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Motivating communities to retrofit their homes: The potential of ***thermal imaging*** in BC

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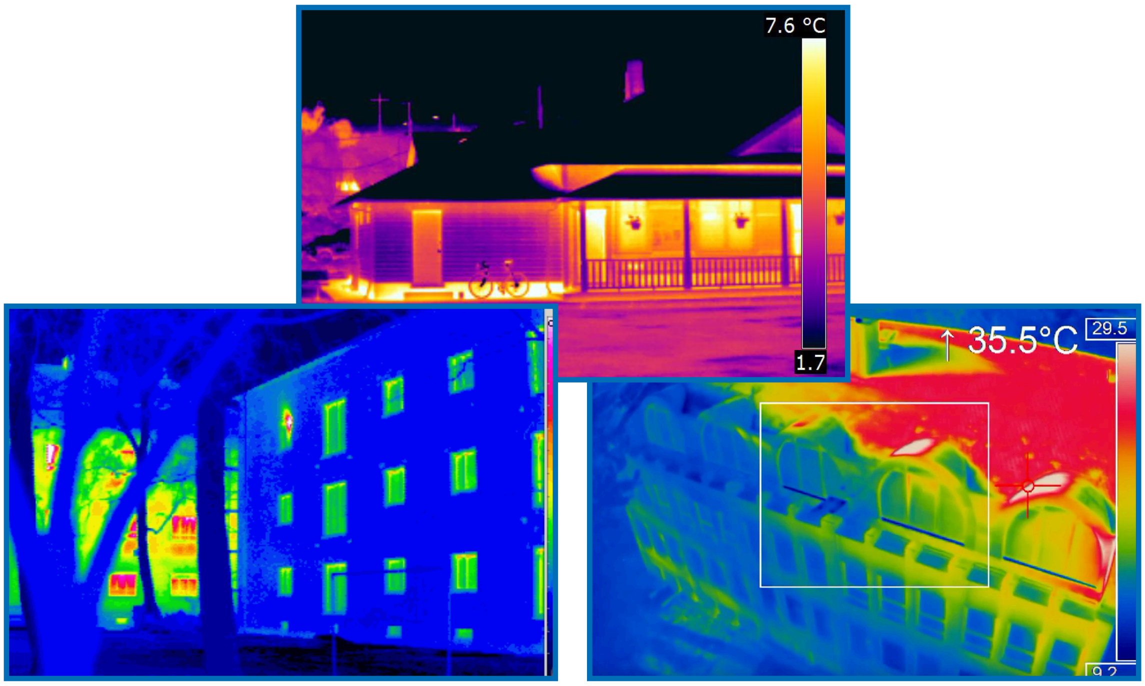

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TABLE OF CONTENTS

EXECUTIVE SUMMARY

This paper presents an argument for the combined use of thermal imaging technology with community engagement strategies as a way of scaling up and accelerating the uptake of home energy retrofits. To date, efforts in British Columbia (BC) to encourage energy conservation in residential buildings have typically relied on government-funded incentives programs, which package financial resources with information about potential cost savings. While there has been some success in the uptake of these programs, they remain limited in their ability to encourage a high enough rate of energy efficiency upgrades to meet BC's targets.

Households accounted for 24% of national energy use in 2014 and 19.2% of the country's greenhouse gas (GHG) emissions.[i] In warmer climates such as BC, buildings account for 11% of provincial emissions,[ii] but in urban centres, buildings can be one of the biggest emissions sources – as much as 55% in the City of Vancouver.[iii] Regardless, on both provincial and national scales, the reduction of fossil fuel use in homes is essential for meeting legislated GHG reduction targets.

This report reviews the technique of thermal imaging as a means of revealing heat loss from single family homes, its current applications in Canada and abroad, and the potential of coupling its use with community-based initiatives to improve uptake rates of energy efficiency retrofits and conservation. By allowing homeowners to see the energy loss (via infrared images) that would otherwise be invisible, thermal imaging provides a powerful visual tool that can engage and trigger a deeper understanding of retrofit needs and opportunities, on both personal (residential) and community (neighbourhood or city) levels.

The paper includes evidence from the United Kingdom that use of thermal imaging can lead to reductions in domestic GHG emissions of up to 14%. When used as part of a voluntary grassroots initiative involving neighbour-to-neighbour social interaction, the use of thermal imaging can lead to much higher rates of energy retrofit, as evidenced by the Eagle Island neighbourhood on BC's own North Shore. This combination of methods represents an emerging best practice in 'scaling-up' community-led retrofitting, and deserves support for further piloting and roll-out in more neighbourhoods.

The paper concludes with 30 sector-specific recommendations to support provincial and local governments, utilities, neighbourhood groups, and academic institutions working in partnership to encourage home energy retrofits. These include opportunities to:

- Encourage the wider use of expert-guided thermal imaging to motivate householders to take action in retrofitting their homes;
- Provide support (e.g. expertise, communications, policies, etc.) for community leaders and groups interested in leading neighbourhood-scale energy retrofit programs for both single-family homes and multi-unit family buildings;
- Tie existing incentive programs to the use of thermal imaging technologies and promote a more comprehensive retrofit strategy that can track and support retrofit activities over time;
- Explore and test innovative funding mechanisms, such as the coordination of bulk purchases of thermal imaging or retrofit supplies, to support community-led thermal imaging initiatives; and
- Foster continued research to measure the effectiveness and limitations of thermal imaging tools and community-led programs in BC in helping to reduce GHG emissions.

