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Recovering from the Backslide

A little over 4 years ago, I wrote an editorial for another journal (*Energy Engineering*, Vol. 114, No 2, "And Now for Something Completely Different," p 5-6), where I expressed that I was not that concerned about what the (then) new U.S. administration might do to our industry (energy management). I was a bit naïve (apparently) as over the next four years I read about an administration doing its level best to undo years of progress.

Now, I am wondering how long it might take our new U.S. administration to undo the hidden damage caused by the previous administration. I had thought that good energy management was not just a Democratic or Republican position. I had thought that both parties understood the long-term positive outcomes; I had thought they just had different pathways toward the end goal. Now, I am not so confident.

I was right about one thing (thank goodness). U.S. federal agencies are (mostly) occupied by career staff that are dedicated to the ultimate goals and foundations of their associated agencies. Programs within the U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, as well as the U.S. Environmental Protection Agency, Office of Atmospheric Programs, found a way to survive (and even make a little progress). I look forward to the confirmations of the current nominations for Secretary of Energy and Administrator of the Environmental Protection Agency. They are both highly qualified and should be successful in advancing the missions of their respective agencies.

For the record, if you happened to work for a U.S. government energy-related program during the past 4 years, I would appreciate hearing (i.e., reading) about your first-hand knowledge, if you would be so bold as to write about it. If possible, we might be able to keep your anonymity. Although I accept that it is a small world, therefore anonymity may not really be possible. Still, I urge you to share your story. You deserve an award, and we could certainly learn from your endeavor.

Energy management has accomplished some amazing feats over the past year. I recently read that during 2020, renewable energy generation

of electricity exceeded that generated by fossil fuels in the European Union (this excludes electricity generation by nuclear). During 2019 in the United States, renewable energy generation of electricity exceeded that of coal. One of my editorial board members dismisses such progress saying it does not mean much until we also address thermal, as well as transportation, energy. This is true, and toward that aspiration, China has been manufacturing and selling in excess of 1 million electric vehicles per year since 2018. I think Europe makes about 750,000 per year and the U.S makes about 500,000 per year. That is less than 3% of the world market, but it is growing. General Motors (GM) has announced that they will be all electric by 2035. Personally, I hope they can pick up the pace. I am not sure we can wait that long.

On a personal note, we have a new permanent home. The nomad life is over (for the time being). Myra and I found a nice home on the Deschutes River in Bend, Oregon. It is a very outdoor-life community. We get to ski Mt. Bachelor during the winters, which we have frequently enjoyed, and I hear the summer activities are even grander. Time to get new bicycles and get to know the area. Hope all of you are doing well. Keep safe.

Steven Parker, PE, CEM Editor-in-Chief, International Journal of Energy Management A journal of the Association of Energy Engineers saparker@aeecenter.org

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The *International Journal of Energy Management* is a premier publication of the Association of Energy Engineers (AEE). The journal is published six times annually for the benefit of AEE's international membership.

The journal invites original manuscripts involving energy management, applied engineering, or analytical approaches to energy management, including (but not limited to) energy engineering, energy awareness, conservation, high-performance buildings, commissioning, sustainability, utility-resource management, utility deregulation, and alternative financing. The journal provides a peer-to-peer communication channel for practicing energy managers, engineers, academics and sustainability professionals.

All articles should be of a practical nature covering energy management, energy efficiency, or other issues of interest to practicing energy managers. If the article appears to be basic research oriented, the author(s) must explain in a leading paragraph why practicing energy managers should know the material. Articles should typically be 6,000 words or less (\sim 1,000 words minimum to \sim 8,000 words maximum). The author(s) may choose either editor review or peer review of their manuscripts.

Articles are published in the English language. All submissions must be the original work of the author(s). The journal does not accept manuscripts that have been previously published by other journals. All accepted articles are published without costs.

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The Possibilities to Finance Building Renovation through Energy Performance Contracting in Slovakia, Central Europe

Veronika Gombošová Michal Krajčík

ABSTRACT

We present the possibilities of using energy performance contracting (EPC) in Slovakia in the region of Central Europe. The first part of this contribution describes the potential to use EPC in Slovakia. The second part is a case study of an apartment building in Bratislava, Slovakia, carried out in 2019. The case study contains inspection of the building, an energy audit with a proposal of energy efficiency measures, and profitability calculations for the measures. Subsequently, a package with suitable measures was created and its suitability for financing by EPC was evaluated. Although some of the potential energy efficiency measures have a negative simple payback, they were recommended for inclusion in the EPC project to allow for a complex building renovation. With an adequate combination of energy efficiency measures, the required payback period of 15 years was attained. Thus, using EPC for complex renovations can be feasible under current economic conditions.

INTRODUCTION

Buildings are an important part of our daily life because we live and work in them. Besides, for example, the urban population spends about 90% of their time indoors. At present, part of the households in Slovakia still have roofs that are not properly insulated and leak, suffer from moisture or mold or have little daylight. Complex or in-depth renovation of a building is typically carried out 30 to 40 years after its construction or previous recovery. Therefore, special attention must be paid to the quality of the current construction or renovation of buildings now, so that they can provide their users with a safe and healthy environment under

economically affordable conditions even in 2050.

An important obstacle to investing in the quality renovation or construction of buildings is, among other things, funding. In most cases, the building owners or investors choose a bank loan as a source of financing. In a few cases, the financing comes from owner capital. However, alternative financing methods exist such as energy performance contracting (EPC). The main advantage of EPC is that financing and the related risk are taken over by an energy service company (ESCO). The present study focuses on the state of energy services, specifically EPC, in Slovakia, a country located in Central Europe. A case study of an apartment building is presented to demonstrate the feasibility of using EPC in Slovakia.

ENERGY SERVICE

An energy service is a service provided under a contract between an energy service provider and a recipient of the energy service. The result is verifiable and measurable (or estimated) energy savings that improve energy efficiency and allow for a financial or material advantage for all parties involved because of the more energy-efficient technology or activity. Such activity includes operation, maintenance or control necessary to provide an energy service [1]. The energy service can be provided as an energy support service and/or as an energy service with guaranteed energy savings. Energy services provided in Slovakia are based on Act no. 321/2014 Coll. on Energy Efficiency and Amendments to Certain Acts [1], where the energy performance contracting and energy performance contracting support are defined. Following the Slovak law, EPC entails an energy service provided under an energy efficiency contract with guaranteed energy savings, which must be in writing. The subject of this contract is the elaboration of an energy study, a proposal for energy-saving measures and economic evaluation. The specific guidance on how to perform the actions as required by Act no. 321/2014 Coll. are defined in Decree no. 99/2015 Coll. [2]. For example, the Decree provides a sample application for the completion of a proficiency test needed to obtain the permission to provide EPC, as well as a sample form needed for announcing the initiation, modification, or termination of EPC. The details on how to elaborate the energy audit, which is a critical part of each EPC project, is provided in Decree no. 179/2015 Coll. on energy audits [3].

The Process of an EPC Project

Figure 1 illustrates the principle of EPC. At first, the building has a certain energy consumption (baseline), which may be considered too high by the owner. To reduce energy consumption, the owner of the building can see EPC as an option. In such a case, the owner solicits through public procurement, and the ESCO responds by bidding. If the owner is satisfied with the offer from ESCO, they subscribe to the agreement. A model contract for Slovakia is published on the website of the Ministry of Economy of the Slovak Republic [4]. After the subscription, the ESCO performs an energy audit of the building, where the efficiency measures are proposed, evaluated, and recommended. The contract is usually signed for 6 to 10 years [5]. However, if there is a reliable investor, for example, the Government or a municipality, the duration of the EPC project could be signed for a longer period, up to 15 years. During this period, the ESCO guarantees savings. These savings reduce the energy consumption of the building and are used to pay back the initial investment costs, which were paid by the ESCO. At the end of the contract, the building hopefully has

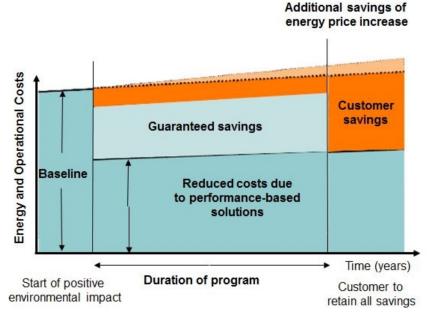


Figure 1. Process of the EPC Project [Source: European Association of Energy Service Companies [17], used with permission.]

substantially lower energy consumption as compared to that before the renovation, and the savings now belong to the customer.

Energy Service Company (ESCO)

Usually, the EPC is provided by an ESCO. ESCO can be a person or a legal entity that provides energy services. At the same time, ESCO assumes the technical and financial risk that arises from the design of energy efficiency measures, their implementation, and operation throughout the project. The project funding can vary; but usually, the ESCO or investors choose a bank loan.

FUNDING OF EPC PROJECTS

An essential part of EPC is the energy performance contracting business model (EPCBM). EPCBM determines the kind of contract for the EPC projects, which has a significant impact on the project's performance [6]. Yet, each of the EPCBM types impacts the EPC project at a different level because various types of EPCBM have their characteristic features related to financing and risk-sharing [7][8][9]. The three main types of EPCBM are the shared savings model, guaranteed savings model, and chaffee model [10]. EPCBM identifies the roles of energy customer and ESCOs and defines the participants' responsibility and risk-sharing in an EPC project [11][12]. It also clarifies the allocation of cost savings [13]. EPCBM determines the contract kind of the EPC project and has an essential impact on energy-saving performance [14]. Although barriers to the implementation of an EPC exist (such as unsound policies, imperfect credit system [12], and financing difficulties [15]) if properly implemented, EPCBM should lead to a win-win situation [13]. Once selected, the EPCBM cannot be changed freely, or participants in the project will pay a fine.

Shared Saving Model

The most common model in Slovakia is the shared saving model. In this EPCBM, the ESCO organizes financing of the total upfront capital cost of the project and is responsible for repaying the lender, therefore assuming performance, credit, and energy price risks. The client pays the ESCO a pre-determined percentage of its achieved cost savings from the project.

Guaranteed Savings Model

In the guaranteed savings model, the ESCO designs and implements the EPC project but does not finance it, although it may arrange for or facilitate financing. The ESCO guarantees that energy savings will be sufficient to cover debt service payments [12][13].

Chaffee Model

In the chaffee model, the ESCO is responsible for the operation and maintenance of the entire energy system for energy customers and they burden the energy costs [15]. The ESCO manages and transforms the energy system for energy customers by self-financing according to targets as defined in the contract. The ESCO obtains all the energy savings if it achieves the targets. Otherwise, it must pay for the shortage to the customers as compensation [6].

Funding of EPC Projects in Europe and Slovakia

In general, EPC is a financing solution with guaranteed savings, whatever the funding form. Customers can opt for EPC, regardless of funding [5]:

- to achieve guaranteed savings, thus ensuring the predictability of the economic results of the project,
- to use the competitiveness of EPC procurement in the case of complex solutions, so that the best solution for finding a provider can be found to obtain the most cost-effective solution in terms of cost-benefit.

