusions

Many of the "core HVAC" and sensing and control companies began by targeting energy efficiency through technical product gains; however, industry attention is beginning to shift to other added value, such as indoor air quality and bundled services. We present the following outlook for the future of advanced HVAC:

Technologies that focus on delivering enhanced ventilation will be strong area of near-term growth. Innovative ventilation technologies centered around heat and moisture recovery, and demand-controlled ventilation are poised to take off. Technologies like heat recovery for ventilation receive regulatory support from ASHRAE 90.1 guidelines, which are increasingly being incorporated into local building codes to drive energy performance. Adequate ventilation also improves indoor air quality, which is one of the foci of third-party green building rating systems, such as LEED. To better manage ventilation, heat and enthalpy recovery technologies are needed, as well as indoor air quality sensing, particularly for CO_2.

Large building controls companies are entering a period of change. Commercial building HVAC was previously a notoriously difficult market for new entrants. Large companies, both on the "core HVAC" equipment side (e.g. Carrier, Vaillant, Daikin, etc.) and on the building sensing and controls side (e.g. Johnson Controls, Schneider Electric, Honeywell, etc.), dominate the landscape. These incumbents will be competing with the upstarts shown in Figure 2, many of which have strong momentum and solid technology. These companies are attempting to gain market share through nimbly installing their own connected devices and offering services – competing with traditional building controls and automation companies. This trend will only continue, as more developers bring connected devices to the market.

Companies in the HVAC space will depend on channel and strategic partnerships for success. Across the board, the successful companies are those that are able to leverage strategic partners for investment, and channel partners to scale. The real estate industry will continue to be risk-averse, and the construction companies (the installers of hardware) will continue to be fragmented and regionally focused. While the venture capital funding in building HVAC technologies is likely to recede from mid-2000 levels, we predict a rise in strategic partnership activities with startups.

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