The Heat Emission-Considered Building Design Criterion in the Early Design Process: Expert Survey

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ABSTRACT

The purpose of this study is to investigate the field experts' perspectives on heat emission in sustainable building design and to establish heat emission-focused design criteria for the early building design process based on the expert survey, including scholars and practitioners. 10 design variables were selected from the literature reviews which were verified to have a significant impact on energy consumption. Based on these variables, the expert survey was developed, including 5 sections of 17 questions, and was distributed to the field experts. In the survey, the experts evaluated the importance of 10 design variables based on their experience and background.

The survey highlighted the top 90th percentile of the design variables for each energy consumption and heat emission ranked by the participants. For energy consumption, the scholars highlighted roof, wall R-Value, window U-value, and window-to-wall ratio (WWR), while practitioners have highlighted WWR. For heat emission, the scholars have highlighted only wall and roof reflectivity, while the practitioners have highlighted WWR. The results also showed the different opinions by the participants' experiences (more than 5 years vs. less than 5 years) as well as the location, such as North America vs the Middle East. To include these design variables in the design process, the participants asked for their suggestions and recommendations based on a list of 12 answers. The scholar opts for developing a simulation tool to explore multiple design alternatives quickly regarding heat emission, while practitioners prefer to define the most influential design parameters and their sensitivity range.

Keywords: Heat Emission, Expert Survey, Sustainable Architecture, Design Variables.

Introduction

Modern cities have demonstrated higher air temperatures compared to rural area due to the urban heat island (UHI). The UHI increased outdoor air temperature within the city metropolitan area (Oke et al. 2017). This increased the heat waves the cities are facing which increased the cooling demand to maintain indoor thermal comfort for occupants (Singh, Kikon, and Verma 2017; Kikon et al. 2016; Zhou et al. 2016). In extreme cases, the increase in indoor air temperature can lead to mortality without air conditioning, or in a case of an air conditioning failure due to a power outage. The maximum summer indoor temperature can increase by 10-14˚C in case of air conditioning failure in two warm climate cities in the United States (Chicago and Houston)(Sailor 2014). Another study evaluated the mortality during the 18-day-long heat wave between July 15 and August 1 2006 in California, showing a total of 582 excess deaths occurred (Joe et al. 2016).

The fast-growing population of the world requires new buildings, and these buildings were built using mostly high heat capacity materials that absorb the heat during the day and emit it at night which accelerates the UHI issue. The sensible heat emission is assumed to be equal to the building's energy consumption (Ferrando, Hong, and Causone 2021) and the heat

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emission from the building has a significant impact on outdoor thermal comfort and urban heat island. Thus, heat emission needs to be considered in the design process, especially to tackle the UHI issue. Although the building performance evaluation, such as energy consumption, daylight, and/or occupant comfort were accepted as critical aspects in sustainable building design (Shi et al. 2016), heat emission was not considered enough in the building design process despite its significant impact on urban heat islands.

The causes of the UHI are due to many factors such as human activity, transportation, factories, and most importantly replacing the natural land area with high-density material to construct buildings (Oke et al. 2017). Building emits heat through three mechanisms, heat rejection from air conditioning systems during hot months, convective heat from the building envelope, and exfiltration from the building zones through leakage or exhaust fans as this might be hot air during the winter seasons (Alhazmi, Sailor, and Anand 2022; Hong et al. 2020). If the same trend continues, cities are expected to have even higher temperatures in the future. For example, the number of days the temperature exceeds 43.3 °C (110 °F) is expected to increase from 53 days currently, to 70 days by 2060 in Phoenix, AZ (City of Phoenix 2021). Recent studies identify that the heat emission from the building is two times higher than its energy consumption (Ferrando, Hong, and Causone 2021; Hong et al. 2020; Alhazmi, Sailor, and Anand 2022). Further, the building code and standard are mainly focusing on minimizing energy used by implementing energy conservative measures (ECM) such as higher insulation, and efficient building system systems for example. These ECM indeed have a high impact on energy consumption, but the focus should also prioritize the heat releases from the building to mitigate the UHI effect.