Figure 2 expresses the percentage of the financing methods in selected 15 countries in Europe. This chart is based on the survey of ESCO in the Europe. The enterprises were asked about the financing method they most often use in their projects [16]. In most of the cases, EPC projects are large projects, and to cover all costs related to the project, enterprises or clients often use the opportunity to borrow money. However, they can only borrow enough when they are financially stable.

Figure 3 describes the financing methods in Slovakia [16]. Most of the EPC projects are funded by a loan borrowed by an ESCO. In many cases, not every designed energy efficiency measure can be done under EPC and the ESCO tries to find another way to fund the measures. In such a case, the most common option is a combination of EPC with a

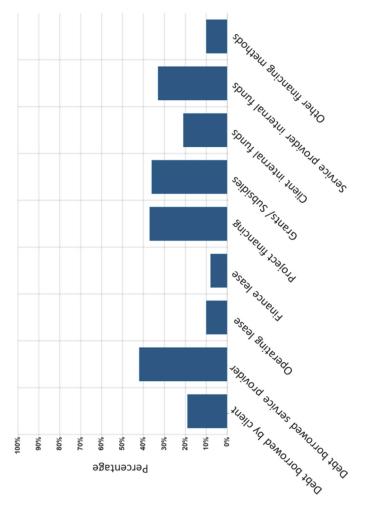


Figure 2. Financing Methods of EPC in Selected 15 Countries of the European Union [Source: QualitEE [16], used with permission.]

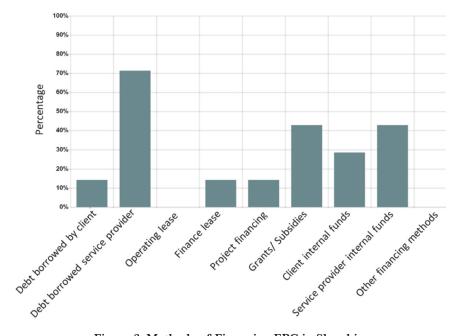


Figure 3. Methods of Financing EPC in Slovakia [Source: QualitEE [16], used with permission.]

contract for work, meaning that a part of the energy efficiency measures are funded by the EPC, whereas the other renovation measures are funded by another way.

CASE STUDY—AN APARTMENT BUILDING IN BRATISLAVA, SLOVAKIA

The apartment building studied, shown in Figure 4, is located in Bratislava, the capital of Slovakia. It consists of 13 floors above ground with an average floor construction height of 2.9 meters. The built-up area of the building is 373 square meters, and the heated volume is 13,649 cubic meters. In 2018, the building underwent a partial reconstruction, when the original openings (windows) were replaced with new ones with insulating double glazing and a plastic frame. The building is built as a prefabricated wall panel system called BA-NKS. The perimeter cladding consists of sandwich construction with a thickness of 300 millimeters. The roof consists of reinforced concrete panels with a thickness of 200 millime-





Figure 4. The case-study apartment building in Bratislava

ters and is insulated with insulation with a thickness of 50 millimeters.

The heat source for the apartment building is a gas boiler room, located on the first floor. The boiler room is equipped with seven gas suspended condensing boilers with a total heat output of 395.5 kW. The boiler efficiency is approximately 86%. The heating system is controlled by equithermic control strategy, i.e., based on the external temperature. The heating system is fitted with 205 cast iron heaters, fitted with thermostatic heads. The preparation of domestic hot water is centralized using two storage heaters with a volume of 750 liters each. The lighting system and sanitary installations have undergone a partial reconstruction.

Energy Inputs

The average annual energy and water consumption in the building for over 3 years (2016 to 2018) is shown in Figure 5. The average annual electricity consumption was 174.1 MWh, in financial terms $20,351 \in$ per year. The average annual consumption of natural gas was 86,900 cubic meters per year, in financial terms $31,224 \in$ per year. The average annual water consumption was 10,300 cubic meters per year, in financial terms $19,051 \in$ per year.

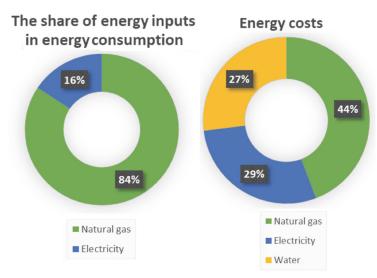


Figure 5. Share of average annual energy and water consumption and energy costs

Part of the energy audit needed for EPC entails the calculation of heat losses and the energy needed to cover the losses. The energy needed to cover the heat losses was 705.5 MWh, assuming solar and internal heat gains of 181.1 MWh and the heat gain utilization factor of 95%. The calculated energy demand for space heating, including heat gains, was 532.6 MWh. The share of various structures on the heat losses is shown in Figure 6.

Energy-efficient Measures Considered

Given the building operation and the level of energy consumption, energy efficiency measures were proposed to reduce the energy consumption, as shown in Table 1.

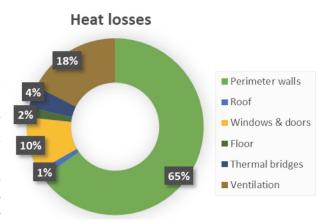


Figure 6. Share of Various Structures on the Heat Losses

Table 1. Designed Energy-saving Measures

Fnarov-afficient Massura	Investments	Savings	Simple Payback
	(€)	(€/year)	(year)
Perimeter walls insulation	175,000	19,177	9.1
Flat roof insulation	12,500	244	51.2
Replacement of doors and windows	17,500	542	32.3
Solar system installation	18,900	637	29.7
Photovoltaic panels installation	7,650	440	17.4
Heat source reconstruction	16,500	474	34.8
Sanitary equipment reconstruction	2,164	3,714	9.0
Lighting system modernization	11,600	3,350	3.5
Energy management system implementation	3,920	1	1

Energy-efficiency Measures for EPC

Previously, it was mentioned that EPC project duration is usually 6 to 10 years; however, in certain cases, the project duration can be up to 15 years. The basis of an EPC project quality is the selection of appropriate energy efficiency measures. Therefore, in the next step the measures that have the most significant impact on energy consumption and operating costs are discussed.

When calculating the investment to an EPC energy efficiency measure, it is necessary to take into account the additional costs of financing the measure by EPC and thus increase the investment for the measure. The ESCO guarantees the energy savings for the whole renovation package funded through EPC over the contract duration.

For this reason, the additional costs related to the risk, management, insurance or reparations, must be reflected in investment costs. The EPC simple payback is calculated as follows:

In some cases, the annual cost of the EPC energy efficiency measure may be higher than the related annual savings, which results in a negative simple payback of the specific measure. However, with a suitable combination of individual energy efficiency measures, we can obtain a favorable overall payback for the EPC project. Table 2 lists the measures that were considered appropriate for the case-study EPC project.

EPC Project Duration

In this case, because the owner of this building is the city, and thus has several buildings under management, it can commit itself to continue to pay the same costs and that there is no downtime. This reduces the risk for the ESCO and enables a longer duration for the project. In this case, the duration of the EPC project of 15 years was therefore enabled. The financial summary of the EPC project is shown in Table 3. Although some of the selected measures have a negative simple payback, combining them with profitable efficiency measures result in a net payback period of 15 years.

Table 2. Energy-efficiency Measures Considered Suitable for EPC

Energy-efficiency Measure	Investments (€)	EPC Investment with Funding (€)	EPC Savings (€/year)	EPC Project Costs (€/year)	EPC Simple Payback (year)
Perimeter walls insulation	175,000	210,000	19,177	7,875	18.6
Photovoltaic panels installation	7,650	9,180	440	344	95.8
Heat source reconstruction	16,500	19,800	474	1,238	-26.9
Lighting system modernization	11,600	13,920	3,350	870	5.6
Sanitary equipment reconstruction	2,164	2,597	3,714	162	0.7

Table 3. Key Parameters of the EPC Project

Investments Savings Payback Investment Savings Payback Investment Savings Costs Payback (€/year) (€/year) (€/year) (€/year) (€/year) (€/year) (€/year) (F/year) (F/year)		
Savings Payback Investment (€/year) (year) (€) (128,578 9.3 212,914 255,497 27,155	EPC Simple Payback (year)	15.3
Savings Payback Investment (€/year) (year) (€) (9-3) (12,914 255,497	EPC Costs (€/year)	10,489
Savings Payback Investment (€/year) (year) (€) 28,578 9.3 212,914	EPC Savings (€/year)	27,155
Savings Simple (€/year) (year) (year) 28,578 9.3	EPC investment with Funding (€)	255 ,497
Savings (€/year) 1	EPC Investment (€)	212,914
	Simple Payback (year)	9.3
Investments (€) 265,734		28,578
	Investments (€)	265,734

CONCLUSION

The energy performance contracting has been used in Slovakia mainly since the late 1990s until 2006. During that time, approximately 20 projects were carried out in the public sector. From 2006 until 2011, the EPC partially passed into the background because of the subsidies on building renovation from European structural funds. Turnover came in 2012, when the interest in EPC started to rise and over about a year and a half, 5 to 15 projects were carried out. These projects were focused on hospitals and school renovation and public lightning modernization. Since 2012, EPC has been regularly used as a funding scheme for energy-efficient renovation.

At present, building renovation in Slovakia is often very much focused on insulating the building envelope. The case study of EPC of an apartment building has shown that renovation of the technical systems may be more feasible than the renovation of building structures. Renovation of technical systems may be especially suitable for EPC, and combining the renovation of technical systems with that of building structures can shorten the payback period down to the level acceptable for EPC. In this way, the EPC can be a suitable financing tool even for complex building renovations.

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Smarter Buildings with Better Data*

Thomas George, Matthew Mininberg, Rebecca Wertz

ABSTRACT

Improvements in data collection and the push to integrate more internet of things (IoT) devices in buildings play a critical role in how organizations measure the energy usage of a building system or space. With circuit level monitoring, property managers have the ability to get a detailed analysis of their building. This leads to easier compliance with regulations, generates savings through improved operational and investment decisions, and provides an easy way to monitor building performance.

Quickly advancing technologies are now able to interact with complex building automation systems, taking that overwhelming amount of data and transforming them into a detailed resource accessible via secure cloud storage on a unified dashboard. With quicker access to more accurate data, property managers can drive changes leading to better building systems and energy efficiency.

INTRODUCTION

The collection and analysis of building data gives building owners the necessary tools to achieve real energy savings and increase operational efficiencies. On a macro-level, harnessing building energy data provides a key opportunity for the United States to cut both its energy spend, as well as its CO_2 emissions. This is primarily because almost 40% of the United States' energy consumption comes from buildings [1]. With 63% of building electricity generation coming from fossil fuels, reducing building emissions is no small undertaking [2].

^{*}Based on a paper presented at the 2020 Virtual AEE World Energy Conference.

Storing energy data is the first step a building owner should take towards reducing their building's energy usage. This allows building owners to keep track of key performance metrics, which can be used to make informed decisions regarding building operations and energy management. Choosing the best technology to reduce or optimize a building's energy spend is oftentimes overwhelming. This is especially true when there are many different objectives and criteria that need to be considered. Typically, this means building owners fall into a pattern of making decisions based on only one measurement, such as cost or energy savings. By harnessing a building's energy data, building owners are empowered to make decisions that are both data-driven and holistic.

