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Shakir Rashid, President, BCBEC

Another Year of Dedication

Welcome to the Spring/Summer issue of *BCBEC Elements* magazine. Still going strong in its fifth year, I extend my appreciation to the advertisers; without their financial support we would not have made it this far.

My appreciation also goes out to individuals who have contributed informative and interesting articles. We are always looking for new articles, so please reach out to us if you have any ideas or features that you would like to contribute.

It is great to see the dedication and passion of the committee members, who put in their effort and time to serve the mandate of BCBEC. At the AGM in October 2018, the following members were nominated to the Board of Directors:

Shakir Rashid (SR Engineering Ltd.) – President

Samer Daibess (LDR Engineering Group) – Past President

Kevin Pickwick (Read Jones Christoffersen Ltd.) – Vice President and Vancouver Island

Jeff Dye (TEC Agencies) – Membership and Assistant Sponsorship

Denisa Ionescu (BC Housing) – Building Research Committee

Josh Jensen (All Round Restorations) – Sponsorship

Richard Kadulski (Richard Kadulski Architect) – Member at Large

Carolina Maloney (Morrison Hershfield Ltd.) – Program

Nichole Brackett (Sense Engineering Ltd.) – Treasurer and Privacy Officer

Kurtis Topping (JRS Engineering) – Website, Elements

Ron Krpan (BCIT) – Assistant Education, Elements

Lorne Ricketts (RDH Building Sciences Inc.) – Education, Assistant Program

We have had a great year so far, with a successful half-day conference organized in collaboration with BC Housing in February. We also have many monthly luncheons that have attracted high attendance. If you happen to have missed any of the past events, you can still benefit by visiting our website and browsing through Past Events under the Events tab.

BCBEC has started working on this year's AGM and Conference, which is scheduled to be held at JW Marriott Parq Vancouver for the second year in a row on November 8, 2019. Please make sure to save the date, as we expect this to be one of our best conferences. We received excellent feedback regarding the venue from both the attendees and the sponsors last year, so I am sure you will not want to miss it.

I hope you enjoy this issue. Please don't hesitate to reach out to me or any of the board members if you have any questions about BCBEC.

Thank you,
Shakir Rashid, P. Eng.
BCBEC President

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Have an article, news or an event for *BCBEC Elements*? Contact our editorial board online at www.bcbec.com

PEOPLE POWER: Q&A with Douglas Watts

By Warren Heeley

Graduating in 1980 from UBC, Douglas Watts of RJC Engineers is a year away from reaching 40 years in his engineering and architecture career. He has had a wide variety of positions both in the public and private sector. In fact, he has come full circle since graduating. His first position in the industry was with RJC, and after going back to school and having a number of positions between 1989 and 2002, he returned to the company and rose to the position of principal in 2011, specializing in the building envelope sector.

As he freely admits, his passion is architecture. He has a master of architecture from the University of Washington and has completed a number of other architectural studies, including the AIBC Building Envelope Program and the UBC A&E Building Code and Certified Professional Course.

Watts has also spent more than 20 years serving on the National Building Code (NBC) committees and particularly, the Standing Committee on Environmental Separation. He is also a former President of BCBEC and has received the Professional Service Award from Engineers & Geoscientists BC as well as being named a Fellow of Engineers Canada.

BCBEC Elements managed to get some time in Watts' busy schedule to talk about his career and building envelope challenges.

BCBEC Elements: With your education and background in engineering and architecture, how did you come to specialize in building envelope science?

Douglas Watts: I would like to say the area of building envelope science has always been a keen interest of mine. However, my involvement in building envelope science was more a "quirk" of my career. I find the sector a nice crossover between engineering and architecture. After going back to school for my master's in the late '80s, I returned to Vancouver to practice architecture, and eventually joined the City of Vancouver in 1998.

In my new position, I was the City's specialist, responsible for representing the City on the National Building Code's Standing Committee on Environmental Separation. This committee deals with the provisions from the Code that apply to the building envelope for both Parts 5 and 9. I continue to serve on the committee to this day, including two terms as Chair.

BE: What have been the most significant challenges for the building envelope sector as it evolved?

DW: The one major challenge the building envelope sector continues to have is educating the industry to understand the science. Too many people in the construction industry still don't understand the difference between air or vapour barriers. If the science of the envelope is not understood and applied, the envelope will fail to accomplish the desired results.

The crux of the problem is that the building envelope is critical to the performance of the building particularly from an energy conservation standpoint. As building structures change, you have to understand the envelope science to apply the right solution. In simple terms, we still need better understanding of building envelope science in the construction industry.

BE: What are the key accomplishments of your career?

DW: One key accomplishment I feel very strongly about was moving RJC towards consulting on more new construction projects. I had the opportunity to work on the original Canada Place project and on the downtown Vancouver Library project, which were highlights of my career.

With schooling in architecture and engineering, I heavily lean towards architecture. For these types of projects, I have to rely on my architectural skills, which I thoroughly enjoy. There are about a dozen or so industry people in Vancouver who are registered in both engineering and architecture, and I believe I may be the only one not still practising architecture.

BE: How has your lengthy involvement in the national and provincial building codes and standards impacted your career?

DW: I have spent 20+ years on the NBC Standing Committee on Environmental Separation, and currently I am serving my second term as Chair. I also took the Certified Professional Program while I was at the City of Vancouver that allows professionals to take on the responsibility of inspecting buildings based largely on Part 3 of the Code. This involvement gave me a new interest and respect for building codes.

One of the challenges I have had as a member of the national committee is that the NBC is already looking at changes coming for the 2020 code, and a province like B.C. is only just now adopting the provisions from the 2015 code. At times I struggle to keep my head around the code provisions that we are actually using in B.C. compared to where we are in the national code development process. There are many new things coming in the building envelope area of the Code that I am proud to have been involved in changing.

BE: Would you encourage young engineers and architects to look at the building envelope industry as a career path and if so, why?

DW: If it's your mindset and you like working in the environment of building science, it can be a very interesting area of work both from an engineering and architectural standpoint. Building envelope science will always be an area of opportunity. People like me find they sort of "walk sideways" into this specialty, but it is very rewarding. B.C. now has master's degree programs offered through BCIT that focus on building sciences. Because of this, we now have more B.C. professionals who enter the industry with building envelope education.

BE: As a past President of BCBEC, what do you see as the association's role in the industry going forward? Will it change in the future?

DW: BCBEC was formed by professionals like me to educate people on the science of building envelopes. It was formed at the time of the "leaky condo" crisis in the province, and there was a demand to have an organization that could provide education on this relatively new area of science. I think the association will continue to focus on education and providing student funding to increase awareness in this important area.

BE: On a personal note, what do you do in your spare time (hobbies, sports, travel)?

DW: I had a bout with cancer some years ago and since I have recovered, I volunteer as a peer counsellor for the Canadian Cancer Society helping cancer patients through their illness. I have been involved in singing groups for most of my life and currently sing in a choir known as Jubilate. I have also been an avid cyclist since the late 1970s.

NOT ALL STRATA PROPERTIES ARE CREATED EQUAL

A followup compilation and cross-sectional analysis of over 200 Depreciation Reports

By Wesley Narciso, M.Eng., P.Eng., CRP, PRA

INTRODUCTION AND RESEARCH OBJECTIVE

Depreciation Reports (DR) provide pertinent technical and financial information to assist property owners with long-term fiscal management of their properties. In a previous compilation and cross-sectional analysis of over 100 Depreciation Reports by JRS in 2014, it was found that certain trends were prevalent among certain types of properties. This created an initial basis of information to better understand what types of properties were in better financial positions based on the type, age and population density of a property.

This research generally provided the following:

1) *Reference Points:* So that end users (lenders, property managers, strata councils, unit owners) can better understand how their property and real estate investment compares to others.

2) *Industry Norms:* To better understand trends, investment strategies and correlations of CRF (Contingency Reserve Fund) finances based on the type, age and population density of the property.

It should also be noted that the resulting information can be used to rank or compare any property regardless of the type or style of their DR or education and training of the Reserve Planner. This is because the results are in the form of things like CRF contributions, number of special levies or cumulative special levy costs, which every DR should have.