1. INTRODUCTION

In 2008, British Columbia adopted legislated targets to reduce greenhouse gas emissions by 33% relative to 2007 by 2020 and by 80% by 2050.[iv] To help meet these targets, energy use and GHG emissions reductions will be necessary across the building sector. An important method for achieving this is via energy efficiency retrofit programs; however, to date their efficacy has been somewhat restricted by limited breadth and uptake.

In this paper, we explore the potential for increasing the success of these existing programs through the use of thermal imaging. Thermographic cameras have been used for decades to pinpoint areas of moisture and damaged mechanical or electrical components in commercial buildings, but only recently have been introduced as a tool to promote the uptake of residential energy efficiency retrofits. We argue that applied to the BC context, the use of thermal imaging (TI) can improve existing energy efficiency and conservation incentives programs by making areas of heat loss in residential buildings visible and tangible to homeowners. Coupled with community-based engagement programs, thermal imaging can significantly increase the rate of retrofitting across the province.

2. RESIDENTIAL ENERGY EFFICIENCY RETROFIT PROGRAMS IN BC

2.1. Programs, past and present

Space heating uses a considerable proportion of household energy demand – in 2008, space heating in Canadian homes accounted for 63% of residential annual energy consumption.[v] Building inefficiencies can account for as much as half of the total heat loss in a building, making the identification and remediation of these sources of heat loss crucial for reducing emissions from the residential sector. These typically occur as a result of either air leakage via inadequate sealing in building envelopes and roofs, and/or losses of heat via conductive heat transfer due to inadequate insulation.

In Canada, both federal and provincial government support for privately owned home retrofits have generally taken one of two approaches. Most common is the provision of standard information on how individual households can benefit from energy conservation and related cost savings, often in the form of flyers or emails. The kinds of consumer "energy behaviours" targeted by such programs can include both purchase behaviours, or one-time investments in more efficient appliances or building envelope upgrades, as well as maintenance behaviours, or occasional activities that improve energy efficiency through e.g. switching to higher efficiency light bulbs. A second and often complementary approach is to provide financial incentives to homeowners who undertake retrofits to offset the cost of upgrading their building envelope or heating and cooling systems.

In BC, residential household energy reduction schemes have been funded and administered through two major programs. From 2008-2014, the LiveSmart BC program provided incentives and guidance for residential, commercial, transportation and community energy efficiency activities. The LiveSmart at Home stream included an Efficiency Incentive Program that offered rebates for various kinds of retrofits, from improving insulation to the replacement of mechanical ventilation systems. To be eligible, homeowners were required to hire a Certified Energy Advisor to perform a home assessment that provided information on total energy consumption and recommended upgrades, followed by another assessment after any upgrades were performed. In 2014, the LiveSmart program was estimated to have incentivized roughly $110 million in energy retrofit investments, with an estimated 15-28% reduction in energy bills for participating households.[vi] According to the Ministry of Energy and Mines, 80% of participants in the LiveSmart program completed some form of upgrade to their homes.[vii]

While the Province of BC's Climate Leadership Plan outlines proposed measures to improve the energy efficiency of new buildings, energy efficiency rebate and incentive programs are now administered by provincial utilities.[viii] BC Hydro's Power Smart program offers information on behaviours to reduce energy use, sources of high efficiency products and technologies, and rebates for insulation upgrades, draft-proofing, and improvements to heating and ventilation systems. These incentive programs offer up to $1200 for upgrading insulation, $500 for draft-proofing, $88 for improving home heating systems, and $50 for improvements to ventilation systems.[ix]

The program is tied to others in the utility's portfolio, including BC Hydro's 'Team Power Smart Program', which offers rebates to households that cut their overall consumption by 10%. The expected expenditures and electricity savings of the residential renovation rebate program were estimated in 2015 to be 67% below what was expected, attributed primarily to the delayed launch of the program following the transition from LiveSmart to the new utility-led model.[x]

FortisBC similarly offers rebates for high efficiency natural gas water heaters, heat pumps, and fireplaces, alongside a number of other programs for lighting, domestic hot water and space heating conservation. In 2014, FortisBC estimated a reduction in annual natural gas consumption of over 94,000 GJ across the 860,000 households covered by the programs. In the same year, BC Hydro and FortisBC launched the Home Energy Rebate Offer (HERO) incentive program for specific home improvements until 2016. In 2015, Fortis BC estimated the total actual energy savings from their Home Improvement program to be 231.2 MWh, with a total expected savings of 6,326 MWh over the lifetime of the improvements. They also noted a total expenditure of approximately $200,000 of the $884,000 approved for the program.

2.2 Program limitations

While the programs listed above have certainly helped to reduce GHG emissions from BC buildings, research has demonstrated several limitations to the success of such programs, including the following:

Uptake: First, in order to meet the 2050 GHG reduction targets, substantial improvements in building energy efficiency will be necessary, especially among BC's approximately 800,000 highly inefficient homes built before 1984.[xi] In order to increase the uptake of home retrofits, additional and more inclusive programs will be needed to mobilize building owners into taking action.

