Canadian building performance modellers' knowledge and skills gaps and learning needs

Nina Doré[1], William O'Brien[1], Umberto Berardi[2], Ian Beausoleil-Morrison[1], Sebastián Carrizo[3]
[1]Carleton University, Ottawa, Canada
[2]Ryerson University, Toronto, Canada
[3]DIALOG, Toronto, Canada

Abstract

Building performance simulation (BPS) has been referred to as a "wild west" practice, where formal and standardized training is lacking, and practitioners undertake ad hoc training that varies in quality and scope. Consequently, the consistency, reliability, and reproducibility of models has been questioned. Large-scale initiatives in the USA have attempted to unite this distributed workforce with a standardized body of knowledge (e.g., IBPSA-USA BEMBook) and certification programs (e.g., ASHRAE BEMP), but these have not gained traction as anticipated, particularly in Canada. Accordingly, IBPSA-Canada surveyed nearly 100 BPS practitioners to (1) understand knowledge and skills gaps and (2) assess the demand for a Canadian-based training and certification program. Findings confirmed that practitioners have diverse backgrounds and that personal networks and mentorship are central to skills and knowledge development. There is substantial interest in a training and certification program, with an emphasis on establishing best practices, standardizing skill levels, and building credibility. The most desirable training topics include specific tool how-to instruction, building systems (independent of software), and application of building codes and standards.

Introduction

Several major trends are increasing the importance of building performance simulation (BPS) in improving new low-energy and low-emissions building designs. The performance path of building energy codes, which requires building simulation, is becoming a prevalent method for new buildings to demonstrate code compliance (Evans, Roshchanka and Graham, 2017). Building simulation is also progressively more integrated into design workflows, such that the performance of multiple design variants can be efficiently quantified long before a building is constructed (Attia, Gratia, De Herde and Hensen, 2012, Granadeiro, Duarte, Correia and Leal, 2013). Therefore, simulation has an increasingly important role in supporting the design process for high-performance buildings that are low-energy, low-emission, and comfortable for occupants.

However, the usefulness of building models is highly dependent on the appropriateness of modelling strategies and assumptions and how results are used to influence design. Moreover, building energy codes are only as effective as the extent to which buildings comply with them. In a review of 50 energy code compliance and enforcement efforts, Misuriello, Penney, Eldridge and Foster (2010) found that that nearly all of them require improved training initiatives. Indeed, compliance using the performance path of building energy codes requires, in part, an educated modelling community to ensure that code requirements are adequately followed in building energy models. It is therefore critical that BPS practitioners (henceforth, "modellers") be well-trained on building simulation tools, as well as understand underlying theory and best practices. For example, it is critical that modellers understand the limitations of BPS tools, assumptions, and methods to abstract the real building into a model (Hand and Crawley, 1997). These gaps in modellers' experience and knowledge are long-standing; Beausoleil-Morrison (2019) stated, "I believe that BPS suffers from a credibility gap and that its full potential will only be realized once we adequately prepare users to effectively apply tools with full knowledge of their applicability, modelling limitations, and default methods and data, and provide them the skill set to scrutinize their results" (p. 308).

Despite the importance of well-prepared modellers, there have been recurrent concerns about their quality. Indeed, the U.S. Department of Energy described building energy modelling (BEM) as the "wild west" defined by a "sparse and distributed workforce", where "quality is difficult to assess and quality services difficult to procure" (Roth, 2019, p. 55). This was demonstrated by Berkeley, Haves and Kolderup (2014) who recruited 12 modellers with a bachelor's degree or higher to model an administrative building for a comparative study. The results showed that annual electricity use predictions varied by a factor of two among modellers, and natural gas use by a factor of 15. The discrepancies were primarily due to decisions regarding problem/building interpretation and modellers' judgement.

The ongoing concerns about the current state of the BPS practitioner can be summarized in five key issues:

Issue 1: Methods and processes. At the 2011 Building Energy Modeling Innovation Summit hosted by the Rocky Mountain Institute (RMI), a series of focus groups found that modellers use a variety of methods, resulting in models that lack quality (unrealistic), consistency, and reproducibility—leading to low credibility for the community (Tupper, Franconi, Chan, Fluhrer, Jenkins and Hodgin, 2011). Likewise, there is a wide range of competing BPS tools, many of which can be difficult to use and/or require significant pre-processing/translation, making it difficult to share and convert across tools and collaborate with other modellers (Tupper et al., 2011).