The purpose of this study is to establish heat emission-focused design criteria for the early building design process based on the expert survey. To achieve this objective, an expert survey has been developed and distributed to the academia and practitioners. The survey is intended to gain additional understanding regarding the experts' views on different design variables as well as their recommendations and suggestions to include these design variables in the design process.

Methodology

Survey Structure

A survey containing a total of 17 questions in 5 sections was distributed to academia and practitioners in the field of architecture design. These sections are explained in the following sub-sections. The important sections of the survey are sections 4 and 5 in which the participants evaluate how important each design variable is on energy consumption and heat emission, followed by a recommendation on how to promote using these design variables in the design process.

First section, personal data. The intent of the first section of the survey is to collect the personal data information of the participants. It contains two multiple-choice questions, and one insert-text question.

Second section, design process. The second section is to understand the experience and expertise of each participant in using the energy simulation tools, and what are the criteria used for the evaluation. This section includes two multiple-choice questions.

Third section, user experience. This section of the survey is to understand if the participant has an experience of the early stage design process. If the participant has no experience with the early stage design process, they can skip the section. However, if the participant has an experience, they must answer five 7-point Likert scale questions.

Fourth section, design variable. This section is the most important part of the survey, where the participant needs to evaluate the impact of each design variable on energy consumption and heat emission by the building. These design variables have been established from the literature reviews. The literature search focused primarily on evaluating the design of the building during the early stage which includes its energy performance, daylight, and thermal comfort. The Google Scholar database was used for the initial search which include a combination of the following keywords "design variable", "parametric", "building", and "design". The initial list included 56 sources. The filtration process excluded any results that didn't consider the early design stage evaluation, and any studies only focused on the evaluation of building energy consumption were also excluded. Finally, the filtration process includes only commercial, residential, and educational buildings. This section contains a question to evaluate 10 design variables on a 5-point Likert scale for energy consumption and heat emission. Table 1 shows the design variables which were asked to evaluate.

Table 1. The 10 design variables were derived from the literature for their importance.

<table>
<tr><td colspan="4">Design variables</td></tr>
<tr><td rowspan="3">Envelope opaque</td><td>Roofs R-value</td><td rowspan="2">Form</td><td>Window to Wall Ratio [WWR]</td></tr>
<tr><td>Walls R-value</td><td>Shading overhang</td></tr>
<tr><td>Wall and roof solar reflectivity</td><td rowspan="3">Equipment</td><td>Cooling setpoint</td></tr>
<tr><td rowspan="2">Envelope fenestration</td><td>U-value</td><td>Heating setpoint</td></tr>
<tr><td>Solar Heat Gain Coefficient [SHGC]</td><td>HVAC COP</td></tr>
</table>

Fifth section, recommendations, and suggestions. The final section of the survey is to understand the participants' own experience with using these design variables in their current design process and how often they use them in their design process. Followed by recommendations and suggestions to increase the utilization of these design variables during the design process.

Table 2. A list of 12 recommendations, and suggestions the participants can choose from.

	Suggestions and recommendations
Simulation tools	1. Enhance the 3D visualization of certain sustainable strategies, which help to visualize the results to make informed design decisions.
	2. Provide/develop a simulation tool which allows designers to explore multiple design alternatives quickly and easily.
	3. Improve the usability and ability to go back and change input parameters.
	4. Enhance the user interface for simpler and fewer inputs to run a simple simulation analysis.
	5. Improve and permit integration between engineers and energy modeler.
Building code	6. Conform to codes and rating systems.
	7. Provide guidelines for building codes & rating systems compliance.
Guidance and suggestions	8. Provide/Develop an easy searchable building inputs database.
	9. Provide templates for different building types.
	10. Allow examining sensitivity and uncertainty of key design parameters.
	11. Analyze weather characteristics and suggest suitable passive design.
	12. Define the most influential design parameters and their sensitivity range.