Additionality: Second, the issue of additionality (or the degree to which such programs stimulate retrofits above and beyond what homeowners would have undertaken without the program) remains a question. Such so-called "free-riders" are thought to simply take advantage of funds made available to reduce the costs of home renovation plans already in place. For example, BC Hydro estimated a free ridership rate of 44% in its LiveSmart Renovation Rebate program between 2009 and 2011.[xii] An independent study of FortisBC's home improvement program similarly noted that 95% of program participants indicated that they intended to purchase energy efficient equipment prior to learning of the rebate program.[xiii]

Effectiveness: Finally, while fiscal rewards remain important motivators for home retrofits[xiv], they cannot be the only ingredient of energy efficiency programs and must be included into a broader array of program components. A lack of technological options or prohibitive costs is often pointed to as reasons for low engagement, but this is not always the case.[xv xvi] Whether or not someone chooses to participate in a retrofit program can be determined by a host of other factors, from the perception of its (in)convenience, what is considered an acceptable standard of comfort at home, or whether or not retrofitting activities have been undertaken by one's peers.[xvii xviii xix xx xxi] A growing body of work on the success of financial incentives for reducing residential energy use point to a number of strategies that can improve uptake, including the need to:

- Include financial incentives into a mix of engagement approaches;
- Segment markets to effectively target incentives and other program characteristics to demographics most likely to participate;
- Simplify program participation to reduce the number of steps or paperwork involved;
- Engage homeowners directly to ensure outcomes are aligned with their personal habits and preferences;
- Partner government-led programs with trusted local organizations; and
- Promote marketing by word of mouth and other community-based, attention-grabbing techniques. [xxii xxiii xxiv xxv xxvi xxvii xxviii]

Nevertheless, most residential energy programs remain focused on top-down models that rely on motivating homeowners with financial incentives, communicated through standard methods of information dissemination and divorced from community forums or processes.

2.3 Opportunity: thermal imaging

These limitations illustrate the need and opportunity to broaden and accelerate the uptake of retrofitting initiatives, and to use more compelling techniques for engaging citizens. One such example is in the use of powerful visual tools that engage and trigger a deeper understanding of retrofit needs and opportunities[xxix xxx], including the use of thermal imagery. Used in conjunction with community-based engagement activities, it has been found to achieve high participation and retrofit rates, as well as important co-benefits such as improved community relations and job creation.

3. THERMAL IMAGING

3.1 Basics and applications

Thermal imaging represents a form of non-invasive testing that allows for a detailed exploration of a building's structure, materials and/or components without any damage (e.g. opening up walls) to the envelope.[xxxi] Thermal imaging(TI) cameras produce digital images in real-time that indicate relative differences in temperature using a temperature scale (see Figure 1). TI cameras can help to identify a number of building deficiencies and risks, including:

- Abnormally hot electrical connections or mechanical components;
- Heat losses or air leakages in building envelopes;
- Roofing heat losses;
- Energy loss from window frames and doors;
- Water collection or leakages on flat roofs;
- Water condensation or ingress;

- The presence of mould or moisture damage;
- Sub-floor hydronic heating system leakages; and,
- Thermal bridges, or areas through which heat is conducted out of a building. [xxxii]

Types of thermal imaging cameras—and how they are used—can vary considerably. While sophisticated cameras can cost upwards of $45,000, simple hand-held cameras can cost as little as $500, making thermal imaging competitive with blower door tests for identifying heat losses. While images produced by such hand-held TI cameras are relatively intuitive, thermographic

Figure 1: A thermal image of the front façade of a single family home © Courtesy of Essess, Inc. http://www.essess.com/technology/machine-vision/

inspections should be conducted by an energy inspector with the appropriate training to ensure meteorological conditions are appropriate (i.e. high temperature differences across building envelopes, dry surface and with low wind) and interpretations are correct. Qualifications in building science, energy auditing, or surveying are also required to make well-founded recommendations for remedial actions. [xxxiii]

Other forms of TI can be performed on broader scales to identify heat losses or moisture accumulation across several buildings or even neighbourhoods. Aerial surveys can be conducted either manually (via helicopter or small plane) or automatically using drone technologies to explore larger areas (Figure 2). Drive-by surveys can also be used to cover large areas by affixing multiple cameras to a car and driving slowly through various neighbourhoods (similar to the process used by Google Maps). While these approaches are able to cover more ground, there are tradeoffs inherent in the level of accuracy or detail when compared to more time-consuming hand-held approaches. [xxxii xxxiii] For example, while aerial imagery can successfully pinpoint areas of moisture ingress and thermal conductivity for the roofs of large buildings, these and drive-by techniques often fail to identify the specific defects and contextual variables important to image interpretation obtainable through the use of a hand-held device. [xxxii]

The use of thermographic imaging technologies is well established in Canada, with several certification programs offered Canada-wide. Appendix A outlines some of the institutions and