Issue 2: Modeller experience and credentialing. "Design firms… assign BEM tasks to junior staff with little experience in BEM or specific analyses, workflows, and tools" (Roth, 2019, p. 56). Modellers lack experience and skills, which employers are largely unable to evaluate (Tupper et al., 2011). The issue is compounded by clients' misguided expectations around the purpose and value of BEM and tight turnaround timelines. Little standardization of skills and knowledge "leaves project execution to modeler judgment and places emphasis on modeler experience" (Roth, 2019, p. 56). The result can be "misuse of the software, use of defaults where project-specific values are needed, or misinterpretation of results" (Roth, 2019, p. 56). For example, modellers rarely distinguish between types of application (comparison, prediction, and validation; Tupper et al., 2011). Modeller inexperience can also be responsible for "an inability to quickly recognize and diagnose the inevitable careless error, by identifying unexpected results" (Roth, 2019, p. 56).

Issue 3: Open design-measured performance loop. Measurement validation is considered costly, time-consuming, and difficult, and so modellers do not do it, leaving open the design-measured feedback loop (Tupper et al., 2011). There is also a lack of high-quality end-use benchmark data to inform the modelling process and a database of measured field data for buildings (to inform inputs) with vetted/ready definitions (e.g., material properties, wall construction, representations of appliances) (Tupper et al., 2011). The "lack of a robust and transparent feedback loop between modeled and measured performance" may be because "[d]ata correlating modeled energy use to measured energy use is not centrally collected or curated. [Many modelers likely] do not even collect this data individually and therefore do not have a quantitative sense of their own level of proficiency, and that if they do, they would be reluctant to share it." (Roth, 2019, p. 56).

Issue 4: Modeller education and training. Most learning is ad hoc, on-the-job, and self-taught (Tupper et al., 2011). Few post-secondary programs include BPS, and those that do are not necessarily aligned with each other or with certificate programs (Tupper et al., 2011). Qualifications such as ASHRAE BEMP (Building Energy Modelling Professional) and IEE BESA (Building Energy Simulation Analyst) are "under-subscribed and not widely required" (Roth, 2019, p. 56). Training offerings are primarily clustered around conferences, with few in-person workshops (primarily offered in large cities). Additionally, most training offerings focus on tool operation (i.e., they are not "tool-agnostic")—not modelling fundamentals, building physics, HVAC, etc. (Roth, 2019). Fragmented learning opportunities can make it difficult to differentiate skill levels and coalesce on a coherent body of knowledge (Tupper et al., 2011). In many cases users learn how to provide inputs, perform simulations, and extract outputs without understanding the underlying calculation methods. For many, BPS tools are treated as "black boxes".

Issue 5: Modelling resources. BPS resources are fragmented, underutilized, uncoordinated, sometimes conflicting, and vary in quality—all factors that may push modellers to devise workarounds, which can cause issues such as low reproducibility (Tupper et al., 2011), particularly if the modeller is inexperienced.

Many solutions to improving the status quo of modeller skills and education have been proposed, including:

- defining methods and processes guidelines (e.g., defining terminology);
- developing a framework for organizing methods; specifying procedures for tasks;
- promoting more collaboration between developers; standardizing tools, methods, and standards—and building tools accordingly;
- encouraging greater validation to demonstrate tool accuracy (to the greatest extent possible; e.g., using other variables, occupant behaviour); and,
- converging on a single certification (BEMP or BESA) that is aligned with (USA) national guidelines and a standardized body of knowledge (e.g., complete BEMBook) that includes stringent and comprehensive professional recommendations (Tupper et al., 2011).

Large-scale initiatives in the USA have attempted to unify and standardize modellers' skills and knowledge through a series of publicly available resources. For example, IBPSA-USA (with the RMI and ASHRAE) developed the BEMBook wiki, a free online tool to organize the core body of knowledge of building energy modelling according to (1) general concepts, (2) methods, and (3) best practices (IBPSA-USA, 2013). BEM Library similarly "aims to improve standardization, expedite modeler training and expand the building energy modeling workforce" (RMI/IBPSA-USA, 2020). While these solutions are good, they have not produced the anticipated results. Efforts like BEMBook and BEMLibrary are largely volunteer-led and are ultimately likely to require substantial funding to regain momentum and finalize the efforts (Roth, 2019).

Another solution to concerns about modellers' skills and knowledge has been credentialing (henceforth "certification") programs. Programs such as ASHRAE BEMP and IEE BESA are exam-based programs that address a wide range of core skills and knowledge. In spite of their potential value, certification has not gained traction as anticipated, particularly in Canada.