Table 2 shows the recommendations and suggestions given to the participants. These were categorized into simulation tools, building code, and guidance and suggestions. The list presented in Table 2 is developed based on a previous study found in the literature (Attia 2010). These 15 questions were distributed into five sections mentioned above. All these questions were required to complete the survey, except section three which the participant can skip if they don't have experience in the early design stage. The estimated time for the survey was between 10 minutes to 15 minutes, depending on the participant's speed.

Survey Distribution and Analysis

The survey has been distributed among academia and practitioners between March and June 2022. The distribution method was primarily email, social network invitations, and a site visit to architecture firms. The result was grouped based on the participants' background, years of experience, and locations as shown in Figure 1. The analysis of the results started with identifying the top 90th percentile of the design variable related to heat emission, and energy consumption for each of the groups mentioned above. The survey highlighted the top three recommendations and suggestions for future integration of heat emission in the design process. Furthermore, the results will assess and evaluate the relationship between energy consumption and heat emission among different groups of participants.

Results

Demographics

A total of 62 participants completed the survey, and the participants who didn't complete the survey were excluded from the analysis. Based on the survey results collected, the results identified three groups. These groups include participants from academia and practice and how their responses differ. Also, the survey highlighted groups with more experience in the field (more than 5 years of experience) and those who were recently employed (less than 5 years of experience). Finally, the survey considers how different geolocation affects the answer of the participants, this includes participants from North America and the Middle East. Figure 1 shows the breakdown of each category.

Figure 1. Initial results of the survey for participants' background (left), experience (middle), and location (right).

93% of the participant responded that considering the energy consumption is important, and 43% of the participants answered that heat emission is important to consider for evaluation during the design process. Furthermore, 61% of all participants think the current simulation tools and/or design process are effective to evaluate the performance of different building design alternatives in the early design stage. 50% of all participants often evaluate for energy consumption during the early stage of the design process compared to only 20% of all participants who often evaluate for heat emission. Then, the participants selected design criteria for the performance evaluation during the design process, which are energy consumption, thermal load, life cycle assessment, construction cost, operation cost, and heat emission. 27% of the participants selected energy consumption only and 46% selected energy consumption and thermal comfort. The response also demonstrated that high-order simulation tools (EnergyPlus, eQuest, Ladybug tools) are used mostly (61%), compared to the simplified order models (EPC, MIT design Advisor) (23%), and 4% responded that they used the medium-order models (Such as WinSim, BuildingCalc …etc).

Design Variables by Group

The fourth section demonstrated the impact of the design variables on energy consumption and heat emission. The participants ranked each design variable on a scale from 1 to 5 where 5 is the highest. Figure 2 shows the average responses from each participant group. In order to identify the importance of each design variable, the top 90th percentile was selected as an important variable. In the data analysis, the T-test was used as a statistical method to identify the statistical significance between the groups ($p < 0.05$).