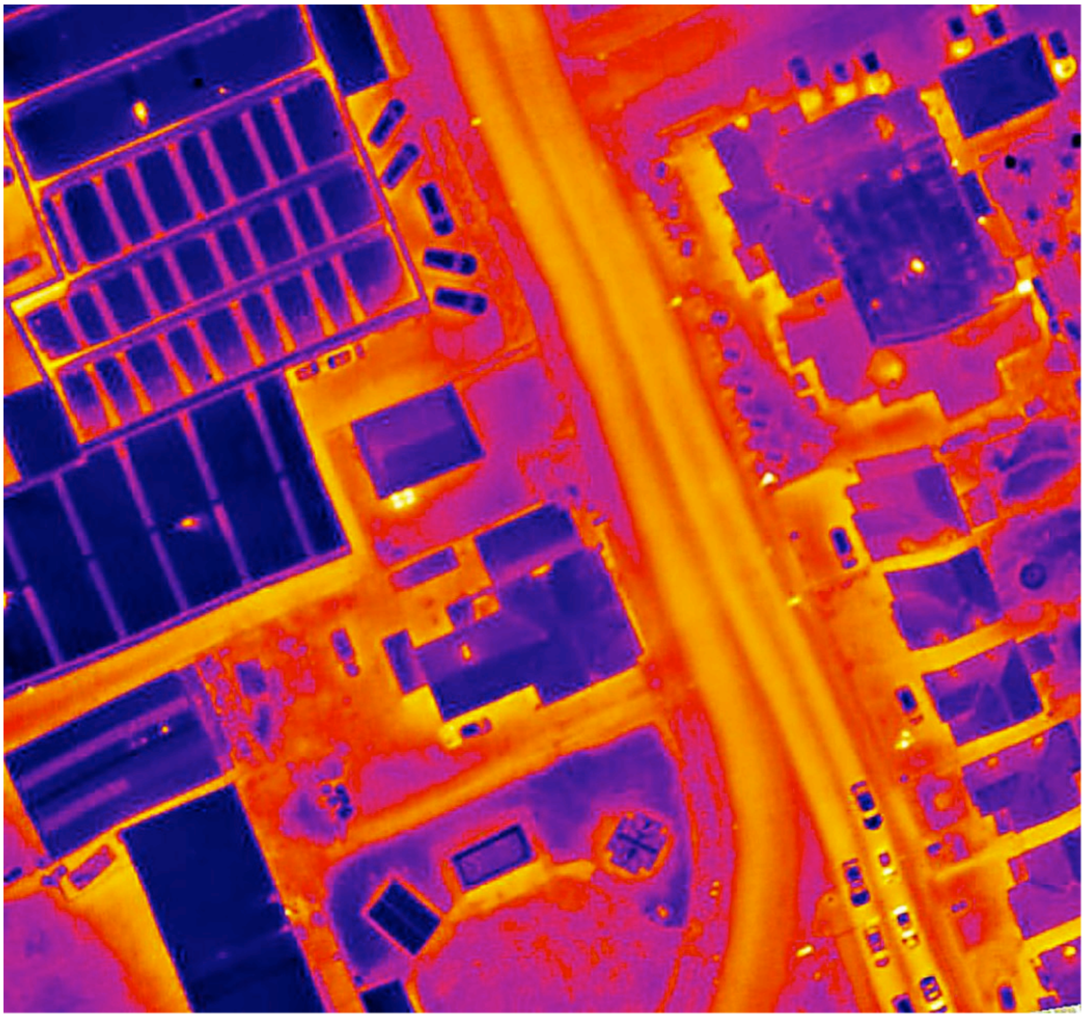

Figure 2: Aerial thermal images can detect heat losses or moisture on building roofs. Points of bright light indicate potential areas of heat loss © BlueSky International

certification programs relevant to thermal imaging inspections that are currently offered to Canadian professionals. The International Organization for Standardization (ISO) also offers a number of TI-related standards for the required qualifications and level of certification of personnel[1]. In BC, a number of companies (e.g. ABM Environmental Inc., PROScan, BC Thermal Imaging Ltd.) and non-profit organizations (e.g. City Green) offer thermal imaging services, from home inspections prior to purchase or move-in, to existing home retrofits, and commercial/industrial safety and energy efficiency audits.

However, while thermal imaging techniques have long been used to assess building performance and potential risks, they have only recently been used as a tool for motivating homeowners to undertake home retrofits. Over the last several years, a small number of local governments in BC have begun to explore the potential of thermal imaging to encourage retrofit activities, but few examples yet exist of the use of thermal imaging as a part of a larger set of program tools to encourage retrofits in single-family homes. In the next section, we explore some of the benefits and existing approaches to thermal imaging in energy efficiency programs.

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1 For example: 9712:2012 for Non-destructive testing; 18436-7:2014 Condition monitoring and diagnostics of machine, Part 7 thermography.

3.2. Large-scale thermal imaging projects

The primary benefit of using thermal imagery in building energy audits pertains to one of the key challenges in communicating energy flows in buildings: their invisibility. While building users may feel warm or cold, they are unable to directly see heat escape or cold enter their home, and therefore have difficulty pinpointing problem areas. Thermal imaging increases energy literacy by providing clear and specific pictures of energy loss to target retrofit actions, and can motivate both building improvements and changes in habitual behaviours. At a city or neighbourhood scale, it can also provide utilities and municipalities with valuable data that can be used to target demand side management (DSM) programs more effectively.

3.2.1. Aberdeen, Scotland

One of the earliest large-scale thermal imaging studies took place in 2001 in Aberdeen, Scotland, in which Aberdeen City Council piloted a city-wide aerial TI survey to "inform its fuel poverty[2] strategy, direct home energy efficiency assistance and to engage householders directly with the thermal inefficiency of their homes".[xxxiv] Thermal images were made available via an online mapping tool that showed the heat loss[3] of the surveyed building roofs via a colour spectrum, and allowed owners to search their home by postcode and street name on the heat map. According to the council, this encouraged 'many' homeowners and tenants to seek advice for houses that were shown with high heat loss. Follow-up thermal imaging surveys were conducted in 2007 and 2009 and published online, but did not lead to further engagement strategies with homeowners leading to building energy retrofits.[xxxv] It was later determined that the images taken in 2007 were not well calibrated, and were furthermore taken over a period of time, resulting in a set of images that did not accurately represent the scanned areas.