A followup analysis was completed with an additional 100 Depreciation Reports (over 200 inclusive) in 2017, to validate or disprove the initial results. Using the same parameters as the first study (e.g. type, age and population density), we are now able to more affirmatively answer the following questions:

- What types of properties have the **least number of special levies**?
- What types of properties have the **least cumulative special levy costs**?
- What types of properties **contribute the most and least** to their CRF?
- What types of properties have the **most building envelope costs** (largest portion of renewals)?

Furthermore, because this study compares Depreciation Reports performed over a five-year period, we are also able to answer the following time-related questions:

- Are strata corporations contributing more, less or the same amount?
- Are the number of special levies and their cumulative costs going up or coming down?

METHODOLOGY AND ANALYSIS

Data was compiled on over 200 Depreciation Reports consisting of almost all types of properties: residential, commercial, hotel, bare land, housing co-op, co-housing and floating home communities.

We obtained the following financial outputs of each property:

TABLE 1: FINANCIAL OUTPUTS OR MEASURABLES FOR EACH PROPERTY.

# of Special Levies in Baseline Funding Model	10 and over
	5 and less
	Average
Average of Total Costs In Special Levies ($)	In 10 years
	In 30 years
Average ($)	CRF Balance
	Annual CRF Contribution
	Operating Budget
	ARFA

Then, we compiled them within the following categories:

TABLE 2: CATEGORIES OF FINANCIAL OUTPUTS.

Type	**Apartment**	low-rise
		mid-rise
		high-rise
	Townhouses	
Age	0 to 10 years old	
	11 to 20 years old	
	21 to 30 years old	
	30+ years old	
Units	0 to 25 units	
	26 to 50 units	
	51 to 75 units	
	76 to 100 units	
	100 to 199 units	
	200+ units	

Therefore, someone who owns in a 35-year-old townhouse complex with 30 units can determine if the number of special levies or cumulative special levy costs in their DR is better or worse than other properties with similar type, age and population density. Conversely, someone who owns a 10-year-old high-rise tower with 120 units can compare their average CRF contributions and operating budgets to other properties with similar type, age and population density, which directly and indirectly informs the owner of how aggressive they should be contributing to their CRF or if their strata fees are much higher or lower than they should be.

RESULTS

The following results are with respect to **special levies**, which focus more on the **physical attributes** of a property (independent on ownership culture and strata council decision-making).

TABLE 3: AVERAGE NUMBER OF SPECIAL LEVIES BASED ON NUMBER OF UNITS.

# of Units	Total # of Properties	Average # of Special Levies
0 to 25	30	11.1
26 to 50	51	9.7
51 to 75	35	8.6
76 to 100	23	8.3
100 to 199	44	9.1
200+	18	5.4

Initial study:	The bigger the population density of the property (# of units), the less the number of special levies.
Followup study:	Validated.

TABLE 4: AVERAGE NUMBER OF SPECIAL LEVIES BASED ON AGE.

Age	Total Properties	Average # of Special Levies (baseline within 30 years)
0 to 10 years old	49	5.2
11 to 20 years old	49	10.7
21 to 30 years old	63	9.9
30+ years old	40	10.4

Initial study:	Younger properties (<10 years old) will have the lowest number of special levies. Approximately 10 years of age is the threshold at which the frequency of special levies increases dramatically (almost doubles).
Followup study:	Validated.

TABLE 5: AVERAGE SPECIAL LEVY COSTS BASED ON THE TYPE OF PROPERTY.

Property Type	Average Special Levy Costs ($K/unit/year)	
	In 10 years	In 30 years
low-rise	1.81	2.50
mid-rise	0.86	1.87
high-rise	0.96	1.67
townhouses	2.02	3.06

Initial study:	Mid-rises and high-rises have the lowest (best) special levy costs (per person, per year) than other types of properties. Townhouses have the highest.
Followup study:	Validated.

TABLE 6: AVERAGE SPECIAL LEVY COSTS BASED ON AGE.

Age	Average Special Levy Costs ($K/unit/year)	
	In 10 years	In 30 years
0 to 10 years old	0.11	1.65
11 to 20 years old	0.98	3.00
21 to 30 years old	2.89	2.88
30+ years old	2.31	1.97

Initial study:	Younger properties (<10 years old) have the lowest (best) cumulative special levy costs in the short term (within 10 years) and long term (within 30 years). Properties 11 to 20 years old have the most costs in the long term and properties 20 to 30 years old have the most in the short term. This may seem logical, but it should be noted that 30+-year properties showed lower long-term cumulative special levy costs than properties 11 to 30 years old. This may be because much older properties have likely performed many of the more expensive renewals already.
Followup study:	Validated.

TABLE 7: AVERAGE SPECIAL LEVY COSTS BASED ON NUMBER OF UNITS.

# of Units	Average Special Levy Costs ($K/unit/year)	
	In 10 years	In 30 years
0 to 25	2.69	3.43
26 to 50	2.14	2.50
51 to 75	1.63	2.43
76 to 100	1.04	2.67
100 to 199	1.23	2.11
200+	0.18	1.05

Initial study:	Population density is inversely proportional to cumulative special levy costs.
Followup study:	Validated.

Observation: With respect to special levies, buy a high-rise, and/or those less than 10 years old, and/or those with as many units as possible. However, owners in these types of properties do not necessarily contribute as much as owners in other types of properties, as can be seen in the following CRF contribution portion of this study.

TABLE 8: DATA ON NUMBER OF SPECIAL LEVIES AND COSTS FOR 2017 COMPARED TO 2014.

Factor/Parameter		Average # of Special Levies in Baseline		Average Special Levy Costs ($K/unit/year)	
		2014	2017	2014	2017
Type	Low-rise	12.6	10.3	2.87	2.5
	Mid-rise	11.9	8.5	2.36	1.87
	High-rise	7.5	8.2	1.71	1.67
	Townhouses	7.9	7.3	3.28	3.06
Age	0 to 10 years old	5.7	5.2	1.77	1.65
	11 to 20 years old	10.8	10.7	3.27	3
	21 to 30 years old	10	9.9	3.13	2.88
	30+ years old	11.1	10.4	2.01	1.97
Units	0 to 25 units	11	11.1	3.8	3.43
	26 to 50 units	10.6	9.7	2.53	2.5
	51 to 75 units	9.4	8.6	2.51	2.43
	76 to 100 units	8.5	8.3	3.04	2.67
	100 to 199 units	9.4	9.1	2.24	2.11
	200+ units	6	5.4	Not enough data	

Initial study:	Average number of special levies within a 30-year time period was **6 to 12.6** and cumulative special levy costs was approximately **$1,710/unit/year to $3,800/unit/year**. Inclusive of all types of properties.
Followup study:	Average number of special levies within a 30-year time period was **5.4 to 11.1** and cumulative special levy costs was approximately **$1,650/unit/year to $3,430/unit/year**. Inclusive of all types of properties. This likely indicates that strata corporations are saving more and/or are actually performing renewals.

The following is with respect to **CRF contributions**, which focus more on **ownership culture and strata council decision-making** (less dependent on the physical attributes of the property).

Contribution/Operating Budget ratios (the higher, the better)

It is often worth observing what strata corporations are contributing to their CRF. However, these contributions may be high simply because they are bigger properties with more unit owners paying more strata fees. Therefore, it is more appropriate to couple this with their operating budget, which is directly related to their strata fee revenues. This normalizes the playing field and allows a more appropriate means of comparing various CRFs' financial health. It should be noted that the Strata Property Regulation requires 10 per cent of their OB (Operating Budget) to go to the CRF unless it is already at 25 per cent of the OB.

TABLE 9: DATA ON CONTRIBUTIONS AND OPERATING BUDGETS FOR PROPERTIES BASED ON TYPE, AGE AND POPULATION DENSITY.