This article explores the common energy and operations challenges building owners encounter, which drive them to consider improvements in data collection and IoT device integration. Solutions to these challenges are proposed, with adjoined examples providing needed context and clarification. The proposed solutions are supported by a case study based on historical observations and interviews with a New York Citybased chocolatier, Supreme Chocolatier. The case study provides witness to the real-world benefits Supreme Chocolatier saw from utilizing its building energy data.

CHALLENGES

The numerous challenges that threaten the continued success of businesses and building owners today are fundamentally different from when many of their buildings were constructed. In the last century, electricity prices have increased by over 350% [3]. At the same time, commercial buildings now dedicate about one-third of total non-fixed operating expenses towards energy consumption [4]. Not only are building operating expenses seeing their highest year-over-year increases in decades (9.8% recently), but the changing economic climate is sending many building owners spiraling [5]. Commercial properties are especially sensitive to changes occurring in the economy, meaning that when the economy goes into a downturn, business closures gradually translate into tenants leaving. Beyond costs, buildings are increasingly becoming more complex to operate and regularly require dedicated staff to maintain building systems. Meanwhile, new building codes, benchmarking

requirements and CO_2 emissions reductions regulations are popping up nationwide.

High Energy Costs

In many buildings, utilities are not measured by the individual tenant's consumptive behavior. Instead, the building's energy bill is divided evenly among the number of units within a structure or the landlord allocates bills by square footage. This leads to a lack of accountability and provides no repercussions for tenants with wasteful habits.

Considering tenants account for approximately 50% of all energy use in commercial buildings, not charging tenants for their consumption effectively prevents landlords from managing half their building's energy. energy use [1].

Overly Complex Building Systems

Operating modern buildings is increasingly becoming a complicated science. However, despite having many intricate processes and system interactions, most building owners are not able to afford a dedicated team of facility managers to oversee operations. This leads to some of the deeper issues building owners face. First, that oftentimes buildings have multiple uses, and subsequently have tenants with needs that must be simultaneously managed in different, sometimes seemingly conflicting ways. Second, there are a multitude of unplanned interruptions, hidden equipment failures, and operation losses that can go unseen for long stretches of time due to the difficulty of peering into the proverbial "black box" of only whole-building master metered buildings [6]. Finally, buildings systems that are maintained and monitored in-person are vulnerable to both human errors, as well as outside tampering. Especially in the age of COVID-19, opening a building to manual walk-up and reads or to unnecessary handling, breeds uncertainty over both building security and risk exposure for occupants.

A New Regulatory Environment

Waste in the building sector has been acknowledged by many international, state, and local governments. Therefore, increasingly regulations are being put in place to try and curb energy consumption. Building Codes such as ASHRAE 90.1 and IEEE, energy efficiency regulations like Climate Mobilization Act, and incentives programs similar to the

New York State Research and Development Authority's (NYSERDA's) solar photovoltaic (PV) incentive program aim to make energy efficiency a priority. To truly maximize these incentives and hit desired efficiency targets, there needs to be a data system in place to track and benchmark a building's consumption over time and provide feedback for where energy is being wasted. In New York City for example, the Climate Mobilization Act has required that emissions in the city be cut 80% by 2050 [7]. This is a steep goal, and building owners are required to provide reports outlining their progress with the measures they are taking to reduce emissions and are required to publicly post their building energy grade.

In New York City buildings account for roughly 71% of greenhouse gas emissions, and of that, tenants and occupants account for 40-60% of a building's energy use [7]. Without finding ways to reduce this consumption, building owners cannot tackle their energy efficiency goals.

INNOVATIVE SOLUTIONS

A societal shift towards environmental stewardship, new-found corporate responsibility and sustainability, combined with increasing financial uncertainty, has thrust millions of building owners into uncharted territory. The abovementioned issues are pervasive, with hundreds of thousands of people contending with what to do to reduce their energy usage. Luckily, the myriad uses provided by building data offer a number of innovative solutions that can be bent towards overcoming these problems. This is because proper data collection forms the foundation of change and allows for data-driven decision making. Figure 1 illustrates a useful pyramid for data collection.

Innovations in Data Collection

As energy efficiency goals advance globally, it is important to recognize the role data play as the foundation to a sustainable future. Creating visibility and accountability for energy use is the first step in reduction.

Data collection is the basis of all sustainability projects. New technology developments allow building managers to move from walk-up reads to real-time remote reading and troubleshooting. Submeters can be added to the system to collect individual tenant usage and implementing circuit-level energy monitors allows the disaggregation of loads by end

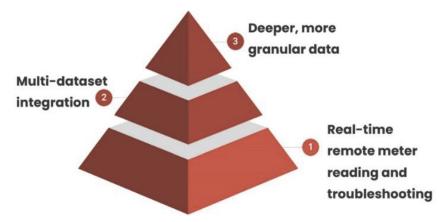


Figure 1. Data Collection Pyramid

use. Data should not be considered in silos; multiple datasets can be integrated allowing for unparalleled comparison and control of seemingly disparate systems. This granularity gives never before seen control and analytics, telling a building manager precisely when, where and how much energy their building uses.

Integrating Systems with the Internet of Things

The integration of IoT technology with building management systems provides a platform to view data collectively and gain a comprehensive view of building performance over time. These data can be used to make operational improvements and reduce the waste of systems consuming more than they should. IoT also allows for further integration into existing building management systems and creates an efficient and secure way to develop detailed insight on a building and its occupants.

Building data can quickly become overwhelming, so it is important to aggregate them into one secure space that provides visibility into all critical systems, utilizes artificial intelligence (AI) and machine learning to eliminate human errors, uses asset digitization to enable platform access, and allows for real-time visualizations of the building's operations in the cloud. Data need to be collected in a way that is actionable, because without usability the surplus of data is worthless. All these aspects must come together in a seamless system; otherwise, the complexity of the data-collection solution threatens to undermine the effectiveness of the solution itself (see Figure 2).

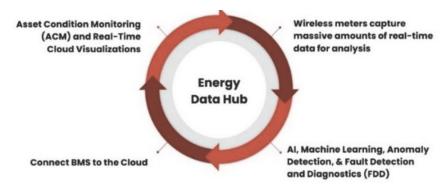


Figure 2. Energy Data Hub

Circuit-Level Monitoring

Circuit-level monitoring allows buildings to gain detailed insight on specific usage metrics within a building. First, it allows a building to disaggregate electrical loads by end use, such as heating, ventilating, and air conditioning (HVAC), lighting, plug loads and other critical systems. Second, with the use of encoded registers like M-Bus, a building manager can monitor additional utilities like water, gas, steam, and total energy (e.g., British thermal unit [BTU]). Finally, dense circuit metering enables building managers to meter multiple circuits together in close proximity, offering a superior, granular view of how energy is consumed.

Predictive Maintenance and Fault Prevention

The advantages of predictive maintenance from a cost-savings perspective are tremendous. This is because predictive maintenance uses data from monitoring and trend analysis, which can minimize planned downtime, maximize equipment life span, optimize employee productivity and increase revenue. Predictive maintenance can revolutionize how a team or organization runs because it helps identify organizational priorities such as profitability and reliability. Additionally, buildings can use data to anticipate and avoid faults, which leads to fewer financial losses.

Regulatory Compliance with Data Collection

Building energy codes, like ASHRAE 90.1, are becoming the new expected building standards. Six states have already adopted ASHRAE's 2016 iteration statewide (NY, CA, VT, NJ, OR, MA) and five more states

are pending adoption (see Figure 3) [8]. Local governments are also implementing more building emissions laws, like NYC's Local Law 97, which calls on owners of buildings of more than 25,000 square feet to decrease their energy use by 40% by 2024 and 80% by 2050, carrying fees for noncompliance. [7] Building managers are also seeing energy benchmarking and data verification requirements, such as NYC Local Law 95 and Chicago Energy Benchmarking, which requires them to report their Energy Star scores to the public [7].

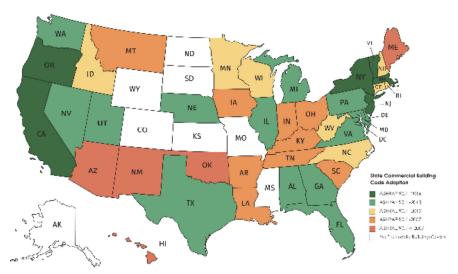


Figure 3. Building Code Adoption by State (Source: U.S. Department of Energy [8])

Ease of Use

When implementing these solutions, it is important to avoid unnecessary complexity. Feature overload can lead to more issues than they are worth. To avoid making the cure worse that the disease, it is better to keep a data system easy to use and understand, than it is to install an expensive system that overloads the user with indecipherable information. Building data, once collected, contain a massive amount of information, making it imperative to simplify the data flow. For the most effective set-up, it is important to have the data aggregated into a data hub that enables both labeling of loads and presents historical trends visually.

CASE STUDY

Quadlogic has supplied Supreme Chocolatier with submetering and billing solutions for the past 2 decades. Quadlogic was again approached by Supreme Chocolatier because they wanted to install solar panels on the roofs of their two adjacent commercial buildings. The chocolate factory wanted to be eligible for NYSERDA incentives, but they did not have the analytical data needed to prove they were complying with all regulations and reporting.

Background

Supreme Chocolatier was established in 1911 on Staten Island, New York by Greek immigrant Emmanuel Katsoris. This staple New York institution started in a retail store kitchen and grew to a 200,000 ft² factory. The business is still family owned and operated by Emmanuel's grandson, Mike Katsoris, who has taken over and expanded the factory, and purchased a second site where he rents out space out to multiple commercial tenants with varied energy needs.

Submetering and Circuit Level Monitoring

The first thing Supreme Chocolatier did to ensure their buildings would be energy efficient was install submeters for tenant billing and energy monitoring. Additionally, through benchmarking, submetering allows buildings of like types to compare data to identify trends and new improvement opportunities. By examining and documenting their buildings' historical use of energy, submeters provide insight into Supreme Chocolatier's future energy costs. Using stored energy performance data also facilitates preventative maintenance and resiliency measures.

While Supreme Chocolatier's submetering technologies have been around for a long time, the integration of IoT has revolutionized the accessibility and usability of these data. Data can now be collected in real time with the ability to view reads remotely, and this information can be recorded in a data hub to allow for long-term analysis. Being able to access data remotely removes the need for someone to physically read the meters at monthly intervals.

Solar Power Production Reporting

Quadlogic developed and installed a PV energy reporting system for

two large arrays for the two Supreme Chocolatier buildings (shown in Figure 4). The system logs kW/kWh data in 15-minute intervals, reports in real time to a cloud application, and pushes data to the NYSERDA database, to fulfill the incentive requirement. Together, the two systems comprise 58,000 ft² total array size and produce >1 MW. The buildings had a huge amount of roof space and with the introduction of the data reporting system, Supreme Chocolatier was able to take part in the NYSERDA incentives program, which helped pay for the solar panels and, overall, helped make the building more energy efficient. One system produced 250,000 kWh on average, resulting in a cost reduction of \$45,000.00 annually.



Figure 4. Aerial Perspective of the Second Commercial Building on the Property with the Solar Panels Installed throughout the Roof

Energy Management System

Once a system is in place and comprehensive building data are being collected (see Figure 5 for an example), energy management becomes easy for building owners, operators, and tenants. Through the optimization of building operations, tenant accountability, and identifying areas of waste, energy usage is reduced, and costs are significantly cut. With a system in place Supreme Chocolatier was able to identify wasted solar power production, made the building data actionable through simplification and aggregation, and optimized their maintenance and operations.