3.2.2. MyHEAT, Calgary

More recently, advances in thermal imaging and web-based technologies have prompted several large-scale thermal imaging projects in North America. The first such study undertaken in Canada was the Heat Energy Assessment Technologies (HEAT) program. In 2010, HEAT conducted a pilot project of 368 residences in the community of Brentwood, in the north-west quadrant of Calgary, using aerial thermal images to create a mosaic of rooftops in the study area. Images were accessible through an open source website that showed residence buildings as polygons on a heat map. As in Aberdeen, houses were represented in different colours, based on a "HEAT Score" that compared the waste-heat levels of the buildings (Figure 3).

As a part of the project, Free Geoweb Decision Support Service software was developed by the University of Calgary to assist homeowners in improving home energy efficiency, save money, and reduce GHG emissions.[xxxvi] An interactive tool enabled users to click on individual buildings to see primary areas of heat loss, and gives a "HEAT score" that compares the house's heat loss with others in the neighbourhood. Homeowners were encouraged to participate in retrofit programs through a voluntary geographic information system that enabled them to define roof materials and help classify their buildings. Since the original pilot, the study has been extended to cover 37,914 single family homes in Calgary, which emit an average of 18 tonnes of $C0_2$ emissions per year – among the highest in Canada.[xxxvii] HEAT further estimates a total potential community savings of $4.915 million and a reduction of 29,026 tons of CO_2 per year in the event that all recommended energy retrofits are undertaken. However, no actual savings via building energy retrofits have been documented.

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2 Fuel poverty describes a household for which fuel costs are so high that the remaining household income is below the official poverty line.

3 According to Roberts et al. (2004) Aberdeen City Council did not systematically collect data that quantified how 'many' householders contacted them.

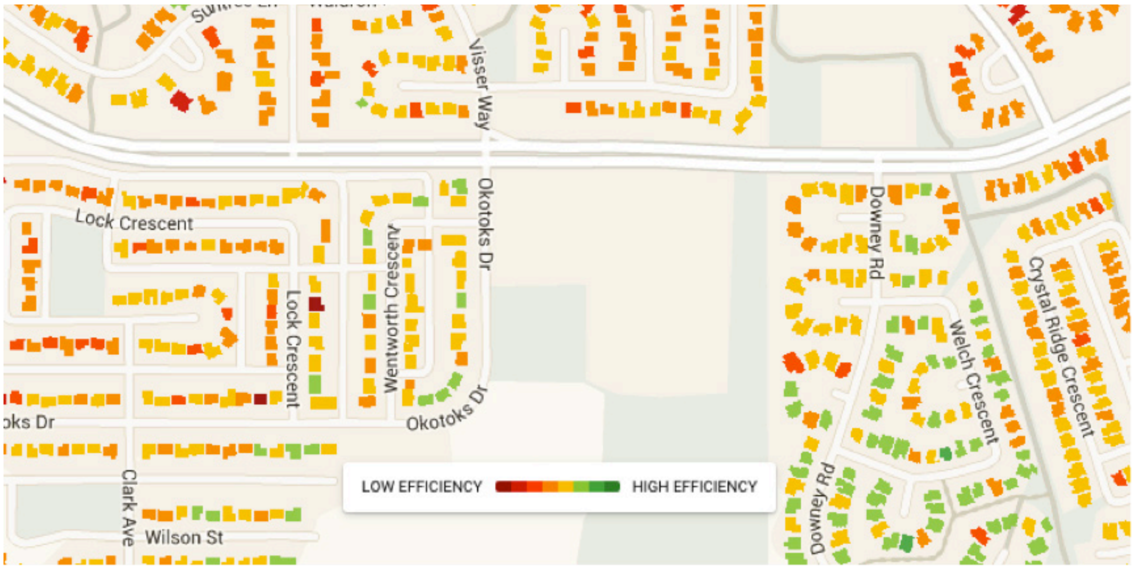

Figure 3. MyHEAT's heat map (https://myheat.ca/)

3.2.3. Mass Save®, Massachusetts

A second large-scale study of note in North America was initiated by the State of Massachusetts, in which a partnership between the state utilities and municipal aggregators ran the statewide Mass Save® energy efficiency program from 2013 to 2015. Under Mass Save®, the Massachusetts Department of Energy Resources' Home MPG ("miles per gallon") initiative was established to increase utility customer awareness of home energy performance and the benefits of efficiency upgrades.[xxxviii] Home MPG hired Massachusetts-based start-up Sagewell Inc. to undertake a thermal imaging scan of approximately 40,000 one and two-family homes in the city of Springfield and seven surrounding communities[4]. Homes were scanned using a drive-by technology that provided thermal images of the front envelope of the building. Thermal images were made available to homeowners through a secured online database, which was promoted via flyers that offered information on rebates and no-cost energy assessments. Two thousand buildings with the highest potential for energy savings were also sent letters, as well as those that had received an energy assessment but that had not yet completed an upgrade.

Evaluations of the program indicated that despite the availability of online images, few owners were aware that thermal images could be accessed for their home. However, a majority of survey participants indicated that they would have found it helpful to see thermal images of their home in order to make decisions on energy retrofits. The results of the more targeted form of outreach for achieving higher uptake rates in energy retrofits are unfortunately unknown.

Since 2011, large-scale thermal imaging scans have been provided by Essess, a company based in the Massachusetts Institute of Technology (MIT). Essess also uses thermal imaging cameras mounted on car roofs to create heat maps of thousands of homes.[xxxix] However, Essess' imaging technology provides 3-D images that discern building facades from the physical environment to improve the overall accuracy of the assessment. This information is combined with household and demographic data (such as mortgage payments and the age of building occupants) to identify homeowners most likely to realize energy upgrades.