In response, the present study aimed to better understand modellers' gaps, wants, and needs with regard to their professional skills and knowledge development in order to propose a potential training and/or certificate program. The project is a joint effort between Natural Resources Canada ("NRCan") and IBPSA-Canada (Canadian chapter of IBPSA). IBPSA-Canada is the primary association representing Canadian modellers. Founded two decades ago, IBPSA-Canada's mandate is to represent these modellers and continually increase their skills, knowledge, and experience through workshops, conferences, public talks, newsletters, and other means. IBPSA-Canada is the largest per capita chapter with 550 members; IBPSA is comprised of over 5000 members.

The overarching research questions guiding this study are:

- What are Canadian modellers' skills and knowledge strengths and gaps?
- What professional development resources are Canadian modellers using and what is their perceived value?
- Is there interest in a potential new Canadian-based training and/or certificate program? If yes, what is modellers' ideal content (topics) and structure (e.g., exam-based, online).

The objective of this paper is to shed light on the typical Canadian modeller's profile and their needs and attitudes toward formal training and certificate programs. The paper summarizes and discusses the results of a survey that was completed by 96 modellers and other related BPS stakeholders in Canada in late 2019.

Methods

To address the above research questions, an online survey was developed based on a review of the literature, an informal focus group with novice and experienced modellers, and anecdotal concerns. The survey comprised five main sections: (1) modellers' demographics, including their educational background and level of modelling experience; (2) modellers' skills and knowledge gaps, using an adaptation of Franconi's (2010) *Black Belt Energy Modeling* levels; (3) modellers' current use of resources to support their BPS learning and development, including e.g., mentorship, training programs, and academic resources; (4) modellers' level of interest in a potential Canadian training and certificate program and its ideal content and structure; and (5) managers of modellers' perceptions of modellers' skills and knowledge gaps and an assessment of the potential benefits of improving the status of BPS (e.g., higher salaries for modellers).

Following clearance by the Carleton University Research Ethics Board (clearance #1111577) the survey was released in English and French mid-November 2019 (hosted through Google Forms). Invitations to participate were distributed to the IBPSA-Canada membership and the IBPSA-Canada board's personal network. The invite was also posted on Prof. O'Brien's LinkedIn page and a third-party contact at Efficiency Canada promoted it to their networks. The survey was closed after four weeks in mid-December.

The target was a minimum sample of 100 responses (about 20% of IBPSA-Canada members, and an estimated 15% of modellers in Canada); 108 surveys were submitted. Of those 108, 96 were complete, valid, and met the criteria for participation (i.e., consent to participate and work in Canada). Duplicate and incomplete submissions were deleted, as were spam responses (e.g., the majority of questions were skipped). Participants had the option of submitting their email address (stored separately from survey responses for anonymity) to be included in a draw for a prize (Amazon.ca gift card); 85 participants submitted an email address to the draw. Seven winners were randomly selected; prizes were distributed in late December.

Results

The results of the survey are discussed below in five sections corresponding to the five sections of the survey: (1) modeller demographics; (2) skills and knowledge strengths and gaps; (3) use of resources; (4) the preferred content and structure of a potential training and/or certificate program; and (5) managers' views on modellers' strengths and gaps.

1. Modeller Demographics

Of the 96 participants who submitted complete responses, the majority of these (n=81) were modellers, while 19 described themselves as managers of modellers also. The remainder were researchers (n=14), educators (n=9), and/or students (n=10). Notably, no participants managed modellers without doing modelling themselves.

Professional certifications/designations varied widely (see Table 1). While most of the participants had P.Eng. status or were EIT, technologists, or LEED AP/GA credentials, only seven had energy modelling-specific certification. This proportion may be even lower for the general modelling population. Most participants had post-secondary degrees: PhD (n=20), Master's (n=25), bachelor's (n=37), and college diploma (5).

Table 1: Professional certifications/designations

Professional certification/designation	n=
P.Eng.	42
EIT	2
LEED GA/AP	33
Technologist	8
CEM	6
BEMP	5
BESA	2

Participants were asked to indicate the tools they use most frequently. The most commonly used tool was eQuest (n=49), with a significant number using IES VE (n=42), EnergyPlus directly (e.g. IDFEditor; n=39), and RETScreen (n=36). Roughly one quarter (n=24) use OpenStudio. Two participants stated that they do not use BPS tools.