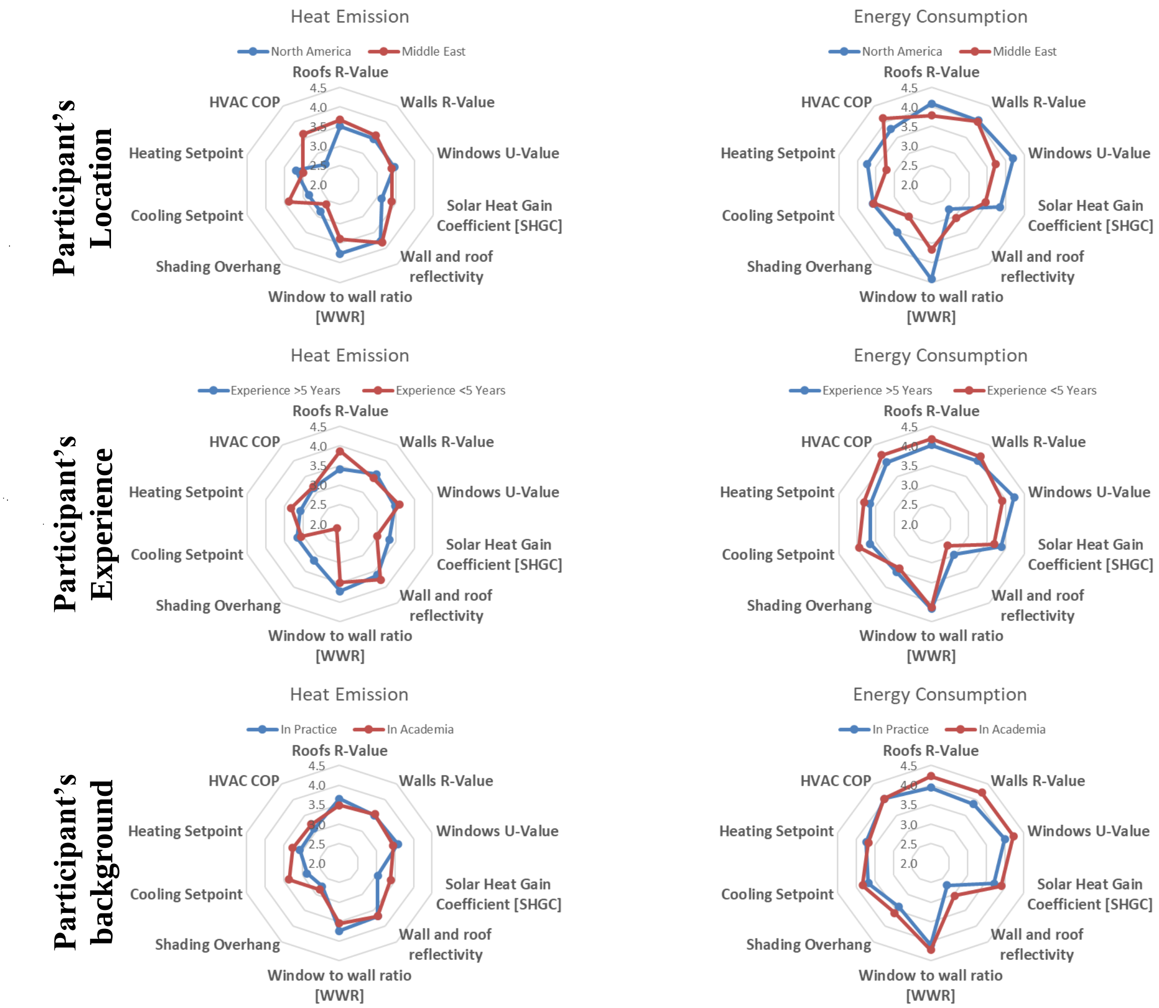

Figure 2. The average results of the participants' selection per each group for the design variables for the heat emission and energy consumption.

The result showed differences between the participant groups. It is clear that the Middle Eastern group and North American group prioritize different design variables regarding energy consumption; the North American group selected WWR, while the Middle East group selected the HVAC COP. On the other hand, both groups chose the wall and roof reflectivity to have a higher impact on heat emission. The HVAC COP for heat emission appeared statistically significant with a P-value of 0.0332, and the WWR was significant for energy consumption (p-value = 0.0326). Similarly, for question 15, ‘How often using the design variables for equipment for energy consumption’, there was a statistical significance between the group ($p < 0.05$).

Furthermore, the more experienced group selected the window U-value, while the roof R-value was chosen by the less experienced group regarding energy consumption. In respect of the heat emission from the building, the more experienced group selected WWR and the less experienced group chose the roof R-value. The result also identified that the shading overhang for the heat emission is statistically significant between these two groups (p-value = 0.0065). Similarly, for question 12, 'How often using the design variable related to envelope opaque for heat emission', there was a significant difference between these two groups ($p < 0.05$). Also, there is a statistical significance for question 14 regarding how often using the design variable for building form for energy consumption as the P-value is 0.0492.

Finally, the practitioners responded that WWR has a higher impact on energy consumption while the academia showed the roof, wall R-value, window U-value, and WWR consistently for energy consumption. For heat emission, the practitioner selected WWR compared to wall and roof reflectivity for academia, which demonstrated clear differences. However, it was verified that there is no statistical significance between the group of academia and practice.