[4] The Massachusetts Department of Energy Resources provided homeowners with an opt-out option of the thermal imaging scan of their building. However, the Department found that many homeowners asked explicitly for the scan.

4. ENGAGING COMMUNITIES WITH THERMAL IMAGING

The projects above demonstrate the utility of large-scale thermal imaging projects in identifying buildings that are suitable for energy retrofits and in encouraging homeowners to implement energy-efficiency measures. However, few of these existing initiatives have documented the effectiveness of different forms of engagement strategies. While Mass Save® aimed to show that more targeted forms of engagement could increase the uptake of retrofit actions and thus the success of thermal imaging programs, no direct evidence has been provided. Nevertheless, for provincial and municipal actors in BC to take advantage of the lessons learned from this existing work, it is important to consider how the utility of such programs can be maximized using more in-depth means of engagement. To do so, we explore two examples from the UK and from BC.

4.1. Examples from the UK

A large portion of existing research in this area has been conducted in the UK in a collaboration between building scientists and psychologists at Plymouth University.[xl xli xlii] One group of researchers conducted two small-scale field studies to show that the visual and intuitive qualities of thermal images make them appealing and interesting to homeowners. [xli]

In Study One, 43 householders were recruited by a community climate action group in a small town in Devon, UK and divided into three groups. One group was shown thermal images of their external facades of their home and completed a carbon footprint assessment, while the second group only completed the carbon footprint audit, and a third group received neither thermal images nor completed the audit. Participants of one group were visited by a qualified thermographer who took external images of the home, which was followed by a meeting with a researcher to show and discuss the images with homeowners. Baseline and follow-up energy use data via utility bills were collected from all three groups. Participants were not required to pay for either thermal imaging or carbon footprint audits.

Study Two was done in collaboration with an educational charity The Eden Project and its "21st Century Living Project", campaign, which encouraged a wide range of sustainable behaviours by way of leaflets, online blogs, and giveaways. Study Two divided 87 householders across England into two groups: the first was mailed thermal images of their home and recommendations for energy-related actions, while the second group only participated in other engagement activities. Study One found that households in the thermal image group each saved approximately 700 kg CO_2, or a collective savings of over 11,000 kg and a reduction of 14% compared to the baseline. Neither the carbon footprint audit group nor the control group reduced their carbon emissions. In Study Two, 26% of homeowners in group one took action to draft-proof their home, compared to only 6% in the control group.

More recently, some of the same researchers conducted a study to determine the extent to which images should be personalized to ensure maximum effect.[xlii] In the study, 980 participants were divided into three groups, each receiving a different type of print-based engagem ent: a "tailored" thermal image of their own home, a "non-tailored" thermal image of other, similar homes in the area, and text-only information on typical energy efficiency issues in local homes. Two hundred and thirty-three individuals participated in a follow-up survey, in which it was shown that tailored images were more likely to be shared with others in the area, and elicited a higher overall energy saving intention among homeowners. A larger project is now aiming to integrate energy visualizations into daily life through smart screens and smart phones (see www.eviz.org.uk). Offering free thermal imaging to householders within the eViz project was met with great interest in early 2013. Out of 9000 people on a mailing list, 1000 registered their interest in the new program within 48 hours.

4.2. Examples from BC: Eagle Island

Another example of the utility of thermal imaging when coupled with more in-depth engagement measures comes from within BC itself: the case of Eagle Island, a small island community of approximately 30 older homes off the shore of West Vancouver. The island is home to a demographically diverse mix of residents, ranging from young families to retirees. The community also represents a "grassroots" effort to improve residential energy efficiency using TI, and has sparked interest in thermal imaging across the municipality.

Initiated by local resident Tarah Stafford, the Eagle Island neighbourhood retrofit initiative was convened through a series of informal social events, during which Stafford collected and distributed information about rebate and incentive programs, including the federal ecoENERGY

Figure 4. A thermal imaging expert conducts a real-time assessment of heat loss using a hand-held infrared camera with a homeowner. © S. Sheppard.

and provincial LiveSmart programs. Members agreed to submit their homes to an energy audit using thermal imaging. Arranged by a staff member of the District of West Vancouver, a member of the local Fire Department visited each home and took images of the home using a hand-held device[5]. In most cases, the homeowner was present during these visits and was able to interact with the thermographer (see Figure 4).

Following these TI sessions, the project coordinator organized a 'Seal Team' of volunteer British Columbia Institute of Technology (BCIT) students to visit the participating homes to carry out remedial measures (at cost to the homeowner), such as caulking windows and doors. To help subsidize the cost of larger retrofits, bulk-buying schemes were established for items such as solar hot water tanks, heat pumps, and window installations.

The Eagle Island initiative demonstrates the power of community-based approaches in its achievement of a 100% participation rate, with 26 of the total 31 homeowners going on to retrofit their homes. While the receipt of financial support from rebate programs was certainly a motivating factor for participation, it was not the only incentive. Initial inspiration for this grassroots initiative came from Stafford's concern for her children and their future security in light of climate change. Other homeowners were similarly motivated, but many reported additional reasons for joining the program, including:

- A desire to be included in neighbourhood gatherings;
- Peer pressure from neighbours;
- The novelty of using thermal imaging in their homes;
- The convenience of having someone organize the audit and other activities, and;
- The financial savings that would ensue from reduced energy consumption in their homes.