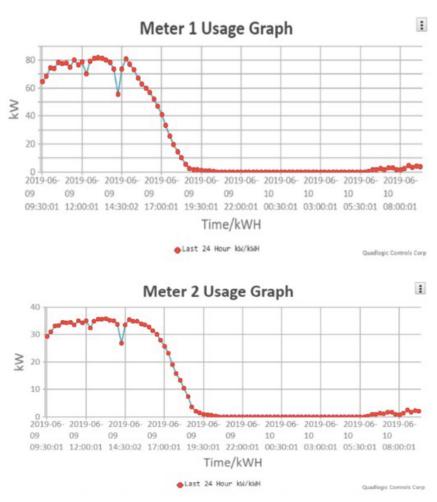


Figure 5. Usage charts that show output as opposed to load. It is clearly shown when there was daylight and when it was nighttime

Future Opportunities Available

Supreme Chocolatier's successes inspire them to look at new possibilities not previously available, such as adding battery storage onsite for their excess solar power production, installing electric vehicle (EV) charging stations in their parking lot, and implementing demand response and greenhouse gas (GHG) offset initiatives to purchase more renewable energy credits.

Data Driven Decision Making

Detailed data ensure that the energy generated can be directed where it is most useful in the grid to minimize demand. Effective energy management systems can analyze building data to decide when it is most effective to store energy, discharge energy, and make adjustments during peak demand times and power outages. This is all done through the use of circuit level monitoring to determine end use of loads, the simplification of the overwhelming amounts of data accessible via secure cloud storage, the aggregation of building data to reduce building systems complexity, and making data actionable through visualization.

SUMMARY

Data and IoT are beginning to play an increasingly important role in building management. Detailed building data give property managers the ability to achieve energy savings, understand how their building operates, identify how much energy their tenants use and disaggregate specific load types. Additionally, a growing body of research is revealing that there are numerous financial benefits to increasing the energy efficiency of buildings, including being able to charge a premium on rent of 2% to 6%, sell for as much as 16% higher, attract desirable tenants, and have lower default rates for commercial mortgages [1]. New technologies allow buildings to aggregate their data in a secure, cloud-based system with real-time information to reduce building systems complexity, all so they can easily cut costs, comply with regulations, and increase energy efficiency through energy monitoring and management.

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Thermal Storage with Phase Change Materials— Shifts Loads, Saves Energy, Costs Less*

Jeffrey L. Ihnen, P.E.

ABSTRACT

Energy storage has been around since shortly after man harnessed fire. A pile or stack of wood is stored energy waiting to be used. More recently, for hundreds of years, ice was harvested from ponds and lakes for preserving foods through the summer and shoulder seasons. Electricity and refrigeration eliminated the need for ice harvesting and storage.

Coming full circle, a nascent industry is emerging to store the benefits of electricity, consuming electricity to "charge" storage materials when electricity prices are low, and discharging the storage materials when electricity prices are high. The storage materials of choice are phase change materials (PCMs). Phase change materials have a great capacity to release and absorb heat at a wide range of temperatures, from frozen food warehouses at minus 20°F to occupied room temperatures. These wide-ranging phase change materials offer an enormous opportunity to shift electrical loads in "grid-interactive, efficient buildings" (GEBs) in which PCMs do the same thing as batteries or other storage technologies, but at a small fraction of the cost. These technologies are in the pre-emerging-technology phase of market adoption. Still the author/presenter believes they will become widely accepted due to their flexibility, cost-effectiveness, simplicity, zero moving parts, longevity, and non-invasiveness.

CONCEPTS

Thermal energy storage using ice produced by mechanical refrigeration (chillers) has been in use for decades. More recently, innovative

^{*}Based on a paper presented at the 2020 Virtual AEE World Energy Conference.

companies are developing a wide range of PCMs to store energy for both heating and cooling applications.

The Beginnings—Ice Storage

Initially, thermal energy storage was used to shift electric loads from peak periods, typically middle to late afternoon, weekdays, when energy and electrical demand charges are high, to off-peak periods at night when prices are low. The primary driver was dollar-cost savings. In most cases, energy consumption increases as chiller efficiencies decrease because of the greater temperature lift required during ice-making. Other energy impactors included additional pumping energy because of a more viscous solution of chilled water and antifreeze and less favorable heat transfer characteristics of the antifreeze.

Cooling loads with ice systems can be shifted entirely off peak, using larger storage systems, or systems can be designed to augment mechanical cooling during peak periods. This latter design concept helps to minimize cost by using the ice-storage system to downsize chilled water plants that would operate at a more level load around the clock, enabling peak loads to be met during the day with both ice and the chiller.

Newer Developments

A variety of materials and solutions that change phase over a range of temperatures introduces a new series of benefits versus pumped storage systems.

First, PCMs can be used in passive ways that require no additional system energy, including minimal added temperature lift described above. This is made possible because PCMs with melting points very close to load temperatures can be used, and therefore, cooling systems see a negligible difference in operating parameters. In many, if not most cases, efficiency increases because the PCM can be charged overnight when cooling conditions are more favorable or even "free" with economizer cooling. Second, there is no added pumping energy or degradation of fluid heat transfer with the use of passive PCMs used in the conditioned space.

Because PCMs are typically situated in conditioned spaces and absorb and release energy at constant temperatures, they are in many instances likely to maintain space conditions at a more constant temperature than spaces that are mechanically cooled only.

Phase change materials are often used for reserve cooling in case of power interruption or refrigeration system malfunction. Like batteries for emergency lighting and computer system uninterruptible power supplies, PCMs will help maintain temperatures during outages for spaces such as marine vessels to cold storage, data centers and telecom shelters.

PCM INTRODUCTION

Phase change materials are available for temperatures ranging from -150°F to 2,200°F. This article features PCMs suitable for conditioning commercial and industrial facilities, and therefore, temperature ranges of -20°F for freezers to the mid 70°F range for occupied-space conditioning.

The following is a brief review of important characteristics of PCMs as well as performance metrics for three types of PCMs: salts, organics, and vegetable-derived materials.

PCM Characteristics [1]

There are several important characteristics of PCM development and performance to consider for each application.

Latent heat of fusion is the heat available for space heating (freezing the PCM) or space cooling (melting). High latent heat is desired.

Sharpness of latent heat is the temperature band over which the material freezes and thaws. A narrow range is desired.

Melting and freezing proximity is the temperature difference, if any, between the freezing point and melting point. The same freezing and melting temperatures are desired.

Stability is the material's ability to maintain its freezing and melting points and latent heat capacity over many freeze-thaw cycles.

Containment systems should have good heat transfer characteristics, be appropriate for the temperature, and resist corrosion. Metals have good thermal conductivity but may be expensive or prone to corrosion. Plas-

tics have limited temperature ranges and have lower thermal conductivity. Plastics can also react unfavorably with certain hydrocarbon PCMs.

Environmentally friendly such that the material is non-combustible, inert, or biodegradable.

PCM TYPES

This article focuses on the application of PCMs to buildings – occupied spaces, and commercial and industrial frozen food storage.

Figure 1 shows the melting range of PCMs researched for this article, including the temperature range of interest in the shaded area. [2][3]

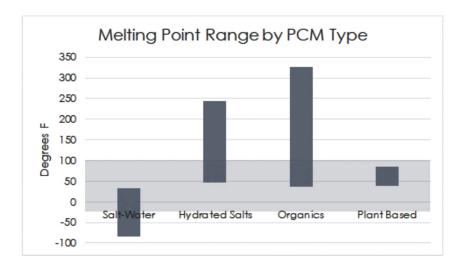


Figure 1. Melting Ranges by PCM Type

Salts in Water

Adding salts to water depresses the freezing point. Salt-water PCMs use blends of salts to achieve various freezing points. The blend of salts and water is fine-tuned such that the entire blend freezes (changes phase) at one precise temperature known as the eutectic point. At lower concentrations, water alone will change phase, leaving a more concentrated salt-water solution as liquid [4]. In this case, freezing would occur over a range of temperatures until the eutectic concentration is reached. Phase

change over a range of temperatures is undesirable to precisely serve a load at a given temperature.

Figure 2 shows latent heat capacity of a range of eutectic freeze points of salt-water solutions. The latent heat capacity declines with higher concentrations of salt and corresponding lower freezing temperatures. While the lower latent heat capacity is less desirable, it simply requires more material for a given amount of phase change heat transfer.

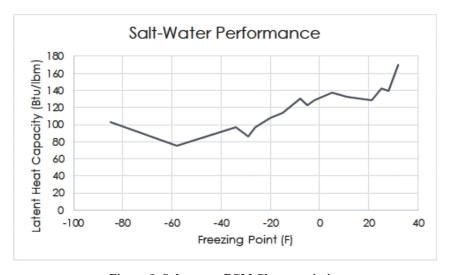


Figure 2. Salt-water PCM Characteristics

Hydrated Salts

Hydrated salts are a different family of salt-water-solution PCMs that freeze above the freezing point of pure water. These PCMs can be trickier to manage because not all of them have a eutectic freeze point. Solutions with eutectic freeze points are said to be congruent. Some solutions are incongruent, which means the salts will crystalize, precipitate, and settle out of solution. Some incongruent solutions may be treated with additives to avoid this. Gels are added to other incongruent solutions such that the salt crystals that form do not settle out of solution and permanently change the PCM's characteristics.

Figure 3 shows latent heat capacity for a range of freezing points for hydrated salt solutions. The latent heat capacity for these solutions is significantly lower than the latent heat capacities of sub-32°F salt-water PCMs.

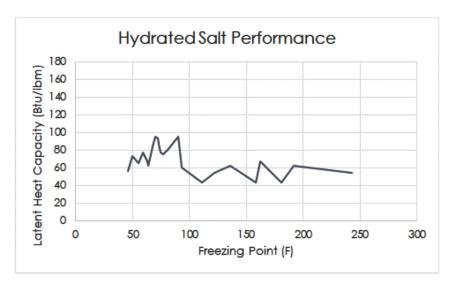


Figure 3. Hydrated Salt PCM Characteristics

Organic

Organic PCMs, by definition, include hydrocarbon chains. PCMs with longer carbon chains have higher melting points which are all above the atmospheric freezing point of water, 32°F. This family of PCMs includes petroleum, animal fats, and vegetable oils.

Challenges with this family of PCMs include a range of melting points because their composition is rarely pure, meaning they have carbon chains of varying length and carbon content. For example, animal and vegetable fats include four or more types of fatty acids, each of which have varying hydrocarbon chain lengths and therefore, melting points [5]. For example, common consumable fats have melting points that vary by 5 to 20°F [6]. While 100% purification is prohibitively expensive, some level of separation is available to shrink the range of melting temperatures.

Figure 4 shows latent heat capacity for 52 organic PCMs. Their latent heat performance is better than hydrated salts but not quite as good as salt-water solutions.