The two leading purposes for modelling was building code compliance (n=70) and early design (n=70), though utility and other incentives (n=62) and environmental assessment schemes (e.g., LEED; n=61) were cited nearly as frequently. Lesser but not infrequently used purposes included detailed design and equipment sizing (n=41), life cycle cost assessments (LCCA; n=32), and audits (e.g., ASHRAE Level 3; n=27).

2. Skills and Knowledge Strength and Gaps

Modellers' skills and knowledge strengths and gaps were self-assessed using a four-level rating system—beginner, intermediate, advanced, and expert. The levels were assigned a numerical value (1 to 4) for the purposes of analysis. Participants were asked to indicate their level for specific modelling tasks (i.e., skills) and topics (i.e., knowledge) that were organized into three clusters ordered roughly from simplest to most complex. The tasks and topics were adapted from Franconi's (2010) *Black Belt Energy Modeling*.

In terms of overall skill level, the majority of participants rated themselves intermediate (n=34) or advanced (n=41). The average score across all three task clusters was between intermediate and advanced (2.69), with a general trend toward the lower levels (beginner and intermediate) for the more complex tasks (see Table 2).

The overall knowledge level rating was also between intermediate and advanced (2.63). There was a similar trend toward lower level ratings as topics increased in complexity (see Table 3). Generally, the topics covered by engineering curricula (e.g., heat transfer, thermodynamics, unit conversions) scored higher than building technologies (e.g., lighting), building codes, standards, and rating schemes, which potentially indicates the importance of formal education for modellers.

The results in Tables 2 and 3 must be taken in the context that the ratings are self-reported and also that the group was self-selected (i.e., potentially more advanced than the general modelling community). While the participants were informed that the results would remain anonymous, there were potential sources of bias. For example social desirability bias may have caused participants—particularly those with poorer knowledge and skills—to exaggerate their responses (Wilson and Zietz, 2004). The manager perspective (presented at the end of this section) helps to balance this bias to some extent.

Table 2: Mean Reported Skill Level by Task

Task	Level
Identify the appropriate modelling strategy for BPS (e.g., comparison, prediction, validation)	2.72
Identify the appropriate BPS tool for a given task	2.61
Assess the appropriateness of modelling assumptions (e.g., definitions for material properties, wall construction, representations of appliances)	2.72
Collect modelling input data (e.g., gather information needed for characterizing the building from construction documents, narratives, survey data)	2.82
Perform input data calculations (e.g., convert data collected from various sources to a form used by the simulation program (fan power calculations, EER to EIR calculations)	2.78
Develop building geometry and zoning (e.g., import drawing or BIM files and manipulate as needed to incorporate into modelling software, develop zoning based on thermal block concepts)	2.81
Create a building input file using software wizard (e.g., use modelling software graphical user interface and complete a basic building model based on the proposed design, project input data)	2.66
Build a minimally code compliant model	2.72
Perform parametric analysis for straightforward design alternates	2.67
Review predicted energy use by end use and costs for reasonableness	2.78
Generate synergistic bundles of energy-efficiency measures that include passive design strategies, load reducing measures, effective control strategies, and right-sized equipment	2.51
Support integrated project design and delivery	2.49
Model complex features, systems, or components that are not directly enabled by the software (e.g., UFAD, chilled beams, make-up air units, thermal bridging)	2.24
Complete a detailed quality assurance review (e.g., use detailed output reports and post-processing tools to perform a reality check on component and system-level results/metrics)	2.38
Perform calibration of models for existing building/s based on utility data	2.20
Understand the engineering algorithms used by the software and modify modelling input/methods to improve input characterizations	2.36
Use supplemental detailed analysis to support simulation software workarounds or short cuts (e.g., use supplementary CFD modelling results to characterize the impact of the natural ventilation strategy and build an hourly infiltration schedule to mimic CFD results and incorporate into whole-building model)	1.97
Balance modelling level of detail against accuracy of results needed to support decision making	2.46

Table 3: Mean Knowledge Level by Topic

Topic	Level
Heat transfer	2.86
Thermodynamics	2.75
Engineering units and conversions (e.g., IP to SI)	3.16
Construction drawings (reading, interpreting)	2.92
Building load calculation procedures	2.73
Mechanical system components	2.67
Lighting systems	2.51
Building envelope	2.77
Renewable energy systems	2.49
Space requirements as outlined in standards and codes (e.g., supply flow rates, outdoor air)	2.49
Reference standards (e.g., NECB, ASHRAE Std. 90.1, ASHRAE Std. 62.1)	2.66
Environmental assessment schemes (e.g., LEED)	2.37
Utility rate structures, primary and secondary energy, emission factors	2.62
Sequence of operations (mechanical systems)	2.43

3. Use of Resources

Survey participants rated the frequency, purpose, and overall usefulness of seven types of BPS resources that may support their work, including: listservs (e.g., BLDG-SIM), community-driven Q&A forums (e.g., Unmet Hours), mentorship, personal communication, academic resources (e.g., textbooks, journal articles), additional resources (e.g., source code, user manuals), and training programs (e.g., workshops, courses).