Other factors that residents found interesting about the experience included the compelling nature of the images that were provided, which clearly indicated areas of heat loss; the use of a hand-held device, which allowed the resident to point to certain areas of the house; and the opportunity

Figure 5. Sign template for neighbourhood recognition having undergone a program like the Cool Neighbourhoods program by Cool North Shore

to converse with an expert over different options and implications. The participation of the Fire Department was also noted as a factor in the program's success, as participants considered them to be inherently trustworthy.

These findings are consistent with research in climate change and sustainability engagement that shows that community-led actions may be more effective than targeting individuals, in that they address important social norms, notions of quality of life, attachments to place, and community

[5] Initially, a trained energy expert conducted the thermal imaging. However, the West Vancouver Fire Department carried out thermal imaging for the remaining Eagle Island homes in order to gain training and experience in the use of the cameras.

identity.[xliii] [xliv] Neighbourhoods offer high visibility of actions taken by community members, spurring action across the community[xlv] [xlvi] [xlvii]

The Eagle Island approach has since spread to 11 other neighbourhoods on Bowen Island and the North Shore with increasing support from municipal authorities. The non-profit organization Cool North Shore has scaled up the Eagle Island project into the 'Cool Neighbourhoods' program[xlvii]i by hiring staff and developing guidance for other communities (see Figure 5). Together, Stafford and Cool North Shore were able to procure grants worth approximately $150,000 from BC Hydro, the Real Estate Foundation, and the federal government to conduct thermal imaging in 1,000 homes across the North Shore. In Eagle Island itself, the initial program has spurred other neighbourhood activities intended to reduce GHG emissions, including the installation of electric motors in residents' boats (replacing diesel) and the installation of an electric charging station. In 2012, the Eagle Island organizers estimated that average carbon footprints from the retrofitted homes on the island had dropped from 5 tonnes of CO_2 /year to 1.7 tonnes.[xlix] In 2013, participation in the program resulted in a total estimated emissions reduction of approximately 387 tonnes/year.

5. DISCUSSION

The examples reviewed above show the benefits of combining thermal imaging technology with stronger forms of engagement with homeowners to encourage retrofits in the residential context. Altogether, the research findings indicate that the use of IT for encouraging energy efficiency retrofit can be highly successful through a combination of:

- Highly practical and intuitive information on areas of energy loss;
- The communication of abstract information in a clear and understandable format;
- A compelling image that invokes a personal attachment to an intimately experienced home environment and that can be repeatedly revisited;
- Opportunities for interaction with experts and other community members;
- Practical advice on how to remedy energy losses; and
- Community-based engagement and encouragement.

Other research has shown the effectiveness of providing aerial thermal imaging images to homeowners and businesses to encourage retrofits and the use of grant measures. [xiv] Such findings have led some to recommend a phased approach to thermal imaging programs, in which large-scale and less expensive surveys can be used to identify broad areas of high heat losses, following which a more targeted and personalized approach at the household level can be used. [xii]

Our findings are also consistent with other research on the use of visual imagery as prompts for behavioural change.[l] For example, making energy consumption visible through smart metering has been associated with energy savings of upwards of 5-15%.[li] Street graphics to advertise the collective energy use of an entire block on Tidy Street in Brighton, UK have also been found to result in significant reductions of energy use over the period of the project.[lii] [liii] Three-dimensional views of real places and buildings are believed to be especially powerful in making scientific information salient and enabling personal connections to lifestyles and home, tapping into strong place attachment emotions.[liv] Local landscape visualisations have also been shown to increase residents' understanding and motivation on climate change mitigation measures.[lv] The results of climate change visualization imagery research at UBC show that certain 3D perspective images are vividly recalled and retained in viewers' memory several years later.[lvi]

The Eagle Island initiative is particularly compelling, in its use of a unique combination of 1) vivid and intuitive images, 2) a place-based, volunteer-led collective neighbourhood engagement process that emphasized fun and neighbourliness, and 3) the use of partnerships with local government and businesses. The Eagle Island initiative allowed for a diversity of values and views to be drawn together into a program that successfully initiated a high number of retrofits across the neighbourhood.

Of course, there are certain limitations on the use of thermal imaging that should be carefully considered. Building thermographic inspections must take place under fairly particular climatic conditions so as to ensure limited influence on building images. Other nearby objects can reflect off the target surfaces of a home, which can lead to image misinterpretations. To avoid these and other potential issues with thermal imaging, camera operators must be adequately trained to take and interpret images.

Scaling up such projects can also be challenging. Demand for retrofitting assistance has routinely exceeded provincial budget allocations, and while the uptake of such programs can rely to an extent on grassroots and community-based initiatives, these still require financial support. Despite significant reductions in cost, the purchase of multiple infrared cameras may stretch certain municipal or community group budgets, while contracting a certified professional may be similarly limiting. Other hurdles may present themselves in involving local groups (such as Fire Departments) due to labour rules, departmental silos, the need for additional training for energy interpretations, and other administrative barriers. Finally, each neighbourhood is unique, and specific methods may have to be adapted substantially to find the right fit. Effective, well-liked local champions are often key to the success of such programs, but are also at risk of “burn out” after protracted periods of time.