Factor/Parameter		Contribution	OB	Contribution/OB (%)
Type	Low-rise	$29,512	$308,929	13%
	Mid-rise	$50,846	$472,685	25%
	High-rise	$73,607	$600,851	13%
	Townhouses	$43,456	$243,603	21%
Age	0 to 10 years old	$46,915	$453,525	13%
	11 to 20 years old	$43,955	$377,224	15%
	21 to 30 years old	$41,943	$221,818	19%
	30+ years old	$37,581	$447,209	14%
Units	0 to 25 units	$11,443	$87,418	15%
	26 to 50 units	$22,569	$129,441	19%
	51 to 75 units	$34,104	$219,720	16%
	76 to 100 units	$47,289	$361,500	14%
	100 to 199 units	$64,683	$475,824	13%
	200+ units	$109,814	$1,521,457	16%

The best are mid-rises, those 21 to 30 years old and those with 26 to 50 units. People in these types of properties contribute more to their CRF. These types of properties probably have more manageable sized renewal projects and older properties probably have had them done already. Newer properties showed lower ratios, as developers may be encouraging lower monthly strata fees than what is actually required, potentially due to market demands.

TABLE 10: DATA ON CONTRIBUTIONS AND OPERATING BUDGETS FOR 2017 COMPARED TO 2014.

Factor/Parameter		Contribution/OB (%) - 2014	Contribution/OB (%) - 2017
Type	Low-rise	13%	13%
	Mid-rise	13%	25%
	High-rise	9%	13%
	Townhouses	17%	21%
Age	0 to 10 years old	9%	13%
	11 to 20 years old	12%	15%
	21 to 30 years old	17%	19%
	30+ years old	11%	14%
Units	0 to 25 units	14%	15%
	26 to 50 units	16%	19%
	51 to 75 units	14%	16%
	76 to 100 units	15%	14%
	100 to 199 units	11%	13%
	200+ units	7%	16%

Initial study:	Annual CRF Contribution/Operating Budget ratios ranged between **7% and 17%** (all types, age & size).
Followup study:	There has been an increase in in this ratio, which now ranges from **13% to 25%**. No average was less than 10% (statutory minimum in B.C.) – further evidence of higher contributions.

Contribution/ARFA ratios (the higher, the better)

ARFA (Annual Reserve Fund Assessment) is a slightly complicated value, but essentially it is the annual contribution required for the CRF to be fully funded. Taking a ratio of what the strata corporation is contributing to their CRF every year, over what they could be contributing to be fully funded, provides the best possible way to know if they're ultimately saving enough money. It should be noted that no strata corporation contributes the same amount as their ARFA (100 per cent), but that it is possible to reach 50 per cent to 75 per cent eventually, as we have seen with properties in Alberta who have had DR-type legislation for many more years than B.C. Note that Vancouver's strata fees are lower than the national average (REW, July 5, 2017), which is why contribution ratios are lower in B.C.

TABLE 11: DATA ON CONTRIBUTIONS AND AVERAGE ARFAS FOR PROPERTIES BASED ON TYPE, AGE AND POPULATION DENSITY.

Factor/Parameter		Contribution	Average ARFA	Contribution/ARFA (%)
Type	Low-rise	$29,512	$219,406	22%
	Mid-rise	$50,846	$355,121	17%
	High-rise	$73,607	$406,515	18%
	Townhouses	$43,456	$330,212	15%
Age	0 to 10 years old	$46,915	$376,959	16%
	11 to 20 years old	$43,955	$327,689	13%
	21 to 30 years old	$41,943	$225,247	18%
	30+ years old	$37,581	$244,063	33%
Units	0 to 25 units	$11,443	$140,215	14%
	26 to 50 units	$22,569	$147,455	29%
	51 to 75 units	$34,104	$228,605	15%
	76 to 100 units	$47,289	$375,199	14%
	100 to 199 units	$64,683	$417,396	18%
	200+ units	$109,814	$653,221	20%

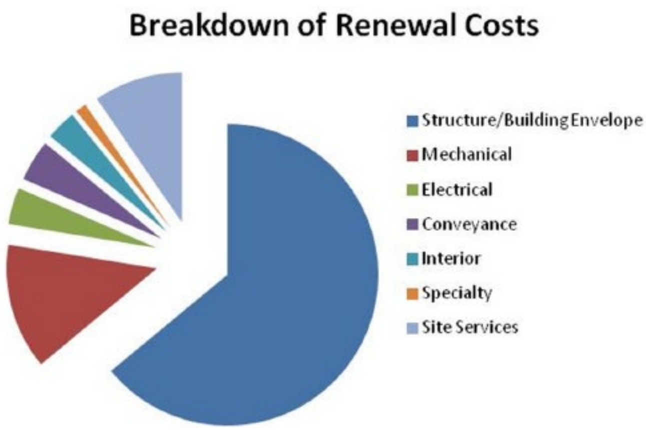
The best are low-rises, older properties (30+ years) and those between 26 to 50 units. These have typically lower ARFA values and can establish higher contribution levels.

The lowest ratios are shown in townhouses and those 11 to 20 years old. These types of properties may have higher ARFA values with impending renewals looming.

TABLE 12: DATA ON CONTRIBUTIONS AND ARFA VALUES FOR 2017 COMPARED TO 2014.

Factor/Parameter		Contribution/ARFA (%) - 2014	Contribution/ARFA (%) - 2017
Type	Low-rise	8%	22%
	Mid-rise	11%	17%
	High-rise	15%	18%
	Townhouses	10%	15%
Age	0 to 10 years old	11%	16%
	11 to 20 years old	13%	13%
	21 to 30 years old	15%	18%
	30+ years old	12%	33%
Units	0 to 25 units	9%	14%
	26 to 50 units	14%	29%
	51 to 75 units	13%	15%
	76 to 100 units	11%	14%
	100 to 199 units	13%	18%
	200+ units	18%	20%

Initial study:	Annual CRF Contribution/ARFA ratios ranged between **8% and 18%** (all types, ages and sizes).
Followup study:	There has been an increase in this ratio, which now ranges from **13% to 33%**. This is definitive evidence that CRF contributions have increased, because with time, construction costs go up and ARFA values increase; however, it appears that CRF contributions have outpaced ARFA increases.



The building envelope is the largest category/percentage of renewal costs, generally ranging at an average of **70 per cent to 78 per cent**.

TABLE 13: AVERAGE PERCENTAGE OF BUILDING ENVELOPE (BE) RENEWAL COSTS BASED ON PROPERTY TYPE, AGE AND POPULATION DENSITY.

Factor/Parameter		Average % of Costs That Is BE
Type	low-rise	61
	mid-rise	55
	high-rise	53
	townhouses	77
Age	0 to 10 years old	58
	11 to 20 years old	60
	21 to 30 years old	67
	30+ years old	63
Units	0 to 25 units	66
	26 to 50 units	63
	51 to 75 units	64
	76 to 100 units	70
	100 to 199 units	59
	200+ units	51

Initial study:	The highest amount of cumulative special levy costs is most prevalent in **townhouses**, properties **21 to 30 years old**, and those with **76 to 100 units**.
Followup study:	Validated.

CONCLUSION

Strata property owners, property managers, reserve planners and building envelope consultants should be able to use the above information to compare the health of their CRFs' finances to other properties of similar type, age and population density.

The good news is that there is significant evidence that strata properties are generally saving and likely spending more on repairs and renewals. From a building envelope perspective, this will be more prevalent, if it isn't already, with middle aged, small-to-medium-size townhouse properties.

Younger, larger high-rise properties tend to have the lowest special levies and cumulative special levy costs; however, they do not tend to contribute the most to their CRFs. So, you don't need to necessarily be afraid of investing into strata corporations that are prone to having more special levies and increased special levy costs because they tend to contribute more to their CRFs, and if so, will likely spend more on asset renewals, which may end up being a better investment in the long run.

DESIGNING THERMALLY COMFORTABLE, LOW-ENERGY HOMES

Introduction to residential thermal comfort design

By Rodrigo Mora, P.Eng., PhD, Faculty, Building Science Graduate Program, BCIT

"Comfort is behaviour… occupants create temperature… not always, but at least at home we do…" [1] How to design homes that meet the dwellers' thermal demands for comfort while using the least amount of energy? What strategies do I normally use to remain thermally comfortable at home?