Data from Figure 2 through Figure 4 were taken from PCM Products, a United Kingdom company. Not shown in Figure 4 are data from Phase Change Solutions, a bio PCM provider based in Asheboro, NC. Their PCM products are all plant-based with quoted latent heat capaci-

ties of 90-110 Btu/lbm over 12 temperature melting points from $39^{\circ}F$ to $84^{\circ}F$.

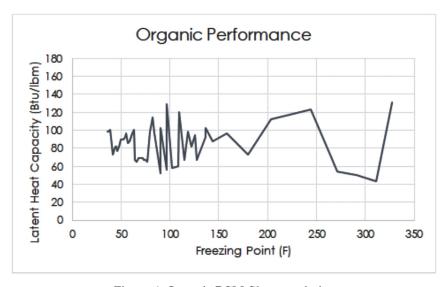


Figure 4. Organic PCM Characteristics

APPLICATIONS

A thorough secondary review of online resources indicates very little research into PCM applications, other than conventional ice storage, has been completed to date. There are many studies of PCM materials, but not many studies concerning their performance in actual applications. Much of the PCM material research has spanned the last 10 or more years indicating there isn't much momentum behind these technologies, particularly in occupied spaces like offices, schools, and hospitals.

There has been greater application of PCMs in refrigerated or frozen storage spaces, transportation of temperature-sensitive products, and serving as a backup to maintain temperatures in case of power outages.

Because field demonstrations and case studies of room-temperature PCMs are scarce with minimal documented design considerations, the author considers and suggests design considerations that have yet to be extensively tested.

Occupied-space Conditioning with Ice Storage

The predominant top-of-mind application of thermal energy storage is likely space cooling to shift cooling energy and electrical demand to off-peak nighttime hours. The conventional PCM is pure water and the conventional means of storing the thermal energy is ice. A simple depiction of this system is shown in Figure 5. The primary loop includes a water-glycol solution for sub-freezing temperatures. The plate-and-frame heat exchanger is used to transfer heat from the building loop (loads) to the chiller primary loop. Note that design configurations are limitless.

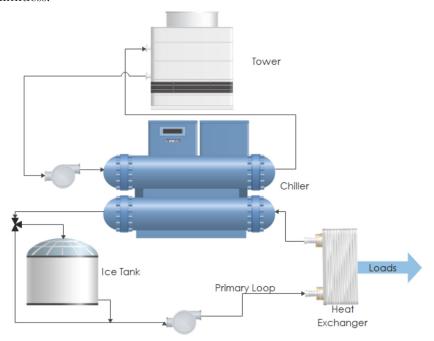


Figure 5. Ice Storage

Ice storage systems represented in Figure 5 have been deployed for several decades. Technical barriers are minimal.

The financial driver for ice storage systems is to shift electricity consumption from more-expensive daytime/peak pricing periods to less expensive off-peak periods. It is also used to reduce peak demand charges for the energy user.

Even though energy consumption is shifted off-peak, net energy consumption is likely to increase compared to storage-less systems. First, it takes more chiller power to produce a 25°F water-glycol solution used to charge the storage tanks with ice, compared to conventional chiller supply temperatures of 40 to 45°F. Second, the glycol solution is more viscous and has poorer heat transfer properties. This requires more pumping power and a greater temperature difference between the evaporating refrigerant and the water-glycol solution.

As noted, design considerations are limitless. Systems can be designed such that the chillers run nearly fully loaded around the clock on design days. This helps minimize system capital cost by using the storage system to offset chiller capacity. Another option is to design the system such that the chillers are not needed during peak periods, maximizing savings at the expense of a chiller plant with greater chilling capacity and an ice storage system that is oversized for days in which design conditions are not met. This latter option is not likely to be the most cost effective because the author's experience has shown that the most cost-effective option is one where all equipment is used closer to its maximum capacity at all times.

In the case of hybrid systems where chillers are needed during design days, one or more chillers can be dedicated to ice making off-peak. If required on design days, that chiller can provide chilled water to the loads along with the ice and other chillers.

Another consideration for ice storage systems is to operate chillers in series rather than in parallel. Chillers operating with less chilled-water temperature lift in each of two chillers piped in series operate more efficiently overall, even though the total temperature drop is the same.

Cold Storage with Salt-water PCMs

Plastic containers, resembling reusable freezer packs common for consumer use in insulated coolers, are used with salt-water PCM energy storage applications. These PCMs incorporate a combination of salts to achieve specific freezing points for various applications, from 32°F down to -85°F.

Salt-water PCM applications include freezer warehouses and walk-in freezers. These are passive applications where the PCM is located in the warehouse or storage unit, but outside the occupied space, typically above the racks in a warehouse. This position not only keeps the PCM out of the way, it also provides free convectional cooling if the power goes out.

Figure 6 shows an application of salt-water PCMs in a walk-in freezer. In this application, the structure is bolted to the ceiling to support the PCM containers.



Figure 6. Salt-water PCM Application (Source: Viking Cold Solutions)

This technology is promising with proven results. It typically saves energy in addition to shifting load to off-peak periods.

A salt-water PCM typically saves energy by charging the material overnight when outdoor air conditions are cooler, requiring less refrigeration compressor lift. Second, it allows systems to run closer to full capacity, which is almost always more efficient than part load efficiency, whether partial loads are met with rotary-compressor rotor shortening, unloading reciprocating-compressor cylinders, or using variable frequency drives. Third, unlike making ice for space conditioning as described above, this PCM can be charged at near-normal temperatures. Therefore, there is very little compressor lift penalty.

In areas with high penetration rates of solar electricity production, the PCMs can be charged during daytime hours to take advantage of an abundance of solar generation.

Salt-water PCM technology has significant non-energy benefits. First, it helps maintain a more constant freezer temperature, especially compared to thermal storage, by simply driving product temperatures lower and coasting through portions of the peak period. This allows for superior load shifting and demand response. Second, it provides substantial backup in case of power outages or equipment failure. Third, there are no moving parts and maintenance is almost non-existent. Forth, it is non-invasive to the refrigeration system and can be installed with minimal disruption to operations.

Introduction to Biological PCMs

Biologically based PCMs are a subset of organic PCMs that use plant or animal-based fats as the PCM. The analysis in this article is based on the Phase Change Energy Solutions products, which are all plant-based.

These plant-based PCMs are offered in several products to be applied for space conditioning. They include blankets that can be added to wall structures, roof decks, or above suspended ceilings. They are also offered in architectural panels that may be easily retrofitted by attaching them to walls or ceilings. Bulk thermal storage is available similar to ice storage except the PCM is the plant-based type rather than water.

Bulk Storage with Biologically Based PCMs

Bulk storage using biological PCMs work like conventional ice storage, but rather than water they employ temperature-tuned PCM material that more closely matches normal chilled water temperatures. Phase-change points include a range of temperatures that are ideal for chillers: four temperature choices from 39°F to 46°F. Therefore, the chiller-lift penalty associated with making 25°F chilled water and antifreeze solution is mostly avoided.

Like conventional ice storage, bio-based PCM storage allows cooling to occur overnight when compressors can run at lower head pressure in cooler conditions for condensing refrigerant. Because there is plenty of time for recharging the PCM, cooling sources can be operated at their most-efficient point. For instance, unlike positive displacement compressors used for cold food storage, centrifugal chillers typically operate most efficiently in the 60 to 70% loading range. Chillers can spend more time operating in their sweet spot rather than what the building demands at

all times. Cooling energy consumption and power demand are also shifted to less-expensive off-peak periods.

Occupied-space Conditioning with Biologically Based PCMs—Blankets

Blankets with packets of PCM sandwiched between multi-layered films resembling a down jacket can be used in a variety of interior space-conditioning applications.

First, it warrants mentioning that occupied buildings are not like cold storage facilities. Occupied buildings have heating AND cooling loads rather than cooling only. Having both heating and cooling loads is a factor because there is dead band temperature between heating and cooling setpoints (e.g., 72°F and 75°F). It may not be economical or feasible to use one PCM material for both heating and cooling, considering that phase change is necessary to maximize energy impacts. Designers also need to consider the heating fuel. If the heating fuel is natural gas, there are rarely demand or time-of-use rates. Buildings heated by electricity, whether electric resistance or heat pump, are often subject to similar demand and time of use tariffs experienced during the cooling season.

Designers need to consider that heating and cooling loads are typically greatest along exterior walls rather than interior partitions. In spaces with exterior exposure, it is beneficial for comfort and phase-change leverage to locate the PCM on or near the exterior surface.

Blankets can be deployed in many ways, but this analysis includes deployment as part of the wall structure, laid above suspended ceiling tiles, or as part of a wall-mounted panel.

With PCM blankets installed behind gypsum board in walls, the material is most likely only suitable for heating or cooling (pick one) as the load penetrates the wall, typically from the outside on its way to the occupied space. This becomes a very complex heat transfer problem and most likely requires testing. It may also be a challenge to freeze the PCM behind the gypsum board. This would require sub-cooling the space to a degree that the PCM can reject heat through the gypsum board or other finishing material to the conditioned space. The gypsum board's insulating value will impede heat transfer (conduction) and temperature difference that drives free convection. The need to charge the PCM by sub-cooling the space may result in a call for heat first thing in the morning for occupancy. This needs to be considered and avoided to achieve

optimal cost effectiveness. Furthermore, melting the PCM would largely require heat transfer through the wall assembly. Does this require more heat gain than necessary for cost effective insulation? Insulation costs versus PCM costs must be evaluated.

Another option for the PCM blankets is to install them on partitions on the building's interior, as shown in Figure 7. [7]

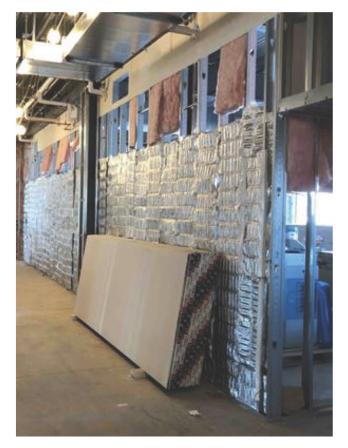


Figure 7. PCM Partition Application

A challenge installing PCM blankets on interior partitions would be the lack of cooling load on these structures. Their only heat gain is ambient indoor air. There is no conduction or radiation like an external wall or ceiling experiences. This may require an unacceptable temperature swing to get the PCM to cycle from solid to liquid.

Another application of the PCM blanket is to install them above

suspended ceiling tiles. This is an easy retrofit application. However, the space above the ceiling tile must be considered. In many cases, these spaces are used as return and/or exhaust air plenums. In these cases, some of the cooling provided by the absorbed heat may be rejected outdoors. Like the wall application, this is a very complex heat transfer situation. Ceiling panels have R-values of about 1 to 1.5 ft²-F-hr/Btu [8], which is not insignificant. Like the wall application, the space may need to be subcooled excessively to recharge the blanket overnight. Most of the temperature-moderating "benefit" could be in the unoccupied space above the ceiling panels.

Architectural panels containing PCM blankets may be the best application for space conditioning in nearly any commercial building. These panels act like water-based panels used for heating or cooling. This application, shown in Figure 8, avoids many of the challenges and uncertainties of the hidden-blanket installations as part of wall structures or above ceiling tiles noted above. It allows heat transfer with the conditioned space with only a minimal amount of thermal resistance caused by the panel material, making it much more like the proven-successful salt-water PCM storage systems used in freezer applications.