6. KEY RECOMMENDATIONS

In investigating both existing literature and practice in the use of thermal imaging for energy efficiency retrofits, it is clear that two broad approaches can be taken: a bottom-up approach, in which grassroots efforts can be supported and scaled-up, and a top-down process, in which local governments or provincial authorities and/or utilities administer a thermal imaging program. In both cases, however, a coordinated effort involving multiple actors is important to improve the overall success of the program and in doing so, the total quantity of energy and emissions reduced. As such, we conclude the paper with a number of recommendations for different bodies and stakeholders **to work in partnership** to foster the wider uptake of retrofit activities, including provincial authorities, utilities, local governments, neighbourhood groups, and academic partners.

6.1 Recommendations for provincial bodies

Provincial bodies can act as both coordinator and program facilitators by promoting and implementing a set of tools and processes for community-based thermal imaging, and streamlining the development of local government programs. Specific actions that provincial bodies can feasibly take include the following:

1. Plan energy efficiency mobilization efforts in tandem, such that they are able to integrate financial and other forms of support (e.g. expertise, communications, policies, etc.), engagement tools and processes, and business contributions to community-led efforts.

2. Provide or host training for fire departments or other local organizations in the use of thermal imaging technologies;

3. Develop or leverage existing guidelines or standards for thermal imaging programs at local government or neighbourhood scales;

4. Provide technical or other support for local governments initiating thermal imaging programs;

5. Promote thermal imaging programs and acclimatize residents to TI technologies via public service announcements and social media; and

6. Coordinate and/or host large-scale thermal image survey data (e.g. aerial, street-view).

6.2 Recommendations for local governments

Local governments are often responsible for the administration of energy efficiency programs and are more readily capable of connecting with households at the community level. Municipalities can also provide support for community or neighbourhood-led energy retrofit programs for both single-family homes and multi-unit family buildings via the following activities:

1. Host and/or promote neighbourhood efficiency competitions and acknowledge neighbourhoods (e.g. via plaques or street signs) for their energy-savings efforts;

2. Help negotiate bulk discounts (e.g. buyers' clubs) for retrofit activities;

3. Cooperate with local Fire Departments or other organizations interested in the training or use of thermal imaging equipment;

4. Encourage local news coverage to widen public awareness;

5. Encourage the combination of thermal imaging audits with other mandatory inspections for e.g. fire sprinklers and gas.

6. Partner with energy advisors, businesses and non-profit organizations (e.g. City Green Solutions and Embers);

7. Foster connections with NGOs/private sector/cultural organizations/public sector / regional governments/civic groups; and

8.Assist negotiations between community groups and utility companies or businesses to secure financial aid and bulk-buying coupons for home upgrades

6.3 Recommendations for utilities

Utilities can tie existing incentive programs to the use of thermal imaging technologies, as well as promote a more comprehensive retrofit strategy that goes well beyond time-limited financial incentives. Some key activities for utilities include:

1. Maintain consistent incentive/rebate programs, to avoid uncertainty over whether rewards are obtainable or not. The current Power Smart program should be continued and expanded;

2. Explore and pilot the use of standardized and/or individualized thermal images in utility bills;

3. Consider innovative funding mechanisms that increase support for community-led initiatives in conjunction with provincial and municipal programs;

4. Provide advisory support to emerging community efforts via community energy managers; and

5. Provide multiple forms of financial support, such as BCSEA's Green Landlords Project,[lvii] which addresses a particular gap in the low-income sector by working with both landlords and tenants.

6.4. Recommendations for community & neighbourhood groups

As evidenced by the Eagle Island case, local efforts can be highly successful in encouraging high levels of participation in retrofit programs, and can form the basis for broader regional programs. Specific recommendations include:

1. Seek federal, provincial and/or municipal forms of financial support;

2. Inform local governments of your activities and solicit administrative, financial, and/or technical support;

3. Solicit businesses and industry programs for technical support and/or bulk discounts; and

4. Offer to share expertise and coordinate efforts with other neighbourhood groups to share resources and experiences.

6.5. Recommendations for academic & research institutions

Finally, universities and research bodies should foster and support continued research on thermal imaging tools and community-led programs in BC. These actors can furthermore support governments and community organizations by obtaining detailed research on program outcomes and best practices for increased uptake rates. As such, specific areas of research that these actors could explore include:

1. Cost-benefit studies that test the uptake and effect of free (subsidized or voluntary) thermal imaging versus at cost or with commercial rates;

2. Required level of expertise for accurate thermal imaging interpretation;

3. Relative effectiveness of indoor vs. outside imaging;

4. Broader pilot programs in BC communities to test the value and cost of thermal imaging as a component of audits and neighbourhood action;

5. Systematic evaluation of real-world mobilization efforts (e.g. Cool Neighbourhoods);

6. Relative importance of strategies and components of grassroots initiatives; and

7. Long-term effectiveness of various retrofit initiatives

APPENDIX A

Examples of institutes offering training	Examples of training programs/courses offered	Types of certification achievable
International Association of Certified Home Inspectors (InterNACHI) Infrared Training Centre (ICT) American Society for Nondestructive Testing (ASNT) Canadian Institute for Energy Training (CIET) Canadian Association of Home and Property Inspectors InterNational Electrical Testing Association BC Institute of Property Inspectors	Infrared Certification Course for Inspectors, Contractors, Energy Auditors and Realtors Level I Thermography Level II Thermography Level III Thermography NDT Level III Personnel Qualification Certification Program for IR	Certified Infrared Thermographer® Certified Energy Manager Certified Energy Auditor Certified Energy Advisor Provisional Certified House Inspector Inspector-in-Training

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