Several studies confirm that dwellers feel more comfortable at home than in the office. This is explained in part because at home thermostats are more readily available and changes to thermostat room temperatures are felt faster. A meta-analysis from field data from various countries concludes[2]: "on the one hand a mechanical system allows dwellers to exercise a considerable degree of control over indoor temperatures, which results in temperature variabilities reflecting their particular thermal preferences; on the other hand, the temperatures found in naturally conditioned buildings are largely determined by the form and character of the building and the response of the dwellers to the environment."

Home characteristics influence our behaviours at home. A field study in Denmark suggests that the energy efficiency of homes affects the dwellers' energy-consuming habits, with correlations moderated by the socio-demographic characteristics of the dwellers. Study correlations suggest that occupants dress lighter and keep higher temperatures in energy-efficient houses, leading to increased energy demand due to changed comfort expectations (i.e. a rebound effect). However, building characteristics were found to be less influential on the frequency of opening windows.[3]

Our personal background and whether we own or rent our home affect how we use it. A recent study in social housing in British Columbia[4] revealed that occupants were not concerned about energy waste because they do not pay the utility bills. Therefore, they were often not careful about opening their windows in cold weather. A field study in Australian residences[5] reveals that the role of occupants is significant in the household thermal energy consumption. The study authors explain that given the diverse activities within, and high levels of personal control over, the indoor environment compared to offices, occupants' behaviour is one of the key uncertainties in predicting energy use in the residential sector.

PREDICTIVE THERMAL COMFORT MODELS[6]

Thermal comfort models are powerful tools to help designers make informed design decisions that can impact comfort and energy performance. The perception of thermal comfort quality is formed at four levels, as illustrated with the pyramid in Figure 1: climate, physics, physiology and psychology. On the left side of Figure 1, a steady-state whole-body thermal balance model links the top three levels of the pyramid to predict thermal comfort using the predictive mean vote (PMV) metric. The PMV model, derived from laboratory experiments on human subjects, assumes that individual thermoregulatory and mental responses to the environment are fixed (i.e. unaffected by any personal individualities or background, or by any local, building, environmental or climate context), which lead to narrow ranges of indoor comfort temperatures. The model can be run under different personal and environmental scenarios, affecting the indoor physics (blinds, fans), personal heat balance (clothing) and physiology (occupant activity), allowing for wide variations of indoor temperatures providing thermal comfort.

In reality, our thermal comfort perception indoors is also largely influenced by the prevailing local weather and climate. After a period of exposure to hot or cold weather, our thermoregulatory system physiologically adapts, and adjusts its response to those conditions (acclimatization). We also tend to expect and accept slightly warmer or colder temperatures indoors, depending on the weather. On the right side of the pyramid in Figure 1, a dynamic adaptive thermal comfort (ATC) model, derived from field studies on humans, considers that humans adapt physiologically and psychologically to given climate and building environmental contexts, which fine-tune their physiological (e.g. lower metabolism) and psychological responses (i.e. tolerate wider temperature ranges), alter thermal perception and expectations, and trigger behaviours consistent with the climate and the environmental controls available. A higher level of perceived environmental control relaxes our thermal expectations on the indoor environment. The adaptive theory views comfort as a main trigger for changes to occupant behaviour (discomfort leads to action). Such physiological and psychological fine-tuning is represented by the dots in the shaded area in Figure 1.

In Figure 1, a thermally adaptive environment is able to respond gradually to outdoor temperature changes, maintaining indoor thermal fluctuations within the ATC model limits and responding effectively to occupants' thermal requests. Further to Figure 1, our comfort perception is also tuned by local and personal contextual factors. Studies reveal that personal (social, economic and demographic) characteristics have a significant impact on household decisions to use their air conditioning system.[7]

In summary, it can be argued that the PMV model can be applied to homes in extreme cold or hot and humid climates or seasons, where dwellers need to rely almost entirely on the mechanical system to maintain comfort. Furthermore, given that the PMV model ignores feedforward (i.e. perceived control) and feedback (i.e. thermal response) human-environment loops that trigger behavioural decisions, the PMV model also seems to be more applicable where limited adaptive personal or environmental control opportunities exist.

In contrast, the ATC model relates indoor thermal comfort to the prevailing outdoor weather; as such, it is suitable to evaluate the effectiveness of passive design strategies. Therefore, the ATC model is applied to naturally conditioned buildings in mild and warm climates or seasons where the prevailing mean outdoor temperatures remain between 10ºC and 33.5ºC, because those ranges of temperatures allow greater flexibility for building occupants to adapt to the prevailing weather conditions, and for buildings to be more effective in moderating the effects of the weather indoors. In theory, ATC models could also be applied to mechanically conditioned buildings, depending on the adaptive opportunities available.

Limitations of thermal comfort models have been acknowledged by industry experts and researchers. Understanding the mechanisms of adaptation sketched in dotted lines in Figure 1 under different climate and personal contexts, and reflecting these in adaptive models, is an active area of research[8]. Over the past few years a wealth of research on residential thermal comfort has emerged, motivated by the need to support thermally comfortable and energy-efficient residential designs. The research has focused on developing residential adaptive thermal comfort models for different climate contexts under the premise that

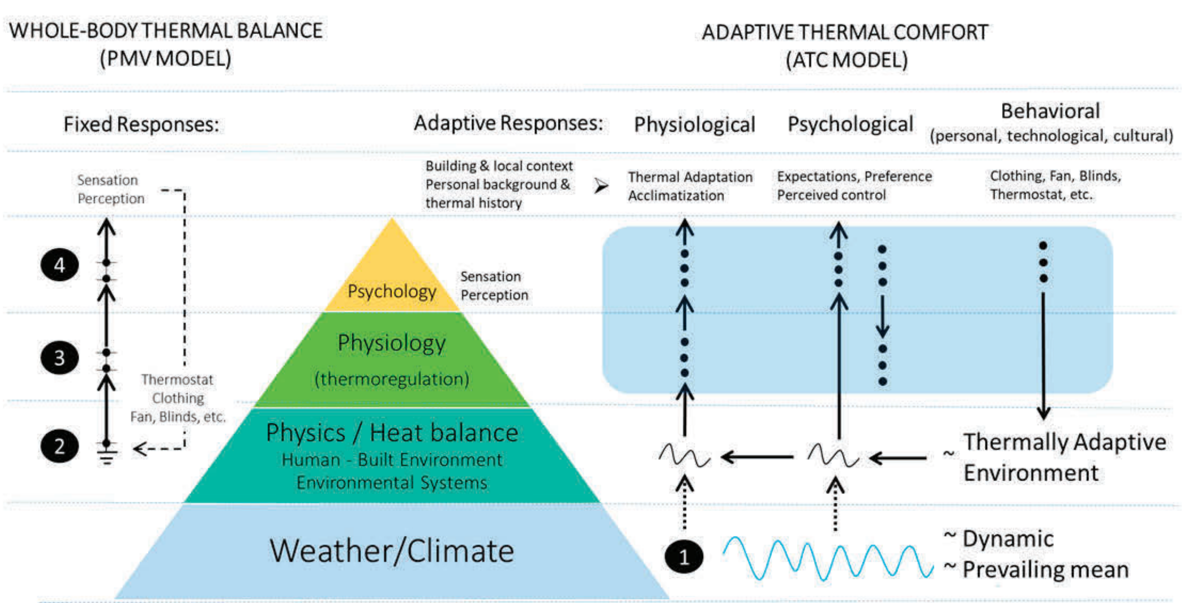


FIGURE 1: SKETCH OF TWO MAIN THERMAL COMFORT MODELS.

dwellers have the freedom to behave upon their preferences, arising from their own residential context, and that those behaviours lead to personal and technological adaptations. Researchers[9] have shown that contextual differences typically lead to a wider range of indoor temperatures in both mechanically and naturally conditioned homes, indicating that occupants at homes are more adaptive and tolerant of cooler and warmer temperature conditions than predicted by existing comfort models.

A BROADER CONTEXT FOR RESIDENTIAL THERMAL COMFORT

Residential buildings in many places of the world are not even equipped with mechanical heating and/or cooling devices. In those places, the building itself must provide sufficient protection against drastic outdoor temperature variations. For example, in Bogotá, Colombia, located 2,548 metres above sea level, ambient temperatures are mild, but below the adaptive comfort zone (Figure 2). However, mechanical heating is not even considered for any type of building in that city. Even though indoor temperatures may fluctuate between 16ºC and 25ºC, dwellers' daily adaptive behavioural patterns include adjusting clothing, drinking warm beverages and opening/closing windows and blinds.