Figure 8. PCM Wall Panels (Source: Phase Change Solutions)

TEST RESULTS

Case studies for PCM applications are scarce, and therefore, the author is relying on his knowledge of energy, heating, cooling, and comfort issues, along with information provided in available documentation.

Most documented test results of room-temperature (about 70-75°F) cover the ability of the PCM to absorb and release heat, and to moderate temperature. However, people do not readily accept a wide band of temperature fluctuations. This is one challenge for these technologies. The only test results found that included metered energy savings were for cold storage and telecommunication. Can PCMs save energy and keep occupied spaces comfortable? The author was not able to find energy-saving impacts for applications of PCMs to commercially or institutionally occupied spaces.

First, this article reviews two case studies showing energy impacts; one for salt-water PCMs in frozen food storage facilities, and a second for a bio-PCM application in telecommunication equipment facilities. Second, this article breaks down two A-B tests showing results for PCMs' ability to moderate temperature and absorb heat in would-be occupied spaces.

Salt-water PCM Test Including Energy Analysis

San Diego Gas and Electric sponsored two studies in one report for using salt-water PCMs in frozen food storage applications [9]. The first is for a walk-in freezer for a mess hall facility at Camp Pendleton. The second is for a frozen food warehouse for the San Diego Food Bank. This PCM technology is conducive to retrofitting in facilities as they are non-invasive and can be located out of the way high in the space above racks and shelves.

The mess hall refrigeration system was controlled to shift load from day and peak periods to nighttime off-peak periods. The food bank system was controlled to use abundant site-generated solar energy to charge during the day.

The mess hall application saved 30% energy and 3% peak demand for the affected equipment. The food bank application saved 39% energy and 11% peak demand. Peak demand, as reported, is the maximum demand regardless of time of day when it occurs. Billed peak demand and especially peak demand reduction during grid-coincident peak

demand could be substantially greater, especially for the mess hall.

The financial performance of these applications included an estimated simple payback of about 6 years for the mess hall project and 3 years for the food bank project.

Bio PCM Test Including Energy Analysis

The Society of Cable Telecommunications Engineers and International Society of Broadband Experts sponsored an energy and simple financial analysis for the application of a bio PCM in two telecommunication shelters located near Davis, CA. [10] This application includes PCM wall and ceiling panels shown in Figure 9. This is an ideal application for superior heat transfer performance and available temperature swing to freeze and melt the PCM around a target control temperature of 78°F in these unmanned facilities.

Savings are reported to be the result of longer cooling system cycles. While this is certainly the case in humid climates where moisture is condensed on coils and then re-evaporated into the space on every cycle, it may have less effect in dry climates like California's. However, as with the freezer application, shifting more of the cooling load to overnight hours can also improve efficiency, depending on cooling system characteristics.



Figure 9. Bio PCM Telecommunication Application

Savings are estimated to be about 15% using retrofit isolation, metering on the cooling equipment, and 20% using whole-building energy analysis using utility meter data. The paper states the latter whole-building approach was normalized to weather conditions to extrapolate savings for an entire year. However, the results show that the metered savings were simply extrapolated by dividing the savings over the metered period to obtain monthly savings and multiplying that by 12 for annual savings. Also, the discussion for weather normalization uses cooling degree days and a balance point of 65°F, meaning that the facility needs no cooling when it is 65°F or colder outdoors. That is a good balance point for homes and light commercial facilities with low internal gains. These telecommunication shelters are likely to have a much lower balance point temperature. Determining the balance point can be straightforward by comparing energy consumption to outdoor temperature.

The estimated simple payback for these tests is less than two years.

Bio PCM A-B Thermal Test

An A-B test was conducted on a Phoenix-area high school using two similar buildings, each with two floors above grade. Room temperatures were monitored before HVAC systems were active in this A-B test, as shown in Figure 10. [11]

Areas F and B are very similar two-story sections of the building. Area F is the control (baseline) section and Area B is the test section. Room numbers beginning with 1 or 2 indicate first or second floor, respectively.

PCMs should dampen the temperature fluctuation from cool nights to hot days, but comparing second-floor data in the yellow (control) and gray (test) curves, the temperature swings for the test area are greater much of the time. Periods near the beginning, middle, and end of the test period from April through May show the temperatures in these second floor test and control spaces are nearly the same.

Test and control spaces for the first floor track more closely, but again, during many periods the temperature swings in the test area are greater than the control area. There also appears to be some forcing of temperatures in these areas because the temperature curves are not smooth.

The PCM in this case is installed on interior partitions (see Figure 7). Its melting point is 73°F. There is minimal discernable temperature

fluctuation at any particular room temperature range (blue v orange or yellow v gray).

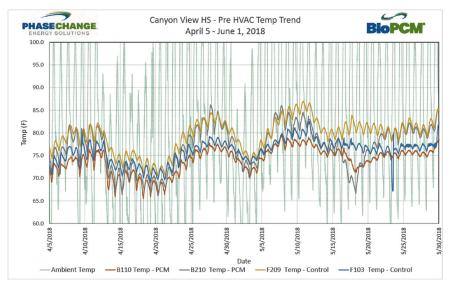


Figure 10. Bio PCM Temperature Test Results (Source: Pure Temp, LLC.)

Salt Hydrate PCM A-B Thermal Test

A second A-B test was conducted recently in Germany [12] to study computational models and demonstrate the dampening effects of PCMs on space conditioning. This case used a salt hydrate PCM in plastic containers resembling the common freezer pack used for food coolers. The melting point of this PCM is 21 to 22°C (70 to 72°F).

The test building and PCM packs are shown in Figure 11 and Figure 12, respectively. The results are shown in Figure 13.

There are two notable findings from these test results. First, the PCM acts as thermal mass and provides an insulating effect even when phase change is not occurring. The insulating effect would be due to blocking radiation from the exterior sheathing and the impedance to natural convective air flow in the wall cavity. The result is less temperature swing in the test space, even when the material remains in one phase, solid (below 20°C [68°F]) or liquid (above 23°C [73°F]).

The second finding is that the PCM has its greatest impact when it is changing phase in the temperature range of 20 to 23°C (68 to 73°F).

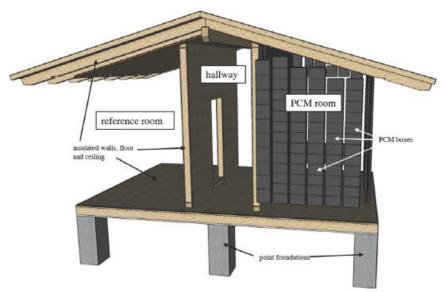


Figure 11. Salt Hydrate Test Facility



Figure 12. PCM Installation

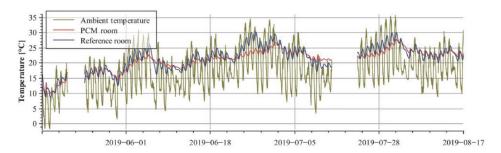


Figure 13. Salt Hydrate Temperature Test Results

CONCLUSIONS

Phase change material deployment is still in the pre-emerging-market phase of adoption. Adoption of PCMs for commercial and industrial refrigeration and other applications where thermal comfort is not a primary factor is far ahead of adoption for occupied commercial space conditioning.

Commercial and industrial refrigeration applications are mostly confined to frozen food warehouses and walk-in freezers. Performance of these PCM applications has proven to be very successful for both shifting cooling loads to periods of lower demand and energy charges, and in most cases, saving energy by charging the PCM (freezing it) during more favorable, cooler nighttime conditions. These applications work well because the PCM is in direct contact with the conditioned space air and out of the way of occupants and equipment used in these spaces.

Facilities that are conditioned to protect equipment or products and are not sensitive to people's thermal comfort issues are also great opportunities for PCMs.

Phase change materials used for occupied space conditioning is largely still in the testing and validation phase of product development. Theory and metered results indicate that PCMs have the desired effect of adding thermal mass to buildings, but their energy-saving and load shifting potential have not been widely proven.

Most test applications have placed the PCM outside the occupied space, in walls behind gypsum board, sandwiched between insulation layers, or blanketed above ceiling panels. PCM incorporation into building design is far more challenging than deploying it in direct contact with the conditioned space. Deployment within the building structure or above ceiling panels would require a lot of testing to get it right because the material needs to cycle from liquid to solid to be effective and this is not a straightforward analysis. More predictable outcomes seem to be available by deploying the same strategies that have been successfully proven in frozen food facilities. The PCMs can be used in architectural wall or ceiling panels, or decorative ceiling hung panels. Any PCM type, including organic, biological or salt-hydrates could be used for these applications. However, the challenge for thermal comfort is to freeze the PCM overnight while avoiding the need for heat in the morning to keep spaces in their comfort zones.

Phase change materials could also be used in refrigerated warehouses and walk-in coolers using organic, biological, or salt-hydrate PCMs.

Overall, energy savings and load shifting potential for PCMs in direct contact with conditioned spaces is vast and possibly cost effective in most applications.

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Liquid Piston Stirling Engine with Parallel Scheme of the Several Units of the Compression-expansion Elements

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ABSTRACT

Nowadays, the interest in the liquid piston option of the Stirling thermal engine is significantly reduced, because of the inability of a liquid piston to develop a high acceleration, which causes considerable limitation of the specific output power of the engine. Nevertheless, the technology of the liquid piston Stirling engines has not reached its development potential, as the characteristic of this type of engine working at the low-frequency cycle might give us some advantages. The article analyzes the features of the liquid piston Stirling engines and shows their advantages compared to the traditional options. It has been established that the liquid piston Stirling engines can be used in medium size stationary electricity generators (1 to 100 kW).

INTRODUCTION

The specific output power of the Stirling Thermal Engines' liquid piston option is considerably limited by its inability to develop a high acceleration. The surface where the liquid and the gas touch each other becomes unstable at high values of vertical acceleration, which causes strong curvature of that surface. After that starts the formation of a two-phase dispersion structure at the liquid and the gas boundary. All these processes are accompanied by significant losses while the conversion of energy from the form of gas into the form of hydraulic energy. The minimum value of the cycle period for moving a liquid piston at 0.1

meter is about 0.1 second, which is 10 to 15 times more than a solid piston Stirling engine. Consequently, the power of the liquid piston engine is significantly lower compared to the power of the traditional Stirling engine. Nevertheless, the technology of the liquid piston Stirling engines has not reached its development potential. The characteristic of this type of engine working at the low-frequency cycle might give us some advantages. Particularly, heat transfer processes require many times that allow the compression-expansion processes to be as close as possible to the isothermal and thus increase the efficiency of the engine. At the same time, the heat transfer between the gas and the liquid piston will not decrease but increase.

MAIN PART

The principle of operation of the Stirling thermal machine is to heat and cool the gas with cold and hot cylinder walls, which are in thermal contact with the high and low-temperature heat reservoirs, respectively [1]. Due to the prolongation of the processes of gas expansion in the hot cylinder and compression in the cold cylinder, these processes are carried out at temperatures close to the temperature of the thermal reservoirs. Regenerative heating and cooling of the gas while moving from one cylinder to another, allows carrying out of a thermodynamic cycle with efficiency close to the Carnot cycle's efficiency. Development of the technology of Stirling engines, which was associated with an increase of their power, this principle was rejected because the heat transfer between the gas and the cylinders' walls is not effective at high frequencies of engine operation. Nowadays, it is widely accepted to heat and cool gas in additional heat exchangers, which causes the formation of excess dead volume.