Recommendation and Suggestion

The last question in the survey asked the participant's opinion on how to include heat emission as a design criterion during the design process in comparison to energy consumption. Figure 3 summarized the findings, regarding the heat emission for each group. These results showed similar trends among the groups.

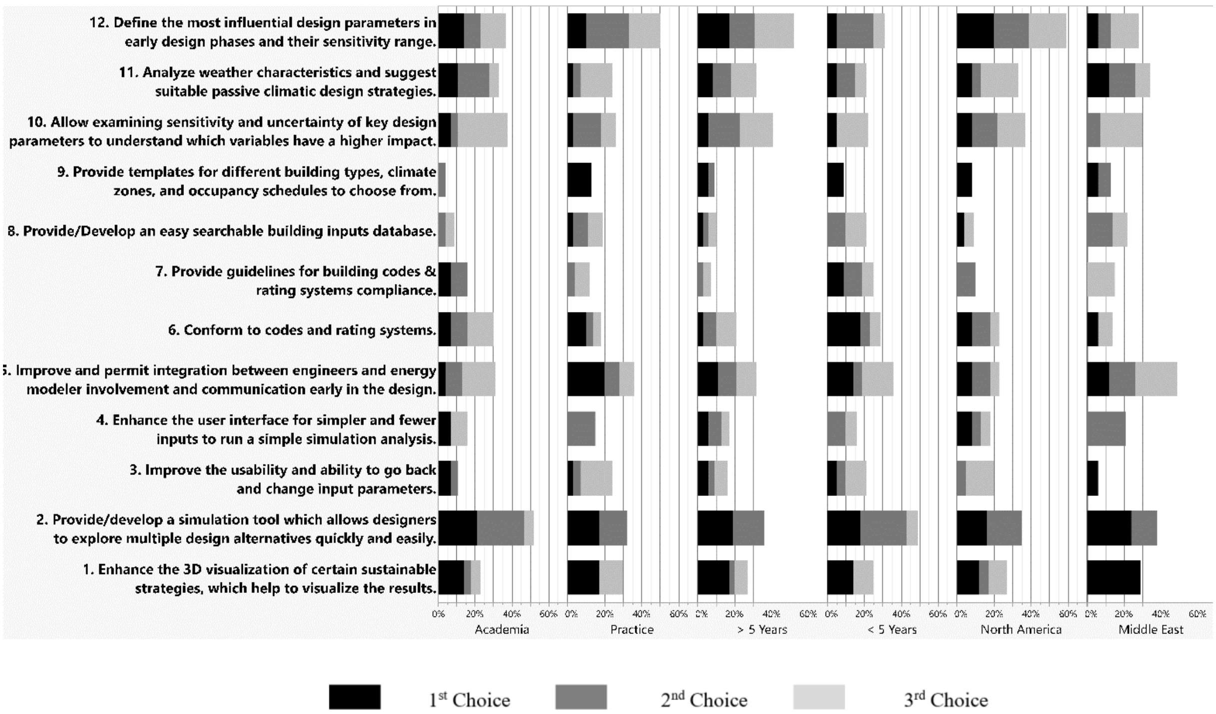

Figure 3. The top 3 choices per participants' group for their recommendations and suggestions to include heat emission during the design process.

The academia group demonstrated a higher preference for their 1st, 2nd, and 3rd choices, which was 'To provide/develop a simulation tool that allows designers to explore multiple design alternatives quickly and easily', which was different from the practitioner group's selection. Their 1st selection was 'To Improve and permit integration between engineers and energy modeler involvement and communication early in the design process' and the 2nd answer was 'To define the most influential design parameters in early design phases and their sensitivity range’. The 3rd choice was also different, which was ‘To analyze whether characteristics and suggest suitable passive climatic design strategies’ (Ex. Natural Ventilation, Orientation, Daylight...), which demonstrates different perceptions of heat emission between the two groups.