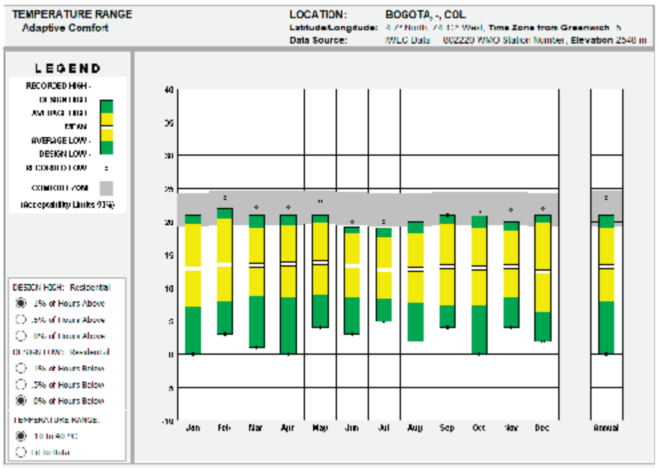


FIGURE 2: OUTDOOR TEMPERATURES, SOLAR RADIATION AND ADAPTIVE COMFORT ZONE IN BOGOTÁ, COLOMBIA.

An Australian field study[7] tested the question, "Do prolonged exposures to air conditioning make people acclimatize to cooler, or perhaps a narrower band of indoor, temperature conditions?" They classified occupants as "heavy A/C users" and "light A/C users." The research found significant differences in the use and duration of the A/C between these two groups of users. The mean room temperature was consistently about 2°C lower in the "heavy A/C user" group compared to the "light A/C user" counterparts. Using a comfort scale, "heavy A/C users" felt "slightly warm" when the room temperature was about 24.5°C, whereas "light A/C users" reported the same level of thermal sensation at a higher room temperature of 26.5°C. However, researchers warn that this is not enough evidence to suggest households' acclimatization to A/C.

In Figure 3, from the same field study[5], researchers developed four predictive curves of adaptive thermal comfort behaviours. In Figure 3, between about 21°C and 28°C, less than 20 per cent of the people rely on mechanical heating and cooling, indicating that this range is most conducive to natural ventilation, minimizing the dwellers' reliance on mechanical heating, cooling and ventilation appliances.

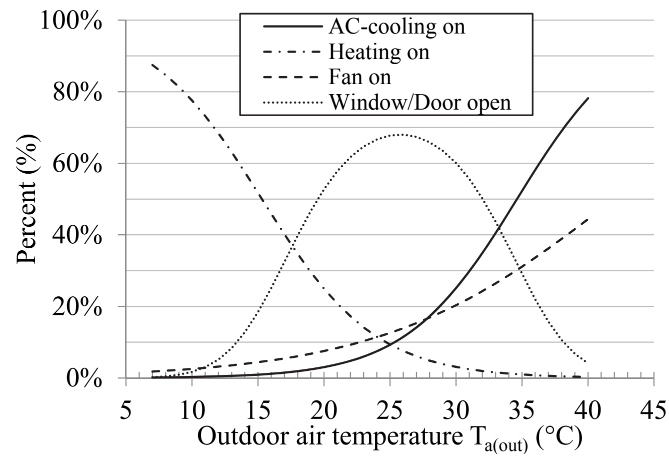


FIGURE 3: THE PERCENTAGE OF DIFFERENT ADAPTIVE STRATEGIES IN USE IN RESIDENTIAL BUILDINGS, AS A FUNCTION OF OUTDOOR AIR TEMPERATURE (REPRINTED WITH PERMISSION OF KIM ET AL.[5]).

Designing residential buildings for adaptive thermal comfort in hot and hot-humid climates is particularly challenging. A study of comfort in households in Japan during hot-humid seasons, focusing on living rooms and bedrooms, found that a large proportion of dwellers were well adapted and satisfied with the thermal environment in their free-running (naturally ventilated) houses. The mean comfort temperature in free running mode was 27°C in hot and humid season. Residents adapted to hot and humid environments by increasing the air movement usage through actions such as opening the windows and using fans.[10]

Buildings without mechanical cooling (Figure 3) abound in tropical towns. However, designing buildings without mechanical cooling would be unthinkable in large cities like Miami or Hong Kong, where occupants demand narrow indoor temperature bands for comfort. So, does the size of a city and the wealth of its residents equate to increased thermal comfort expectations and need for mechanical energy for thermal comfort?

FIGURE 4: ADAPTIVE COMFORT PRINCIPLES APPLIED IN THE DESIGN OF SCHOOLS IN A HOT-HUMID TROPICAL CLIMATE (REPRODUCED WITH PERMISSION FROM "PLAN:B ARQUITECTOS"[11]. PHOTO CREDIT: ALEJANDRO ARANGO).

With due consideration to increasing urban densification and the heat island effect in larger cities, low-energy designs can be achieved as long as some fundamental priorities are followed (Figure 5): 1) design for the local climate and the dwellers' particular needs and expectations on their homes; 2) maximize the design of passive strategies, combined with proper zoning and a high-performance enclosure; and

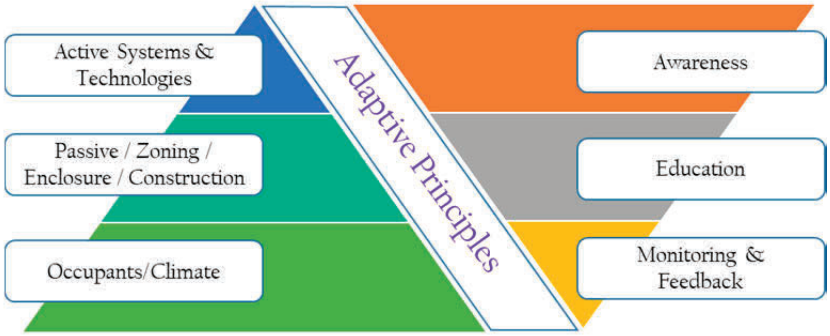


FIGURE 5: RESIDENTIAL DESIGN SOCIO-TECHNICAL PRIORITIES.

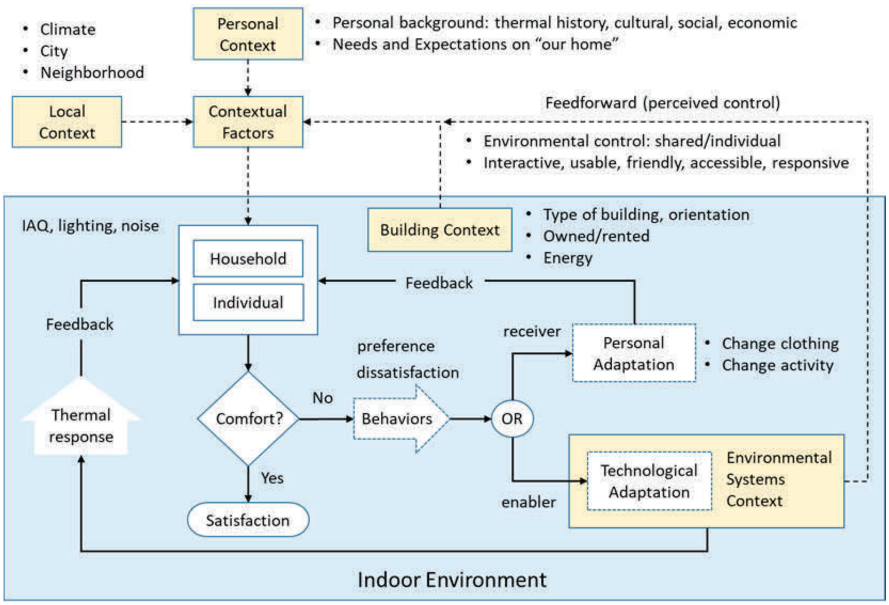


FIGURE 6: CONTEXTUAL FACTORS IN RESIDENTIAL THERMAL COMFORT.