The most frequently used resources were:

- Mentorship and personal communication (“frequently”, n=43 and n=58, respectively);
- Academic and additional resources (“frequently”, n=25 and n=29, respectively);
- Community-driven Q&A forums and training programs (“frequently”, n=14 and n=10, respectively); and
- Listservs (“frequently”, n=6; 46 respondents claimed not to use this resource at all).

Usefulness ratings largely mirrored frequency trends, with mentorship and personal communication being rated overall much more useful than all other resource types. Listservs lack of popularity echoes Miller, Quintana and Glazer (2019), who found a drop in listserv use over the past five years, primarily in favour of Q&A forums.

Figure 1 shows the purposes (uses) for each resource type. The survey results suggest that peer support is not only the most useful resource for a modeller, but it also addresses a wide array of skills and knowledge needs. Training addresses a range of needs fairly evenly, as well.

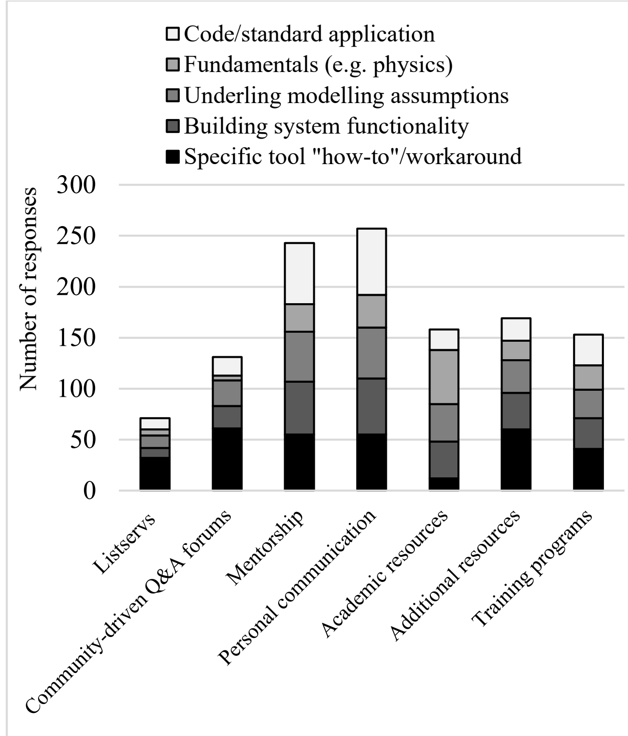

Figure 1. Purpose for Each Type of Resource.

4. Potential Training/Certification Program

Nearly 70 respondents reported participating in at least one paid workshop or course, whereas 57 reported participating in a free workshop or course. Only fifteen reported that they have not participated in a course or workshop. It is perhaps unsurprising that there was overwhelmingly positive interest in a Canadian BPS training program (“Quite interested” to “Very interested”, n=83), particularly in-person in the following formats: hands-on activities (e.g., at-home practice tasks), courses (i.e., multiple sessions), and lectures (i.e., one-time presentation).

In terms of topics, the survey results showed that “best practices” (n=85) and “error checking” (n=77) were among the most requested topics for a potential training program. Other topics such as “modelling fundamentals” and “building science fundamentals” were also highly requested (see Table 4).

When asked about the fee model for training courses, participants greatly preferred a free program (see Figure 2), even over programs they would be paid to participate in. This finding might be due to the number of managers in the sample.

There was also significant interest in a certificate program (“Quite” to “Very interested”, n=76), which the majority of participants (n=83) felt would help to (1) “Standardize the levels of BPS modellers’ skills and knowledge around a central body of knowledge” and, to a lesser extent (n=68), and (2) “Provide modellers more credibility as a profession” (n=68). There was no clear preference in terms of certification program structure (participation-, experience-, or exam-based, tiered, streamed).