The results for the first three choices combined of each group showed consistently high selection for mainly two recommendations and suggestions. The academia group and less experience group highlighted the importance of ‘to provide/develop a simulation tool that allows designers to explore multiple design alternatives quickly and easily’, while the participants from the practitioner, more experience, and the North American group selected option number 12, ‘To define the most influential design parameters in early design phases and their sensitivity range’.

Noticeably, for the Middle Eastern group, they selected option 5, ‘To improve and permit integration between engineers and energy modeler involvement and communication early in the design process' for both energy consumption and heat emission. Among the other suggestions and recommendations, namely selection numbers 3-4, and 7-9 showed less preference and selection by participants from all groups.

Discussion and Conclusion

This study first aimed to understand how experts in the field evaluate various design variables for heat emission and energy consumption. Second, it aimed to comprehend the significance of including heat emission and energy consumption for building design. Further, this study developed a framework to include heat emission as a design criterion in the design process. A total of 62 complete responses were collected, representing a diverse group of backgrounds, experiences, and locations. The survey results indicated differences among the groups, highlighting different design variables that impacted energy consumption and heat emission. The findings revealed that the top 90th percentile of design variables, affecting energy consumption are wall and roof R-value, window U-value, and WWR. Meanwhile, the top 90th percentile for heat emission consists of material reflectivity, and WWR represented both academia and practitioner.

Additionally, the majority of participants prioritized the significance of evaluating energy consumption over heat emission. This was evident in the participants' preference for energy consumption and thermal load as the primary evaluation criteria for building performance during the design process. These two design criteria accounted for 46% of the selections, compared to only a 6% for heat emission, which ranked as the least utilized evaluation criterion throughout the design process. This disparity between heat emission and energy consumption appear to be impacted by the current practice. Energy consumption by a building tends to have higher importance for building owners due to its direct impact on reducing electricity bills. This might also be attributed to building design codes that has more emphasis on energy regulations. These codes require increasing building energy efficiency by improving the insulation and minimizing air leakage, thus amplifying the importance of energy-related considerations in building design. Recent initiatives in updating building codes and standards, providing innovative programs and incentives, and showcasing demonstration projects around the world to accelerate the deployment of cool surfaces (materials with high reflectivity) in the building sectors. These initiatives have demonstrated a substantial positive impact on reducing heat emission from the building envelopes, while improving overall buildings efficiency (Alhazmi, Sailor, and Levinson 2023).

Additionally, the participants have selected two main recommendations and suggestions. The first one is to provide/develop a simulation tool that enables designers to explore multiple design alternatives quickly and easily. These tools should also define the most influential design parameters during the early design phases, along with their sensitivity range.

This can be achieved by utilizing the use of a regression model, which would generate faster predictable results based on a few samples of the actual simulation. This methodology has been employed in previous studies (Rezaee et al. 2019; Bragança, Vieira, and Andrade 2014; Alhazmi et al. 2023). Alternatively, users can opt for simplified simulation tools such as Excel spreadsheets to estimate building performance results with minimum inputs, compared to the more dynamic simulation engines which requires detailed inputs (Hoon Lee, Fei, and Augenbroe 2014; Kim, Augenbroe, and Suh 2014) or the use of the recent online applications and cloud computing engines such as cove or speed tools ("Cove.Tool" n.d.; "SPEED" n.d.). It is worth mentioning some of these recommendations have yielded low selections, namely the numbers 3-4, and 7-9. These recommendations include improving the interface and usability of simulation tools, as well as providing a template and/or searchable database.

Although there are significant findings in this study, it is important to acknowledge several limitations that might affect the accuracy of the results. One notable limitation is the different backgrounds and perceptions of the participants. For example, participants from different climate zones, such as colder vs warmer regions, may tend to answer the survey questions based on their geographical location. Further, the building size and type, such as residential or commercial, and their different behaviors might have different impacts by these design variables. These factors might not fully captured in the participants' responses. Some future directions of the survey might include a wide range of participants, such as students, as it can shape their understanding regarding the profession. Furthermore, involving the policy makers and building owners could offer insights into their interest and how can affect their decisions. By incorporating these diverse viewpoints, a more comprehensive understanding of the subject matter could be achieved.

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