Overall Needs & Expectations		Enablers: principles, technologies	Circumstances (Facts)	
			opportunities	constraints
1.	Comfort: thermal, visual, acoustic, olfactory, relax, feel in control, aesthetics, environmental fluctuations, response time	Passive design, solar shading, insulation, air-tightness, fenestration, zoning, thermostat, environmental systems & controls, fans,	Climate, seasons, site, orientation, view	Urban, densification, zoning, regulations, neighborhood, humidity, noise
2.	Health: hygiene, cleanliness, tidiness, fresh air	Operable windows, HRV, filtration, materials	Moderate climate, mild seasons	Outdoor pollution, noisy street
3.	Simplicity: ease, familiarity, accessibility, usability, responsiveness	Environmental systems & controls, individual control, local control	Diverse family, children, elder	Diverse family, children, elder
4.	Resources: economy, environment, time	Easy to maintain, low-energy, heat recovery, renewable	incentives, local context, utility pricing	Busy schedules, pricing, on-budget
5.	Social (others): owner, tenant, care, avoid-conflict, appearance, neighbour, community	Universal design, no stairs, shared versus individual features/services, feedback, awareness, education	Level of engagement, beliefs, attitudes, pro-environment	Habits, economic, cultural, values scales, demographic
6.	Safety, security, privacy	Windows, Blinds, shades, space zoning: private-social	Safe neighborhood	Children, busy or unsafe neighborhood

TABLE 1: HOUSEHOLD NEEDS, ENABLERS AND CIRCUMSTANCES.

3) supplement or enhance these with the use of low-energy technologies or mechanical heating and cooling. In parallel, household awareness, education and monitoring/feedback mechanisms need to be implemented to involve dwellers and learn how to design comfortable, low-energy buildings to the right measure. These priorities will permit a more integrated approach to housing design that acknowledge rather than constrain human thermal adaptation at home.

THE RESIDENTIAL CONTEXT

Contextual differences exist between residential and non-residential applications that affect our thermal perception and acceptability. On the one hand, occupants at home are more in-control, than elsewhere, of all aspects affecting the indoor environment, and therefore are free to act upon their preferences. On the other hand, the needs and expectations at home are fundamentally different from those in other buildings. For example, productivity is not a main concern at home. Figure 6 breaks down the contextual factors affecting thermal comfort in residential applications into: 1) personal, 2) local, 3) building, and 4) environmental systems factors. The premise is that these contextual factors have a stronger influence at home on how we adapt thermally to the environment (receivers): wearing more comfortable clothing, relaxing and changing posture, drinking a hot/cold beverage, etc.; and how we adapt the environment to our thermal needs and preferences (enablers): thermostat setting, window opening, etc.

At the core of the contextual factors are our personal differences in needs and expectations on our homes. Human needs are broad, and span from fundamental physiological and safety needs, to psychological and self-fulfilment needs.[12] Household needs and expectations can be classified in the six groups in Table 1 (adapted from [9]). These needs and expectations become motives that drive our actions at home. In the context of thermal comfort and indoor environmental quality, these actions are enabled by design principles and technologies that are implemented under particular circumstances.

RESIDENTIAL DESIGN FOR THERMALLY COMFORTABLE LOW-ENERGY HOMES

Home environmental systems are not always responsive to dwellers' requests. A local study on social housing revealed that radiant floor systems were problematic for elders because of their slow response[4]. However, if properly

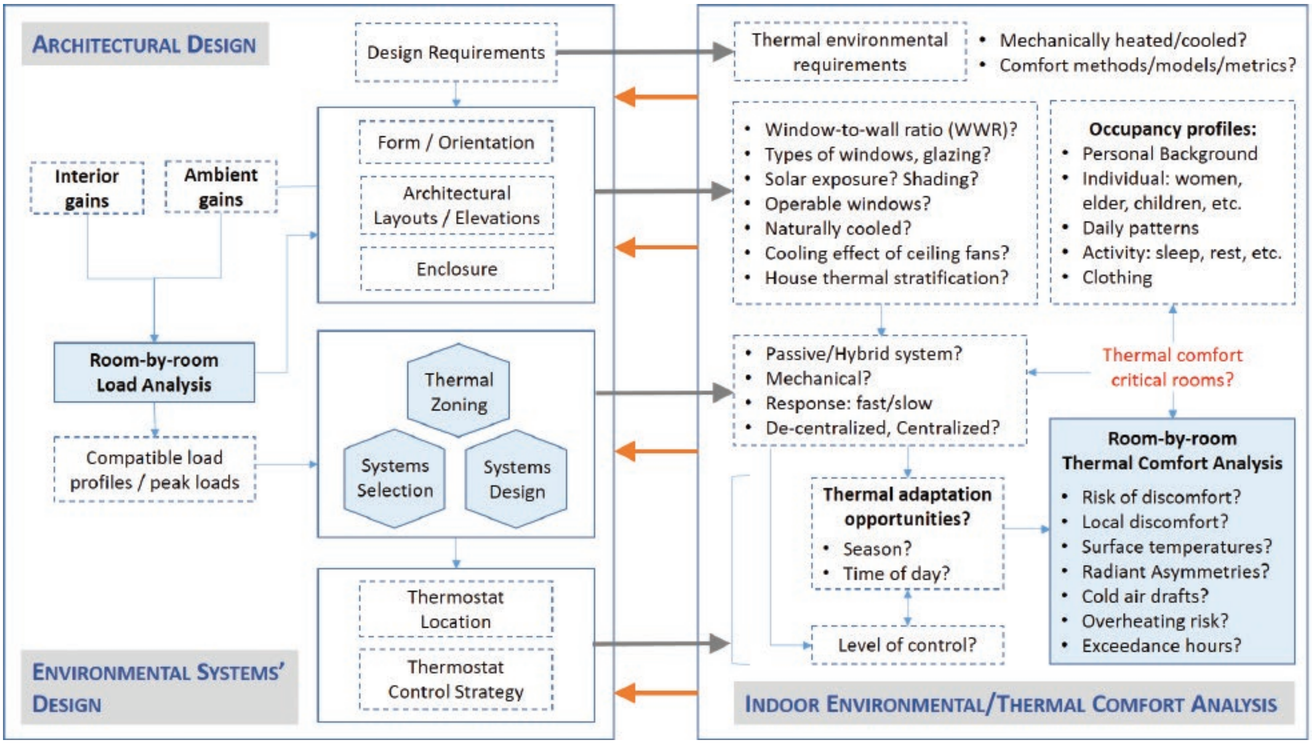


FIGURE 7: ARCHITECTURAL DESIGN AND ENVIRONMENTAL SYSTEMS' DESIGN INFORMED BY THERMAL COMFORT ANALYSIS.

designed and controlled, radiant floor systems will meet dwellers' comfort expectations[13]. A main challenge in indoor environmental design is balancing the fulfillment of the, often conflicting, household needs and expectations. A first step is to understand the occupants.

The left side of Figure 7 shows how main architectural decisions lead to thermal zoning, and environmental systems' selection and design. Room-by-room heating and cooling load analyses inform architect-engineer-owner discussions on strategies to reduce ambient loads and/or use them to help regulate indoor temperatures consistent with expected occupancy patterns. The right side of Figure 7 illustrates corresponding thermal comfort requirements, questions, occupancy profiles and analyses, which inform both architectural and mechanical design processes. Asking the right thermal comfort questions is the first step in raising awareness and promoting a deeper level of thinking and discussion about key design considerations for addressing low-energy thermal comfort concerns.

Thermal comfort standards, such as ASHRAE Standard 55-2017[14], provide a benchmark for designers to use as a frame of reference to help them understand the conditions for comfort, ask the right questions and evaluate alternative design solutions from a thermal comfort perspective. The standard has not been developed specifically for residential applications. However, its methods and metrics can be generically applied to residential buildings. Standard 55 incorporates both the PMV model and the ATC model that can be used to analyze comfort depending on the application[6]. As such, Standard 55 can be used with caution (aware of models' assumptions and limitations, Figure 1 and [6]) to guide and document residential thermal comfort analyses. In the meantime, the development of a residential thermal comfort standard specific to North American climate regions is underway.