Table 4: Training Topic Requests

Topic	n=
Best practices (design and modelling)	85
Error checking and verification	77
Modelling advanced features and technologies	75
Modelling fundamentals	71
Modelling to inform design	67
Building science and fundamentals	64
Effectively communicating modelling results	60
Tool-specific skills	59
Jurisdiction-specific building codes	53

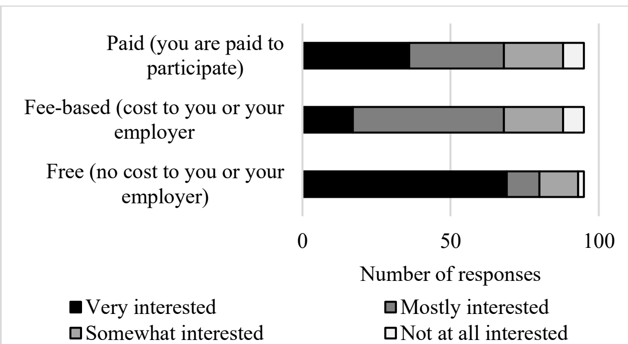

Figure 2. Interest in Training Programs by Cost/Incentive.

Table 5: Ways to Improve the Modelling Career

Response	N=
Clients with a better understanding of the role and scope of BPS in the building life cycle	70
More time to complete BPS tasks to allow for problem-solving and critical thinking	63
A database of measured field data for buildings (to inform inputs) with vetted/ready definitions (e.g., material properties, wall construction, representations of appliances)	62
A stronger BPS market demand	56
Better communication between modellers (e.g., to share solutions)	55
BPS tools better aligned with building codes and regulations	54
Better transferability capability of data/models between BPS tools	48
Easier-to-use BPS tools	45
Standardized BPS tools	37

Participants were asked to consider what changes might help to improve their modelling careers, beyond a training and/or certification program. Notably, the top three reasons are not within modellers' immediate control, nor are they related to skills/knowledge.

5. Manager Perspectives

Participants who manage modellers were asked about their satisfaction with BPS job candidates on a 1 (not at all satisfied) to 4 (very satisfied) scale. The mean response was 2.65, indicating moderate satisfaction overall. However, managers were not uniformly satisfied with all of their modellers' skills and knowledge areas. Figure 3 shows managers' responses across skill and knowledge categories.

When asked how much time they would allocate for their modeller employees to participate in training, managers' mean response was 50 hours per year with a standard deviation of 44 hours. When asked what annual salary premium they would pay their modellers if they held ASHRAE BEMP or similar certifications and ignoring responses that clearly misinterpreted the question (i.e., provided total annual salaries), managers' average stated premium was $4,600 per year, with a range of 0 to $10,000.

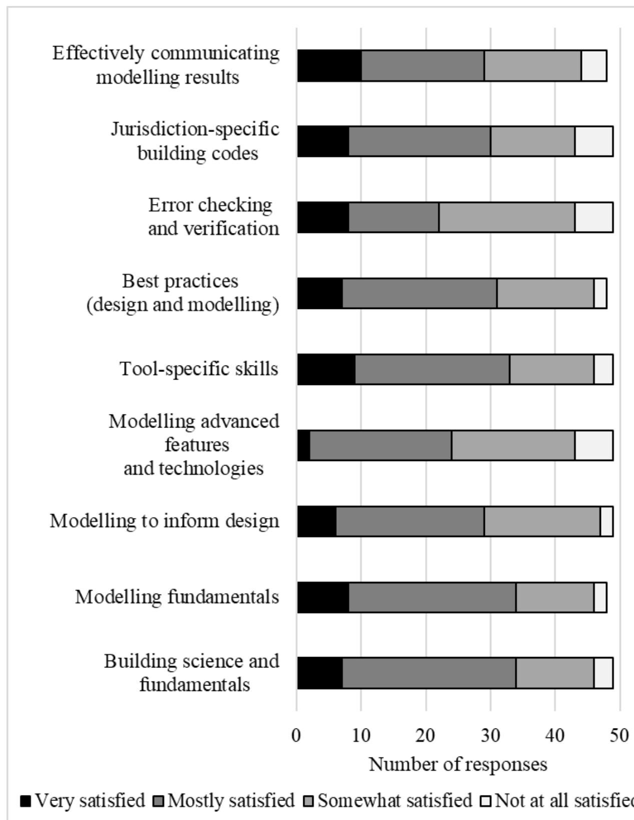

Figure 3. Manager Satisfaction with Modeller Skills

Discussion

The results of this survey illuminated several noteworthy realities of modelling in Canada. While the sample of the participants for this survey described in the paper may be slightly biased towards being more educated, on average, it serves as a basis to assess the ideal characteristics for Canadian BPS training and certification schemes.