Heat exchange with heat reservoirs is carried out not during the expansion and compression processes, but during the passage of the gas through the heat exchanger. The heat transferred in these processes ensures the rise of the gas temperature. Therefore, it is principally impossible that the given processes approach to reversible. It is also irreversible to mix the gas coming from the heat exchanger and entering in the relevant reservoir with the locally existed gas, which temperature differs from the incoming gas. This circumstance reduces the efficiency

of the Stirling thermal machine. The working fluid in a liquid piston Stirling engine presents the piston on which the gas performs work. Besides, it can also perform the function of a heat transfer agent between the gas and the heat reservoirs. Also, the working fluid can be divided into two parts. One part has a low temperature and removes heat from the gas, while the other part has a high temperature and delivers heat to the gas. To organize heat transfer between the gas and the liquid heat transfer agent allows the supply of the heat to the gas during the expansion and compression processes, thus returning to the initial principles of the Stirling thermal machine, which ensures the approach to the highest efficiency. It should be noted that there are alkali alloys with quite low melting temperatures. For instance, for the eutectic of the sodium-potassium alloy, this temperature is around minus 11°C, which allows removing heat from the gas at a low ambient temperature corresponding to the circumstances and to increase the efficiency additionally.

The use of liquid metals as working fluids allow the conversion of hydraulic energy into electrical energy using the magnetohydrodynamic method. The machine assembled according to this principle does not have solid moving parts, which significantly increases the operational resource.

Another important feature of the liquid piston option is the ability of more flexible control of the operation process compared to traditional engines. Existing industrial prototypes of the Stirling engine are beyond the initial principles of this machine, which ensures the highest efficiencies. This is proved by the fact that in these solid piston prototypes there are no separate processes of expansion and compression in the hot and cold volumes. In solid piston machines, in which movement is controlled by a certain kinematic scheme, the given processes are partially coordinated, which harms the efficiency of the machine. The correction of this defect is possible in a liquid piston scheme.

Simultaneous maximization of the specific engine power and efficiency of the Stirling machine is impossible because high efficiency requires the performance of the reversal heat exchange process, which can be achieved using the cycle's long period and with the long regenerator, while achievement of the high power requires cycle's short period and short regenerator with low resistance.

The possibility of solving these contradictory conditions is presented through the principal scheme of the liquid piston Stirling engine (Figure

1), where the low-frequency processes are compensated by the parallel operation of the several units of the compression-expansion elements (1, 2, 3, 4, 5), which has common accumulation storage of energy (8-9 common accumulation volumes).

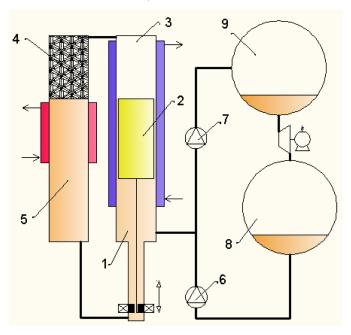


Figure 1. Principal scheme of the Liquid Piston Stirling Engine

As can be seen from Figure 1, at the moment when the displacer (2) is at the top dead end of the cylinder (1) (V_{hot} = 0; V_{cold} = V_0) the suction (6) and compression (7) valves are closed. The pressure in the cylinder is $P = P_3$. While the displacer moves to the lowest dead end, the working gas through the heat exchangers (3 and 5) and the regenerator (4) flows from the hot to the cold area. The temperature and consequently the pressure in the system decreases. When the pressure value reaches $P_4 = P_{min}$ and ($V_{hot} + V_{cold}$) < V_{max} , the suction valve (6) will open and the liquid from the low-pressure accumulation storage (8) will be sucked into the working elements. Absorption ends when the displacer reaches the lowest dead end [2].

It should be noted that the following conditions must be considered to assemble the engine: When the displacer occupies the lowest dead end, the upper torso surface of the 5th element must match with the level of the upper surface of the displacer.

The displacer movement backward causes the flow of the working gas into the engine's hot area. Consequently, its temperature and pressure increase. When the pressure reaches $P_2 = P_{\text{max}}$ and $(V_{\text{hot}} + V_{\text{cold}}) > V_{\text{min}}$, compression valve opens (7), and the fluid transfers to the high-pressure storage volume (9). Compression accomplishes when the displacer reaches the top dead end. Then the operational process is repeated.

The diversity of the Stirling engines' designs greatly complicates the description of the physical processes taking place in it with the one common theory. There are currently several approaches to the theoretical analysis of thermal engines [3]. Existing models are based on the dividing of the engine's parts into finite elements. A system of thermal-gas-dynamic equations is used to describe the processes that take place in these elements, which includes the laws of mass and energy conservation. Solutions for these equations based on analysis face insurmountable barriers; therefore they are often solved using numerical methods.

All existing dividing programs for the cylinders, heat exchangers and regenerator require knowledge of the dimensions of these engine elements. [4].

The calculation model is based on the following assumptions: 1) instantaneous pressure values are the same everywhere in the system; 2) the ideal gas equation PV = ZRT is fair for the working gas; 3) the leaks from the working gas system are equal to zero; 4) we do not have a temperature gradient in the heat exchangers; and 5) it is ideal mixing of the working gas with each other in the cylinder's volumes.

Based on these assumptions, it is possible to determine the working gas masses that we have in a high-temperature volume, refrigerator, and regenerator:

$$M_g = \frac{P_g V_g}{R T_g}$$

$$M_x = \frac{P_x V_x}{R T_x}$$

$$M_R = \frac{P_R V_R}{R T_x}$$

$$M_R = \frac{P_R V_R}{R T_R}$$

where, P, T, and V are pressure, temperature, and volume in the respective zones.

Because the instantaneous pressures are the same in these volumes $M = P_g = P_x = P_R$, while the mass of the working gas remains unchanged in a cycle according to the law of mass conservation $dM_g + dM_x + dM_R = 0$, we will have:

$$P\left(\frac{V_{g}^{i}}{T_{g}} + \frac{V_{x}^{i}}{T_{x}} + \sum \frac{V_{R}^{i}}{T_{R}^{i}}\right) = \left(M_{g} + M_{x} + \sum M_{R}^{i}\right) \cdot R$$

Considering the total mass of the working gas, it is possible to determine instantaneous pressure at any point in the cycle:

$$P = \frac{M \cdot R}{\frac{V_g^i}{T_g} + \frac{V_x^i}{T_x} + \sum \frac{V_R^i}{T_R^i}}$$
(1)

Determining pressure values, as shown in equation (1), requires dividing the whole system into elementary parts and also determining the working gas temperatures in the elementary volumes of the regenerator.

Figure 2 shows a scheme of the regenerator dividing into elementary volumes, which schematically shows the heat exchange process in it between the gases and the material of the regenerator's grid. Based on the law of energy conservation we can write the equation of balance for the heat exchanging between the regenerator's material and the gases:

$$dQ = \alpha \cdot f_p dT$$

$$dQ_H = dm_H \cdot C_H dT_H$$

$$dQ_g = dm_g \cdot C_g dT_g$$

$$dQ_H = dQ_g = dQ$$
(2)

By converting equations to finite-difference, we get the following system of equations:

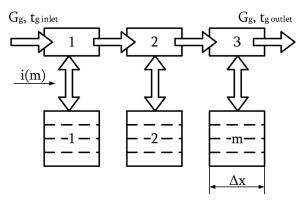


Figure 2. Regenerator's parts

$$\Delta Q = \alpha \cdot \Delta f_p \left(T_g^i - T_H^i \right)$$

$$\Delta Q_H = \Delta m_H^i \cdot C_H \left(T_{Hi}^{\tau+1} - T_{Hi}^{\tau} \right)$$

$$\Delta Q_g = \Delta d m_g^i \cdot C_g \left(T_{gi}^{\tau+1} - T_{gi}^{\tau} \right)$$
(3)

Calculation of the working gas temperature values (3) from the system of equations requires additional use of the following equations for each step of counting:

$$\Delta m_g^i = m_g^{\tau+1} - m_g^{\tau}$$

$$m_g^{\tau+1} = \frac{V_R^i}{RT_g^i} \left(P_i^{\tau+1} - P_i^{\tau} \right)$$

$$\tag{4}$$

The use of numerical methods requires a detailed study of the problem of summability and the sustainability of the solution. The criterion was established to ensure the summability and sustainability of the solution in the asymptotic approximation way from the initial state of the system to the stationary state. It has the following appearance:

$$\frac{\alpha \cdot \Delta \tau}{\rho_g C_g \cdot \Delta \left(\frac{V_R}{f}\right)} \le 10 \tag{5}$$

where, α – heat-emitting coefficient, W/(m²-K); ρ_g – the density of the

working gas at the working pressure of the cycle, kg/m³; C_g – the heat capacity of the working gas, J/kg–K); ΔV_R – the elementary volume of the regenerator, m³; f – the surface area of the regenerator grid, m²; and $\Delta \tau$ – time step, seconds.

Figure 3 shows a diagram created according to the above-presented equations for the liquid piston Stirling engine with 100 ml volume. Using this diagram, it is possible to estimate the cycle performance and obtained output power.

P,bar

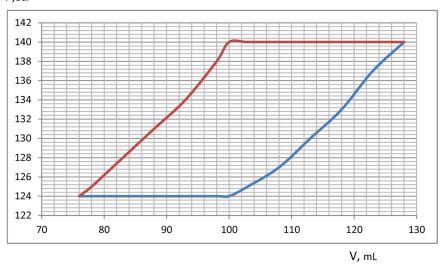


Figure 3. Indicator diagram of the Liquid Stirling Engine

The pressure values in the storage volumes P_{\min} and P_{\max} are selected in such a way to obtain the maximum performance and capacity in the cycle (Figure 4).

In the future, liquid piston Stirling engines as energy converters can be used in machines with liquid-metal heat conductors. For example, in stationary generators of medium power (1-100 kW). The following aspects can be considered to be the advantages of liquid piston Stirling engines: the low cost of its installed capacity, large operational resource, and the high efficiency of heat energy conversion. Unlike the traditional scheme of the Stirling engine, the liquid piston option allows the heat of the working gas to be supplied and dissipated by direct contact with the liquid heat conductor.

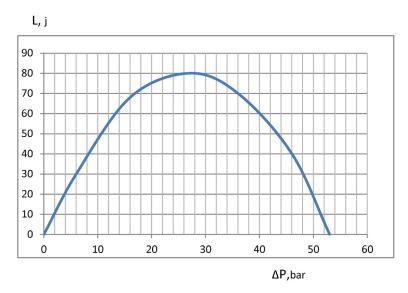


Figure 4. Engine's operation dependence on pressure difference in accumulation volumes

The possibility of using liquid metals in the liquid piston Stirling engines allows us to use the magnetohydrodynamic method of converting hydraulic energy into electricity.

VERIFICATION AND VALIDATION

We, authors of this publication, verify that the presented research is original, and the analysis is performed by us. Also, the proposed modified design, which specifies a new product as a liquid piston option of the Stirling engine, is developed by us.