A LOCAL EXAMPLE OF THERMAL ADAPTATION AT HOME

A small group of houses has been monitored as part of a study funded by BC Housing. One of those houses – a high-performance, net-zero energy home in Burnaby, B.C. – was carefully designed with passive and adaptive principles in mind. Even though the house has mechanical cooling, the occupants do not use it, and feel thermally satisfied year-round.

Figure 8 shows the temperature variations of the rooms monitored during the summer up to November. The basement (Bm) shows more stable temperatures, followed by the ground floor (Gd) and the top floor. Basement rooms face south. The ground office faces south and west, the kitchen faces north, the living room faces south, and the master bedroom faces south and east.

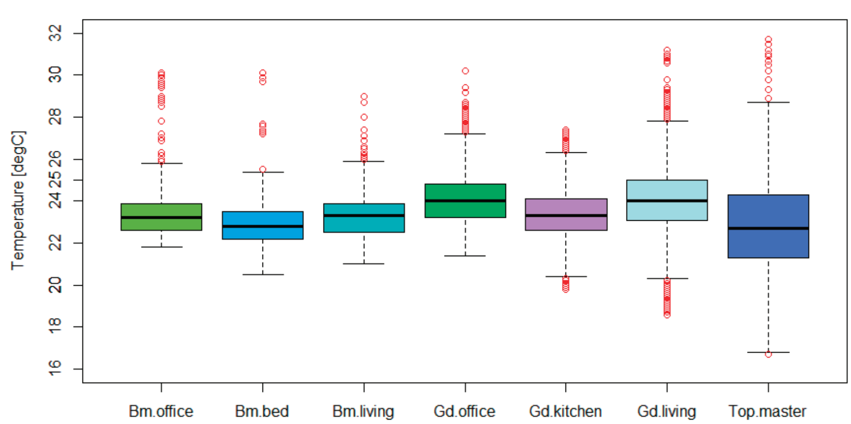


FIGURE 8: TEMPERATURE VARIATIONS IN THE ROOMS OF THE HOUSE OVER THE SUMMER AND FALL.

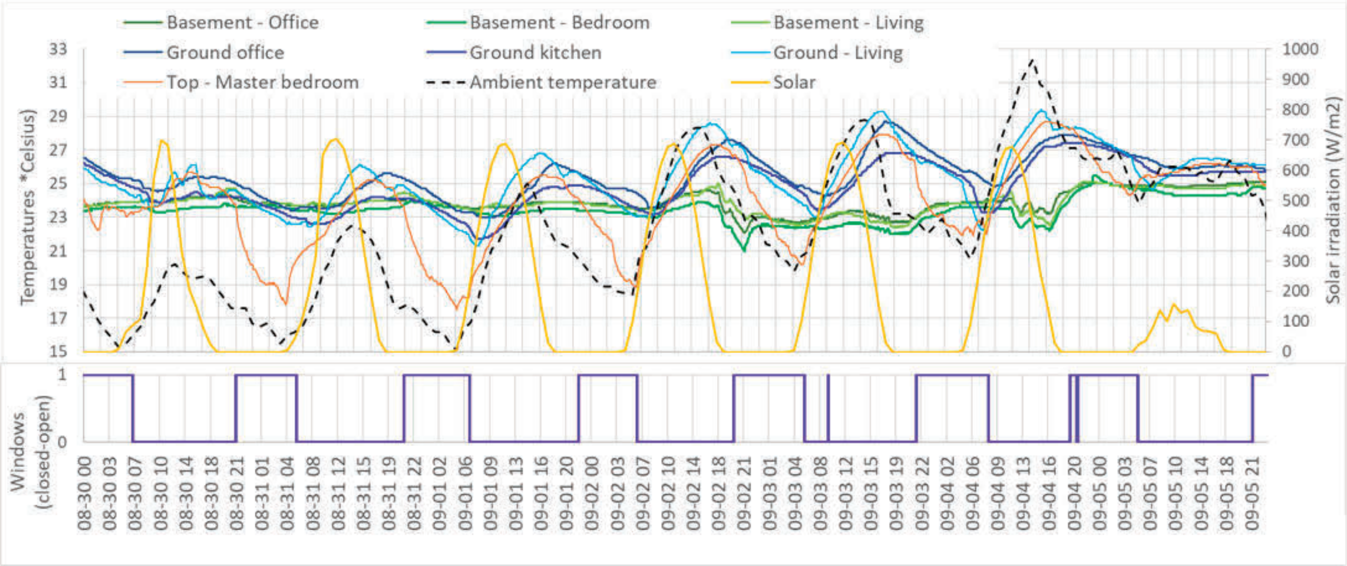


FIGURE 9: TEMPERATURES IN THE ROOMS OF THE HOUSE OVER A WEEK, AND WINDOW OPERATION IN THE MASTER BEDROOM.

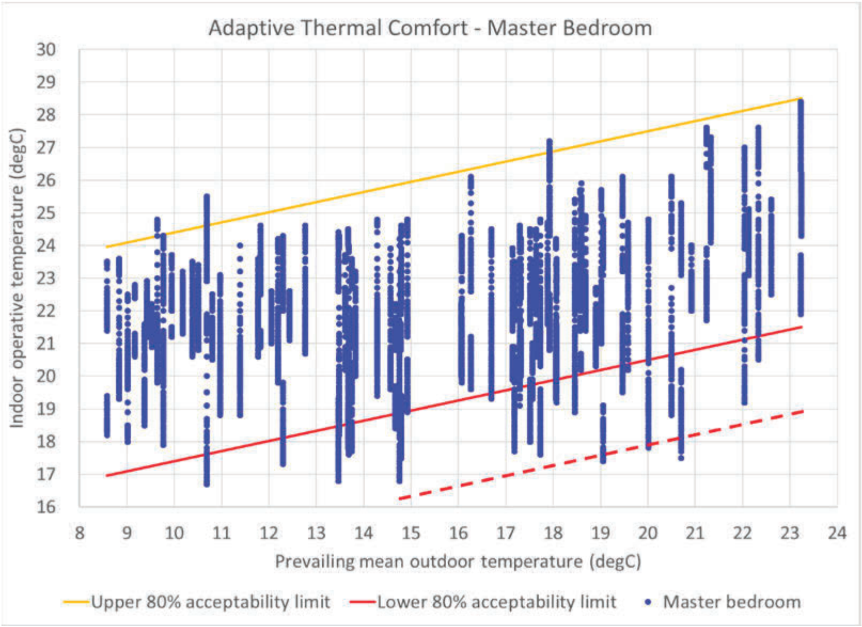


FIGURE 10: ATC LIMITS AND TEMPERATURES FROM THE MASTER BEDROOM FROM 10 P.M. TO 7 A.M.

Figure 8 shows large temperature variations in the master bedroom. This is explained in Figure 9: the occupants open the bedroom windows every night before going to bed, and close them early in the morning. The reason they do this is because they like cool temperatures for sleeping, which also cool down the bedroom thermal mass for the next day.

As a consequence, the master bedroom temperature remains within the 80 per cent acceptability ATC bands as indicated in Figure 10, with some overheating and overcooling. Within the ATC bands, occupants are expected to readily adapt thermally in relation to the outdoor temperature. However, the ATC bands were not produced from bedroom data. A field study in the UK[15] shows that quality of sleep may be compromised if the bedroom temperature rises much above 24°C. The dotted red line in Figure 10 represents a hypothetical expanded comfort zone of this house's dwellers that reflects that given the opportunity to adapt, dwellers are willing to adapt further and expand their comfort zone. In this house, dwellers voiced no complaints with the home temperatures.

Interestingly, as seen in Figure 11, some overheating and overcooling is observed in October, when the house is already mechanically heated. From the outdoor temperature and solar irradiation it seems that occupants opened the windows in some sunny October days, which overcooled the room. Comparing the outdoor temperature in Figure 11 with that of Bogotá (Figure 3), we can see that while locally it is common to mechanically heat our homes in October, in Bogotá, at lower outdoor temperatures this option is not even considered, no matter how clear or cloudy the sky is, or how rainy or humid the weather is.