The survey and literature indicate that there are a few Canada-specific issues as well as areas of importance that may serve as justification for a Canadian BPS training program. These include Canadian codes and standards, climate conditions, and building design considerations; building science and technology fundamentals; and hands-on aspects – both BPS tools and real buildings and their performance data. From the survey and literature, the training program should be:

- Comprehensive and scope with key areas of building physics and building system fundamentals; modelling fundamentals as well as tool specific best practice/how-to skills; knowledge and application of building codes and standards; model validation and calibration; and communication of results to influencing decisions;
- Include a combination of theory with hands-on experience – both using tools and understanding the building systems that are being modelled;
- Be a full day or course with multiple days over several months; and,
- Be held online or locally.

Moreover, several graduate-level BPS courses in Canada should be examined carefully for their content and pedagogy (Bernier, Kummert, Sansregret, Bourgeois and Thevenard, 2016, Beausoleil-Morrison, 2019). It is noteworthy, that these engineering courses place great importance on "soft skills" (e.g., selecting problem-specific appropriate modelling tools and strategies and justify the corresponding assumptions) that are not normally part of tool-specific workshops. Error-checking, model verification, reflection, and comparison to real data are also seen as important areas.

Beausoleil-Morrison (2019) explained an autopsy step, which involves a group discussion on diagnosing the issues with student models. Another critical aspect of his course was to work with a real building. Given the lack of post-secondary programs devoted or focused on buildings, many modellers enter BPS jobs without fundamental knowledge and working experience with buildings and their systems. This is reflected by the current survey where participants ranked knowledge of sequence of operations for mechanical systems near the bottom, for example.

For on-going education and specific questions, asynchronous community-driven resources (e.g., listservs, Q&A forums) seem not to be the primary source of support for modellers. Therefore, they cannot be considered to be the sole channels for communicating or standardizing skills and knowledge, despite their attractiveness from a centralized programming perspective.

In contrast, synchronous peer-to-peer communication such as mentorship and personal communication were reported to be used more frequently and provide a wider range of support than asynchronous resources. However, these resources are difficult to scale (an issue also identified in Tupper et al., 2011). Moreover, they are not archived, meaning that the they are a relatively high effort method for knowledge transfer. Moreover, mentorship is more challenging in small companies and companies with lone modellers. As such, the role of mentorship to standardize the body of knowledge and skills of modellers is unclear, as such relationships are relatively organic compared to official resources, programs, and services.

Modellers and managers alike seem to be very open to a BPS certification scheme. Nearly four-fifths of participants expressed interest in participating in a Canadian BPS certificate program. Moreover, managers claimed to be willing to pay certified modellers an average of $4,600 more than their non-certified counterparts; on an annual basis, this is about 30 times the cost to obtain ASHRAE BEMP certification and retain it for three years (before recertifying). Yet, only seven of the respondents had obtained BEMP or BESA certification; it is not clear if this is due to cost, effort, or a perceived lack of value. If the respondents are any indication, LEED accreditation is much more popular than BEMP and BESA.

Much like some of the limitations of existing non-academic training programs, which tend to focus on tool how-to rather than fundamentals (e.g., heat transfer, building technologies, model verification, appropriate modelling strategies), the leading existing certification programs (BEMP and BESA) seem to focus greatly on tools and standards that are somewhat US-specific.

According to the survey, the vast majority of modellers, including those without any professional designations, are members of one or more building-related organizations (e.g., IBPSA, CaGBC, etc.), which may suggest that these organizations could be of value in hosting, promoting, or otherwise supporting a potential training/certification program. These organizations may also be in a good position to strengthen the BPS community and its reputation e.g., develop a coherent code of ethics among modellers as a subset of their membership.

Interestingly, there was a strong and varied response to factors beyond training and certification that may help the modelling community. For example, tight timelines can not only lead to modellers making and missing errors, but also reduce the likelihood that they will seek third-party validation and/or peer review. In the longer term, this can promote isolation and reduce the effectiveness of larger-scale efforts at improvements to the BPS practitioner community.

Understanding time limits and other contextual factors that facilitate and hinder modellers' skills and knowledge development and overall practice (e.g., clients' misunderstanding of the role of BPS) could lead to initiatives that support improvements indirectly. For example, information campaigns for clients to provide concise information booklets to clarify the role and value of building energy modelling throughout the life cycle of a building. Moreover, a free, accessible Canadian database of measured field data (e.g., through crowd sourcing) could be developed, such as the Compass project (Compass, 2020). Some of these resources have already been—or begun to be—developed in the U.S. (e.g., RMI's *Building Energy Modeling for Owners and Managers* guidelines) and provide a good starting point.