CONCLUSIONS

The liquid piston option of the Stirling thermal engine is unable to develop a high acceleration, which causes considerable limitation of the specific output power of the engine. Our design and approach of the operation of the liquid piston Stirling engine particularly working at the low-frequency cycle gives us the following advantages: the heat of the working gas is supplied and transferred by the interaction with the liquid

heat conductor, the lower cost of the installed capacity compared to the traditional option of the Stirling engine, large operational resource and the highest efficiency of heat energy conversion. Also, it has been established that the Liquid Piston Stirling Engines can be used in the medium size stationary electricity generators (1 to 100 kW).

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Why and How to Utilize Wastewater Energy Recovery Heat Pumps For Domestic Hot Water, Air Conditioning and CO₂ Reduction*

Lynn Mueller Elisa K.D. Passos Matthew Wardlow

ABSTRACT

With the rising environmental awareness and new government laws and regulations focused on cutting carbon emissions, cleantech solutions are becoming very relevant. At the same time, customers and industries continuously pursue cost-effective solutions, whether for their homes or businesses. In that sense, the PiranhaTM T10 HC wastewater heat recovery system was installed in a multi-family building pilot plant in North Vancouver in order to assess its performance when it comes to greenhouse gas (GHG) emissions, energy reduction and cost savings. The results showed the Piranha T10 HC system was able to provide up to 100% of the domestic hot water and space conditioning to the building, with an energy and cost savings of over 60%. The system can fully offset the natural gas consumption and, consequently, the GHG emissions.

INTRODUCTION

SHARC Energy Systems was selected by Electric Power Research Institute (EPRI), as one of the top 10 companies in the Incubatenergy© Labs Challenge, to participate in a clean energy pilot project for energy utility companies. The project's objective was to assess Piranha HC system performance, the impact on facility energy use, GHG emissions, and

^{*}Based on a paper presented at the 2020 Virtual AEE World Energy Conference.

its cost-effectiveness as an energy and load resource for supply utilities. The project was sponsored by EPRI, Southern California Edison, American Electric Power, Ameren, Consolidated Edison, and the Tennessee Valley Authority.

METHODOLOGY

A PiranhaTM T10 HC, with a heat capacity of 120,000 Btu/h, was installed at the LEED platinum Seven35, a 60-unit multi-family building in North Vancouver, to heat domestic hot water by re-using energy contained in wastewater that would otherwise be lost down the drain. The PiranhaTM HC model bundles cooling capabilities for simultaneous domestic hot water production and air conditioning. The existing natural gas boiler was left in place as a backup or to supply non-domestic hot water applications. The study was performed in phases, where the domestic hot water load provided by the Piranha HC was increased progressively, from 50% load (100°F) to 100% load (140°F). The air conditioning (AC) system operation was performed in the last phases, with 75% and 100% load. The primary refrigerant used to run the system was the R513A (GWP 573). The R314A (GWP 1,430) was applied during a small period, for 75% and 100% loads, in order to compare with the R513A.

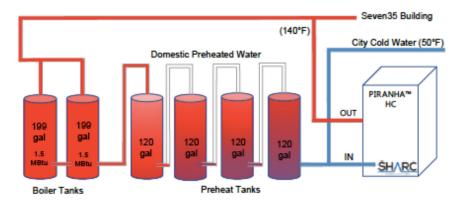


Figure 1. Piranha's Schematic Diagram with 100% Domestic Hot Water





Figure 2. Piranha System Installed at the Seven35 Building (left) and the Hot Water Piping at the Seven35 Building (right)

RESULTS AND DISCUSSION

For the first 2 weeks of the project, the Piranha T10 HC ran at 50% load, delivering hot water at 100°F. The gas boiler backup system heated the water from 100°F to 140°F before delivering it to the building. In this setup, the system reached a coefficient of performance (COP) of 4.4. The Piranha load was then raised to 75% for the following 6 weeks, delivering hot water at 120°F, with the boiler system producing the extra 20°F. In this configuration the COP decreased to 3.6, as expected. The COP decreases as the output temperature increases. Finally, the system was setup to 100% load, delivering 100% of the domestic hot water at 140°F directly to the building, keeping the COP at 3.6. The air conditioning was applied for 75% and 100% and COP was not affected. The COP performance can be seen in Figure 3.

When it comes to running time, the system ran from 10 to 14 hours every day and could produce 100% of the hot water demanded by the building, as can be seen in Figure 4. Because the system was not using its full capacity, its hours of operation can be extended to store hot water and shift peak loads. The cold-water usage at the Seven35 is a daily average of 9000 U.S. gallons, and the hot water 2000 U.S. gallons, as shown in Figures 5 and 6. The water usage didn't change from before to after

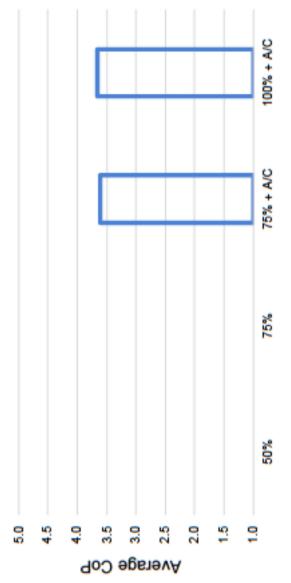


Figure 3. Piranha's Performance with Loads of 50%, 75%, 75% and 100% with air conditioning

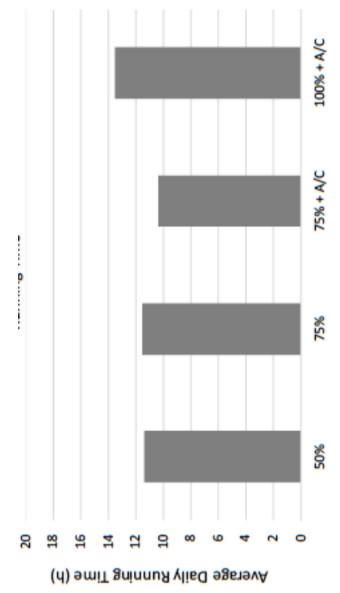


Figure 4. Piranha's Running Time with Loads of 50%, 75%, 75% and 100% with Air Conditioning

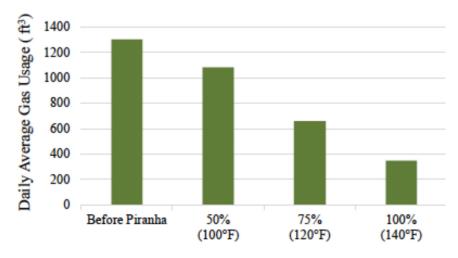


Figure 5. Gas Usage at the Seven 35 Building Before the Piranha Installation and After the Installation with $50\%,\,75\%$ and 100% Loads

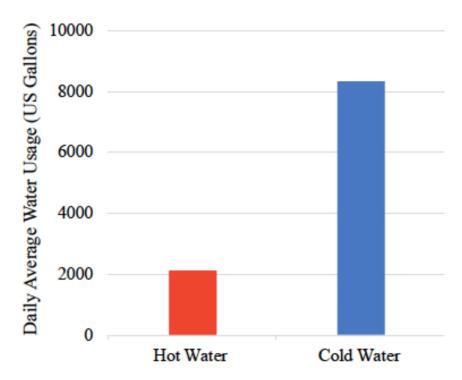


Figure 6. Hot-Water and Cold-Water Usage at the Seven35 Building During the Project Time Frame

the Piranha T10 HC installation. However, the gas usage showed a continuous decrease as the Piranha load was increased, with less than $400~\rm{ft^2}$ per day at 100% load.

Regarding the input and output temperatures, as the Piranha load is increased, the output temperature also increases, reaching 140°F at 100% (Figure 7). The wastewater temperature showed a slight variation between 60°F and 70°F, and the city's cold water was pretty steady at 58°F throughout the monitoring period.

The project results showed that the building could save \$10,000 / year if the natural gas boiler is offset by the Piranha system, which represents a 60% energy savings, as shown in Figure 8. When it comes to GHG reduction, the Piranha can reduce almost 100% of CO² emissions when compared to gas boilers (Figure 9).

The Piranha system was tested using two different refrigerants, the R513A and the R134A. The resulting performance was very similar, with the COP over 3.5, as presented in Figure 10. The global warming potential of R513A is 573, while the R134A is 1,430.

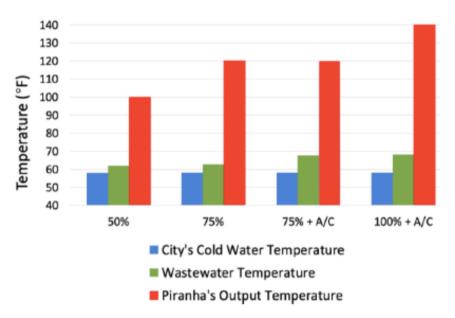


Figure 7. City's Cold Water, Wastewater and Piranha's Output Temperatures as a Function of Domestic Hot Water Load

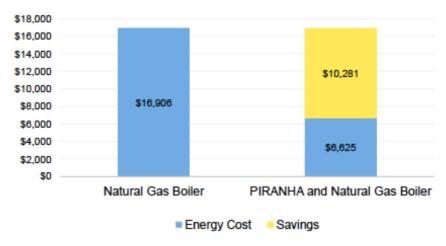


Figure 8. Comparison of Annual Energy Cost Between a Natural Gas Boiler and a Combination of Piranha System and a Gas Boiler Backup

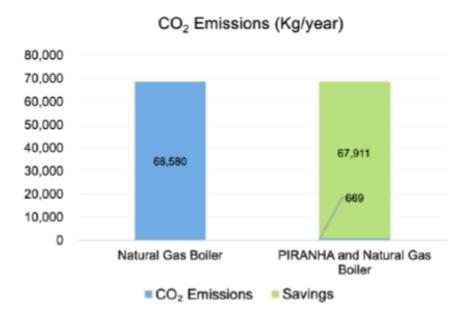


Figure 9. Comparison of CO² Emissions between a Natural Gas Boiler and a Combination of Piranha System and a Gas Boiler Backup

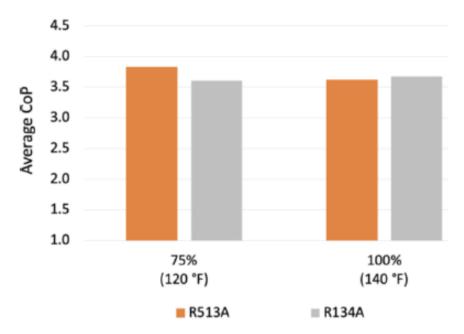


Figure 10. Comparison of Piranha's Performance with both Refrigerants R513A and R134A

CONCLUSIONS

Piranha T10 HC could produce 100% of the hot water at 140°F, with an average COP of 3.7. In addition, there was almost 100% reduction in GHG emissions as a result of the renewable electricity generation. The Piranha system enabled 60% saving in energy cost compared to the gas boiler, which can be enhanced by its capacity to shift the peak load due to the hot water storage capacity. The study results suggest that Piranha T10 HC should be part of future integrated strategic plans to reduce carbon emissions in all cities.



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