The example illustrates that when given opportunities to adapt, dwellers create indoor temperatures and expand their comfort zones. Obviously not all buildings or rooms in a house can afford cross-ventilation, or having the windows open at night. In dense urban settings, designing adaptive opportunities within the building form and character is more challenging. Designing multi-unit residential building (MURB) suites for comfort is more challenging because of high window-to-floor ratios, and operable windows that can only provide single-sided ventilation, which is not optimized (i.e. operable window type, size and placement in the exterior wall). High-end high-rise MURBs being built in Vancouver are designed with mechanical cooling with little or no consideration for solar protection or natural cooling. However, the effectiveness of single-sided ventilation for natural cooling is limited. Research studies on schools and offices show single-sided ventilation air change rates between 1 and 4 ACH, compared to 5 to 22 ACH for cross-ventilation[16].

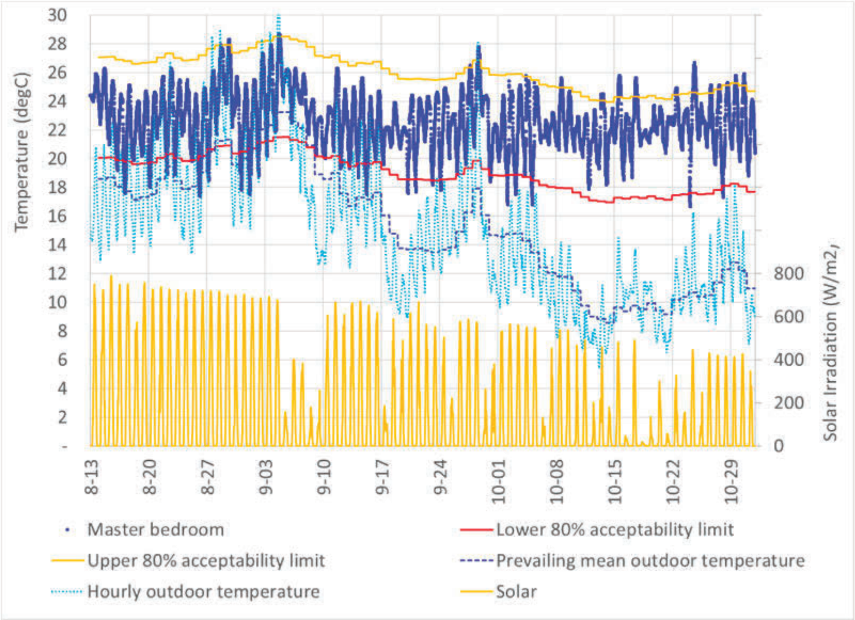


FIGURE 11: MASTER BEDROOM TEMPERATURES FROM 10 P.M. TO 7 A.M., AND ATC LIMITS IN TIME-SERIES.

Furthermore, single-sided ventilation can only reach the rooms with windows.

A successful low-energy adaptive thermal comfort design needs a robust integration of construction, enclosure, active systems and technologies, and controls. Low-energy technologies can help expand the individual comfort zone. For example, ceiling fans can raise the comfort zone by 1.5°C to 2°C, depending on their speed. Furthermore, low-energy local and personal heating or cooling devices allow more effective personal heating and cooling when needed, while enabling larger variations of room and house temperatures[17]. However, the thermal effectiveness and energy efficiency of these technologies have not been tested in residential applications.

CONCLUSIONS

We are inherently adaptive at home. Designing thermally comfortable, low-energy homes involves creating adaptive environments that are capable of regulating temperatures within the limits of thermal personal adaptation of the intended occupants, while providing sufficient opportunities for technological adaptation to let occupants expand their comfort zone as needed. Otherwise, uncomfortable dwellers will feel compelled to override the design intent for thermal environmental control by setting the thermostat to unreasonably high/low temperatures, using energy-intensive local heaters, installing window air conditioners, opening windows when conditions are not favourable, etc. Thermal comfort analyses based on well-established methods implemented in comfort standards provide a suitable benchmarking reference to evaluate design alternatives for comfort.

Continuous efforts are needed to collect local subjective feedback from dwellers on their needs, expectations, satisfaction, use and maintenance of their homes; together with objective monitoring of building environmental and energy data; and correlate these with demographic data and building typologies and vintages. In parallel, awareness and education campaigns are also needed for households to learn the impact of their thermal comfort behaviours on energy consumption.

The socio-technical approach outlined above to low-energy residential thermal comfort can in turn become a platform for the development of novel systems and technologies and their integration into buildings to provide increased opportunities for low-energy technological thermal adaptation and increased satisfaction of dwellers.

ACKNOWLEDGMENTS

This work has been performed within the framework of the International Energy Agency – Energy in Buildings and Communities Program (IEA-EBC) Annex69: Strategy and Practice of Adaptive Thermal Comfort in Low Energy Buildings (www.iea-ebc.org, annex69.org). Funding for this research project has been provided by BC Housing. The support of BC Housing is greatly appreciated.

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BCBEC FOUNDATION AWARDS PROFILE: Ali Vaseghi

By Matthew Bradford

In 2016, the BCBEC Foundation awarded Ali Vaseghi a bursary of $1,000 from the Tom Morstead Education Foundation. Now, three years later, *BCBEC Elements* is catching up with the British Columbia Institute of Technology research assistant to discuss his burgeoning career and industry ambitions.

BCBEC Elements: What is your current role in the industry?

Ali Vaseghi: I am a building envelope consultant at BC Building Science Ltd. and a graduate research assistant (Master of Applied Science) in Building Science at the British Columbia Institute of Technology (BCIT). I am also a fellow of the Sustainable Building Science Program at the University of British Columbia. My expertise lies in performing building envelope design and field reviews, building envelope energy modelling, building condition reviews and reserve fund studies. I also prepare engineering reports for new or existing high and low-rise buildings and have been working extensively on thermal bridging analysis and improving the thermal performance of building envelope details of concrete buildings throughout my master thesis under the supervision of Dr. Fitsum Tariku.

BE: What attracted you to the building science field?

AV: My father was an engineer, and throughout my undergrad studies he had the most influence on me when it came to choosing my future graduate program and career. Throughout his career, he has proposed solutions to reduce building energy consumption and help combat global warming. Also, my passion for research and state-of-the-art building topics propelled me toward building science where I would be able to create synergies between the thermal, structural, acoustic and energy systems.

BE: What role has BCBEC played in supporting your career?

AV: Winning the BCBEC Foundation Award was a significant achievement for me. It encouraged me to work toward my research thesis with more confidence. As well, BCBEC organizes top-notch seminars and conferences that not only helped me to increase my knowledge regarding the most recent building science topics, but they introduced me to building science professionals and the community.

One of the highlights from my most recent job interview was when I was asked to describe more about my accomplishment in receiving the Tom Morstead Award and my master thesis presentation at the 2015 BCBEC AGM and Conference. Having the BCBEC award and presentation listed in my professional resume definitely catches the attention of building science firms.

BE: How do you hope to give back to the community?

AV: Parallel to my professional work, I also run the BCIT Building Science Student Club (BSSC), which was founded to help create positive working and social relationships, and to foster enhanced work and social environments between building science students, faculty and industry.

At BSSC I organize events, including academic seminars and site visits for students and future building science industry employees. Also, my intense interest in high-performance buildings drives me toward proposing solutions to reduce building envelope energy consumption as well as the carbon footprint. All in all, I will be advocating for more energy-efficient buildings and a healthier environment.

BE: What advice would you offer other students looking to enter the industry?

AV: I strongly suggest students and new graduates actively participate in BCBEC seminars and events where they can get themselves out there, grow their professional networks and eventually meet their potential employers.

The Tom Morstead Memorial Award was created by the Morstead family in 2009 to support industry up-and-comers in their post-secondary studies. For information on how to apply or donate, visit bcbec.com/bcbec-foundation.

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A platform for industry-wide knowledge exchange

BCBEC hosted their annual full-day Conference and AGM, which took place on October 26, 2018. The event was well attended and served as a platform for thought-provoking discussion and industry-wide knowledge exchange on a number of interesting and relevant topics.

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