Conclusion

This paper described a survey of 96 BPS users and practitioners with the purpose to assess the need and characteristics for training and certification programs. In general, the participants are keen on both training and certification programs and indicated a willingness to pay (via time and/or money) for such programs.

In general, while the participants rated their knowledge of engineering fundamentals and basic BPS tool functionality relatively highly, this cannot be said for building technologies and advanced BPS skills (e.g., model verification). Using the paper and pertinent literature, this paper provided an initial set of traits and other recommendations for a Canadian BPS training and certification program.

While insightful, there were several limitations to this survey study. First, many participants have a college or university education, but the survey did not ask participants to specify the degree focus (e.g., Bachelor's in Civil Engineering). This information may have helped to better clarify participants' building- and/or modelling-related background skills and knowledge.

Most modellers self-assessed as intermediate and advanced in skills and knowledge; external validation of this assessment (e.g., via test tasks) was not the focus of the study. Whether this level of competence is due to formal training (e.g., educational background, training programs), a strong support network, or a lack of evidence and checkpoints to suggest otherwise (e.g., managers who are unable or do not provide feedback) cannot be determined from this dataset.

Furthermore, although managers of modellers were not the primary focus of the study, there was not sufficient data from managers and too small a sample size to confidently generalize any of the survey findings to the general manager population.

Finally, the current survey is part of a larger initiative to assess the most appropriate method(s) to raise the skill and knowledge level of building performance simulation practitioners and the models they create and use. Parallel to this survey, code officials were interviewed to better understand the recurring weaknesses and deficiencies they observe in models. This information was used to create a curriculum and recommendation for a certification program.

Acknowledgements

The authors acknowledge Natural Resources Canada for funding this work, IBPSA-Canada for providing valuable feedback, and the study participants for their insights.

References

Attia, S., E. Gratia, A. De Herde and J. L. M. Hensen (2012). "Simulation-based decision support tool for early stages of zero-energy building design." *Energy and Buildings 49*: 2-15.

Beausoleil-Morrison, I. (2019). "Learning the fundamentals of building performance simulation through an experiential teaching approach." *Journal of Building Performance Simulation 12*(3): 308-325.

Berkeley, P., P. Haves and E. Kolderup (2014). Impact of modeler decisions on simulation results. *Proceedings of the ASHRAE/IBPSA-USA Building Simulation Conference*.

Bernier, M., M. Kummert, S. Sansregret, D. Bourgeois and D. Thevenard (2016). "Teaching a building simulation course at the graduate level." *Proc. eSim*.

Compass, E. (2020). "EnergyCompass." Retrieved March 7, 2020, from https://energycompass.design/about/.

Evans, M., V. Roshchanka and P. Graham (2017). "An international survey of building energy codes and their implementation." *Journal of Cleaner Production 158*: 382-389.

Franconi, E. (2010). Black Belt Energy Modeling*, Rocky Mountain Institute.*

Granadeiro, V., J. P. Duarte, J. R. Correia and V. M. Leal (2013). "Building envelope shape design in early stages of the design process: Integrating architectural design systems and energy simulation." *Automation in Construction 32*: 196-209.

Hand, J. W. and D. B. Crawley (1997). Forget the tool when training new simulation users. *Proceedings of Building Simulation*.

IBPSA-USA. (2013). "BEMBook." Retrieved March 7, 2020, from https://bembook.ibpsa.us/.

Miller, C., M. Quintana and J. Glazer (2019). Twenty years of building simulation trends: Text mining and topic modeling of the Bldg-sim email list archive. *Building Simulation* Rome, Italy.

Misuriello, H., S. Penney, M. Eldridge and B. Foster (2010). "Lessons learned from building energy code compliance and enforcement evaluation studies." *Proceedings of the 2010 ACEEE Summer Study on Energy Efficiency in Buildings 8*: 245-255.

RMI/IBPSA-USA. (2020). "BEM Library." Retrieved March 7, 2020, from https://www.bemlibrary.com/.

Tupper, K., E. Franconi, C. Chan, C. Fluhrer, M. Jenkins and S. Hodgin (2011). Pre-Read for BEM Innovation Summit. *Boulder, CO, Rocky Mountain Institute.*

Wilson, M. L. and J. Zietz (2004). "Systematic bias in student self-reported data." *Journal for Economic Educators 4*(4): 13-19.